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Fairplay4Food

A first step towards a weighing system for the effects of different protein sources on health, environment and society

RIVM report 2023-0475

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Synopsis

Fairplay4Food

A first step towards a weighing system for the effects of different protein sources on health, environment and society.

People in the Netherlands have plenty of healthy and safe food at their disposal and enjoy a long life expectancy. Although food in the Netherlands is generally safe from both a microbiological and toxicological standpoint, the current dietary patterns of the Dutch population cause substantial health losses, especially from chronic diseases. Besides, our current food system poses a major burden on the environment because of significant greenhouse gas emissions, land and resource use (e.g. water and phosphorus), soil and water contamination by nutrients and pesticides, as well as waste production.

A protein transition, less consumption of animal-based protein and more consumption of plant-based protein could help to improve both our health and the environment. Apart from affecting our health and the environment, such a transition may also have consequences for economic and various socio-cultural aspects.

Fairplay4Food (Fp4F) describes the effects of various scenarios that aim to contribute to a protein transition and aims to identify the best option. To this end, we built a multi-criteria decision analysis tool that was used to find a balance between health and sustainability, while accounting for the economic and socio-cultural aspects involved.
Three scenarios were developed: a supermarket strategy with higher meat prices and/or an information nudge (1); a scenario in which consumers no longer consumed pork (2); and a scenario in which consumers no longer consumed pork and in which farmers no longer produced pigs (3). Experts were asked to value the effects of these scenarios on human health, the environment and socio-economic aspects. These values were included in the tool.
Finally, we tested the developed tool. Four (virtual) policymakers who were responsible for either human health, the environment or economic affairs were asked to indicate their preference for the domains of health, the environment or for economics, by giving weight to these domains. After the inclusion of their preferences, the tool calculates/selects the scenario that fits in best with a policymaker's preference. Out of the three scenarios tested, a scenario in which pigs were no longer produced (in the Netherlands) and in which pork was no longer eaten by Dutch consumers turned out to be the preferred scenario contributing to the desired protein transition for policymakers, responsible for either human health, the environment or economic affairs.
This study shows that, despite different preferences, agreement is possible, and that this tool can be very useful in a discussion on complex issues such as the protein transition.

Keywords: protein transition, MCDA, pork, producer, consumer, supermarket, decision

Publiekssamenvatting

Fairplay4Food

Een eerste stap op weg naar een afwegingskader voor het meten van de gevolgen van een eiwittransitie. Effecten op onze gezondheid, het milieu en de samenleving.

In Nederland bestaat voldoende aanbod van gezond en veilig voedsel. Hoewel ons voedsel in het algemeen veilig is, draagt ons huidige eetpatroon bij aan een aantal chronische ziekten, zoals hart- en vaatziekten en overgewicht. Ook het milieu ondervindt problemen. De productie van al ons voedsel, met name van dierlijke producten, gaat gepaard met de productie van broeikasgassen, land-, water- en fosfaatgebruik, verontreiniging van bodem en oppervlaktewater met nutriënten en gewasbeschermingsmiddelen, en met de productie van veel mest en afval.

De Nederlands overheid heeft als doel gesteld om in Nederland minder producten van dierlijke oorsprong en meer van plantaardige oorsprong te consumeren en produceren. Met het minder produceren en consumeren van dierlijke producten als vlees, eieren en zuivel, zou een belangrijke bijdrage geleverd kunnen worden aan het verminderen van een aantal ziekten en van de zojuist genoemde milieuproblemen. Maar zo'n verandering heeft meer gevolgen, bijvoorbeeld voor de koopkracht van consumenten en voor de handelsbalans van Nederland. We verdienen bijvoorbeeld veel geld aan de export van dierlijke producten. Aan de andere kant genieten we misschien wel meer van onze omgeving als er stallen verdwijnen en als de stankoverlast minder wordt.
Maar hoe kun je het gedrag van consumenten veranderen, hoe kun je ze minder vlees, zuivel of eieren laten kopen? En wat gebeurt er als we in Nederland stoppen met het eten en produceren van bijvoorbeeld varkens? In Fairplay4Food (Fp4F) beschrijven we de ontwikkeling van een methode waarmee we de effecten van een aantal scenario's (waarin we minder dierlijke producten kopen, eten en/of produceren) kunnen vergelijken. Verschillende experts op het gebied van gezondheid, milieu en economie is gevraagd om de gevolgen van die scenario's te beoordelen. Wat zijn de gevolgen voor onze gezondheid, voor ons milieu, voor onze economie als we in Nederland geen varkens meer produceren en/of eten?
Ten slotte hebben we met deze methode verschillende (virtuele) beleidsmakers het optimale scenario laten selecteren. En wat blijkt? Hoe je er ook naar kijkt, als vertegenwoordiger van het Ministerie van VWS, van Milieu of van Economische zaken: minder vlees produceren en minder vlees consumeren is gunstig voor de volksgezondheid, gunstig voor het milieu én gunstig voor de economie: Minder vlees? Een afgewogen keuze!
Dit afwegingskader kan dus erg nuttig zijn in discussies over complexe onderwerpen als de eiwittransitie.

Kernwoorden: eiwit, transitie, MCDA, varken, varkensvlees, producent, consument, supermarkt

Contents

Summary

In the Netherlands, plenty of healthy and safe food is supplied and the Dutch people enjoy an increasing life expectancy. Although food in the Netherlands is generally safe from both a microbiological and a toxicological standpoint, the current dietary patterns of the Dutch population cause substantial health losses, especially from chronic diseases. Besides, our current food system poses a major burden on the environment because of significant greenhouse gas emissions, land and resource use (e.g. water and phosphorus), soil and water contamination by nutrients and pesticides, as well as waste production. To achieve a healthier and more environmentally sustainable food consumption pattern, a drastic change in our current food system is necessary; a change that not only guarantees high standards of health and sustainability, but also addresses the economy (i.e. industry's profitability) and consumers' perspective (e.g. price, taste, etcetera). To this end, an integrated food policy that takes into account safety, health and sustainability, as well as socio-economic and cultural aspects, is required.

Not all measures favouring healthy diets are absolutely environmentally or economically sustainable, safe, or acceptable to consumers and producers. Finding a balance between health, safety, and sustainability, while accounting for the socio-economic and cultural aspects involved, necessitates a deep understanding of the complex interconnections among the various domains of the food system. One way to help decisionmakers in choosing between different policy options is the development of an multi-criteria assessment framework that estimates the effects of potential policy measures on the various aspects of these domains.

For balancing problems in environmental and health analyses, multi-criteria decision-making (MCDA for Decision Analysis) methods are useful instruments. The primary goal of MCDA is to weigh different criteria (indicators, attributes, objectives). One type of MCDA framework is the Analytical Hierarchy Process (AHP) framework. The AHP framework uses expert opinions and stakeholder-dependent weighing factors for comparing and balancing the effects of the various scenarios in the domains of health and sustainability.
In this study, an AHP framework was developed and applied to three hypothetical food policy measures, all aiming at a diet containing less animal-based protein and more plant-based protein. The first food policy measure was based on a randomised controlled trial (RCT), which examines the effect of a fiscal measure (higher meat prices), an information nudge (information on the environmental impact of meat production and the role of the consumer in that regard) and the combination of both on meat purchases in a Dutch virtual supermarket. As a second (hypothetical) policy measure, the effects of eliminating pork from the Dutch diet, yet producing the same number of pigs, was tested. In the third scenario that was developed, pigs were no longer produced in the Netherlands and, as in the second scenario, pork was eliminated from the Dutch diet.

After developing the scenarios, indicators for the domains of health, environment and socio-economic aspects were identified. In total, 20 indicators were applied, 9 in the domain of health, 6 in the domain of environment and 5 in the domain of socio-economic aspects. For each scenario, the effects of a scenario on the identified indicators were calculated and experts were asked to value the outcomes. Additional experts compared and balanced the outcomes for the various scenarios within their own domain.

By adjusting weighing factors in the AHP model, we aimed to mimic different virtual policymakers in order to gain insight into the preferred scenario in case of different perspectives. For example, what is the preferred scenario when health is considered most important? Or which scenario is preferred from an economic point of view? From this exercise, we learned that all policymakers prefer the scenario in which both consumption and the production of pork is reduced over the current situation, the scenario in which we don’t eat pig meat and the scenario with higher meat process and information nudgets.

What should be done to contribute optimally to the desired protein transition? How to move from an animal-based diet to a more plant-based diet? What is acceptable, what is most important: Human health, the environment, employment? And is it possible to arrive at a solution that is acceptable to all stakeholders? Our study shows that, despite different preferences and arguments, agreement is possible. Moreover, it shows that an MCDA model such as the AHP is a very promising tool in a discussion on complex issues such as the protein transition.

1 Introduction

1.1 Background

People in the Netherlands have plenty of healthy and safe food at their disposal and enjoy an increasing life expectancy. Although food in the Netherlands is generally safe from both a microbiological and toxicological standpoint, the current dietary patterns of the Dutch population cause substantial health losses, especially from chronic diseases. Besides, our current food system poses a major burden on the environment because of significant greenhouse gas emissions, land and resource use (e.g. water and phosphorus), soil and water contamination by nutrients and pesticides, as well as waste production.

In its ‘Transitie Agenda Biomassa en Voedsel’ (Transitieteam Biomassa & Voedsel, 2018), the Dutch government aimed at a protein transition in which the plant-based/animal-based protein ratio in our diet shifts from 40/60 to 60/40, a transition that should contribute to health and sustainability. To promote such a healthier and more environmentally sustainable food consumption pattern, a drastic change in our current food system is necessary, a change that not only guarantees high standards of health and sustainability, but also addresses the economy (i.e. industry’s profitability) and consumers’ perspective (e.g. price, taste, etcetera). To this end, an integrated food policy that takes into account safety, health and sustainability, as well as socio-economic and cultural aspects is required.
However, not all measures favouring healthy diets are absolutely environmentally or economically sustainable, safe, or acceptable to consumers and producers. Finding the best option, balancing health, safety, and sustainability, while accounting for the socio-economic and cultural aspects involved, necessitates a deep understanding of the complex interconnections among the various domains of the food system. One way to assist decisionmakers in choosing between different policy options is the development of an multi-criteria assessment framework that estimates the effects of potential policy measures on different aspects of different domains. This will then allow for the assessment of the potential outcomes of certain policy measures in such a way that different stakeholders would be able to play an active role and cooperate in inducing the transition at various levels.

1.2 Multi-criteria decision analysis: MCDA and AHP

Decision Analysis (Operations Research) is a mathematical analysis method that is strongly focused on econometrics and business administration, which has spread in many forms over time, and is still under development. Numerous subfields focus on specific mathematical problems, such as linear (convex, integer) programming. These are usually uni-criterion techniques, such as maximising yield, etcetera. Other methods focus on multi-criteria decision analysis (MCDA), or dynamic programming, game theory, network analysis, and so on.

MCDA methods are especially important to balance problems in environmental and health analyses from the RIVM point of view.[1]

The primary goal of MCDA is to weigh various criteria (indicators, attributes, objectives). In most of the balancing problems, it makes sense to arrange the criteria in a tree structure. Thus, one distinguishes the main criteria, which break down into sub-criteria, some of which can be subdivided into sub-sub-criteria, etcetera (for an example, see https://www.mindtools.com/a7y139c/the-analytic-hierarchy-process-ahp). Weights are assigned to each criterion. Many MCDA methods allow these weights to be determined in a systematic way, either by the decisionmaker or through a group process. On the basis of the tree structure of the criteria, pairwise comparisons are made at one and the same (sub-)criterion level (Brunelli, 2015).

The RIVM report "What is on our plate?" published in 2017 (Ocké et al., 2017) presented an MCDA-type framework to identify the caveats and opportunities for such policies, providing a qualitative knowledge base for informed decision-making: the Analytical Hierarchy Process (AHP) framework, designed and refined by Thomas L. Saaty (1926-2017). The AHP method has been described in detail in the literature (Saaty, 1980; Saaty and Vargas, 2012; Ishizaka and Nemery, 2013; Brunelli, 2015). Many works by Saaty were published later on.
The AHP framework uses expert opinions and stakeholder-dependent weighing factors to compare and balance the effects of various scenarios in the domains of health and sustainability. The AHP method is ideally suited for comparing outcomes in totally different, and initially incomparable, units: DALYs; tons of nutrient/year; kcal/day; kg CO2 equiv., etcetera. It is unnecessary – and even undesirable – to map out scenarios and effects in one unit.

1.3 Fair play for food (FP4F)

From 2019 to 2022 RIVM commissioned and conducted the FP4F project within the framework of strategic projects. The general aim of FP4F was to further develop an assessment framework to map the consequences of food policy measures promoting a healthier, safer, and more sustainable food consumption pattern among the Dutch population, also considering socio-economic aspects.

In "What is on our plate?" (Ocké et al., 2017), it was concluded that lowering the consumption and production of red meat (meat from ruminants and pigs) is the preferred scenario for achieving the protein transition. For further development of the framework in FP4F, we developed three policy measures, each aiming at a diet containing less animal-based protein and more plant-based protein.

One of the food policy measures that is taken into account in the framework is based on a randomised controlled trial (RCT), which examines the effect of a fiscal measure (higher meat prices), an information nudge (information on the environmental impact of meat

[1] It is impossible to provide an overview of the many MCDA methods in this specification. The entry 'Multi-criteria decision analysis' (Wikipedia, 2020) lists more than 40 methods. A good, not too extensive, recent overview is the monograph by Ishizaka (Ishizaka & Nemery, 2013). Additional references are (Clemen, 1996) and (Greijn, 2017).

production and the role of the consumer in that regard) and a combination (higher meat prices and an information nudge) on meat purchases in a Dutch virtual supermarket.
As a second (hypothetical) policy measure, the effects of eliminating pork from the Dutch diet, while producing the same number of pigs, will be tested. The contemporary Dutch diet includes approximately 78 grams of proteins, consisting of 39% plant-based proteins and 61% animal-based proteins, of which approximately half is meat (VCP 2012-2016; Van Rossum et al., 2020). The most frequently consumed types of meat are poultry, pork and beef. Of all meat consumed in 2020, 47.7% originated from pigs, 29.1% from chickens and 19.9% from cattle. Only 3.3% originated from other animals (Vleesconsumptie - WUR).
Next to the two measures focusing on the consumption of meat, we also developed a scenario that focused on lowering the production of red meat. Whereas the beef production chain (in 2020: 433 million kg of beef (including veal; StatLine - Landbouw; vanaf 1851 (cbs.nl)) is rather complicated, with beef sourced from both dairy and beef cattle, the pork production chain (in 2020: 1658 million kg of pork; StatLine - Landbouw; vanaf 1851 (cbs.nl)) is relatively simple, as there is only one source type. In the last scenario that was developed, pigs were no longer produced in the Netherlands and, as in the second scenario, pork was eliminated from the Dutch diet.

After developing the scenarios, indicators for the domains of health, environment and socio-economic aspects were identified. In total, twenty indicators were applied, nine in the domain of health, six in the domain of the environment and five in the domain of socio-economic aspects. For each scenario, the effects on the identified indicators were calculated, and experts were asked to value the outcomes, using a dimensionless unit. Such dimensionless outcomes from the various domains can be compared and balanced using the AHP framework. Additional experts compared and balanced the outcomes for the various scenarios within their own domain. The outcomes of the three scenarios were compared to each other and to a reference scenario: the contemporary situation in the Netherlands.

1.4 Outline of this document

After this introduction, the report will describe the scenarios that are to be compared in this study. Chapter 2 includes the experiment on the effect of a fiscal measure and information nudge in a virtual supermarket. In Chapter 3, three additional scenarios are described, extreme scenarios that could result in a lower intake of animal-based protein. Chapter 4 describes the analysis of the sector and the production chain. The relevant criteria and sub-criteria used to compare the effects of the various scenarios are shown in Chapter 5.
Chapters 6 to 9 describe the method of an AHP model in general and the development and application of the AHP model in this project. Finally, in Chapter 10, the discussion and conclusions are presented.

2 The virtual supermarket: “Less meat in the shopping basket”

The design and results of this study are described in Vellinga et al., 2022.

2.1 Introduction

To meet the Paris Climate Agreement and its goal to limit global warming, urgent action is needed. There is a growing consensus that decreasing the environmental impact from food production and consumption is an essential part of the action (Garnett, 2009; Tilman and Clark, 2014).

From both an environmental and a health perspective, measures to reduce meat consumption can provide a win-win situation (Broeks et al., 2020). Lower meat consumption combined with lower meat production will, among others, mitigate climate change and reduce pressure on biodiversity. Lower red and processed meat consumption is associated with lower risk of developing type 2 diabetes and cancer. Implementing measures to reduce meat consumption or purchases, however, is difficult. Lowering meat purchases, as a stand-alone measure, is not a good business model for supermarkets or the out-of-home eating sector. From a consumers’ perspective, part of the population might be against lowering meat consumption, since eating meat is central to the Dutch eating culture for many population groups. From the political perspective, therefore, striving for lowering meat consumption entails political courage and perseverance.

National governments have various types of policy instruments at their disposal to steer consumers’ dietary choices (Temme et al., 2020). Informative, administrative, behavioural and market-based instruments can be implemented. According to the current state of knowledge, changing the food consumption patterns is most effective in a policy mix (United Nations System Standing Committee on Nutrition 2017, Lang and Mason, 2018; De Schutter et al., 2019), involving longer-term financial incentives, and certainly both information measures and nudges.
Currently, hardly any implemented food policy focuses specifically on the reduction in meat consumption (Temme et al., 2020). Moreover, policies combining health and sustainability objectives are rare and often only implemented via informative measures. These measures include, for example, dietary guidelines that recommend a maximum consumption of meat. However, their effectiveness as stand-alone measure for reducing meat consumption by providing information only is low (Latka et al., 2021). Effectiveness might increase when other, more stringent, measures are added. Taxes, expenditure, and subsidies are powerful tools that governments can implement to achieve behavioural change. Pricing is an important factor in consumer habits and might therefore be a suitable instrument to lower meat consumption.

Therefore, this experiment examined the effect of higher meat prices, an information nudge, and a combination of both measures on meat purchases in a three-dimensional virtual supermarket.

2.2 Methods

The paper published (Vellinga et al., 2022) describes the design of the study and methods. The trial was registered in the Netherlands Trial Register identifier NL8628 on 18/05/2020. ICTRP Search Portal (who.int) NTR (trialregister.nl).[2] The study was carried out between 22 June 2020 and 28 August 2020 in the validated Dutch virtual supermarket software (Waterlander et al., 2015). This is a three-dimensional computer software system simulating the in-store environment of a real supermarket (Waterlander et al., 2011).

See Figure 2.1 for the design of the study. In short, a parallel designed randomised controlled trial with four conditions was performed. Participants who were solely or largely responsible for their household groceries (aged ≥ 18 years) were randomly assigned to the control condition or one of the experimental conditions: a 30% price increase for meat ('Price condition'), an information nudge about the environmental impact of meat production and consumers' role in that regard ('Information nudge condition') or a combination of both measures ('Combination condition'). The final sample included 533 participants. Participants were asked to shop for their household for one week. The primary outcome was the difference in the total amount of meat purchased in grams per household per week.

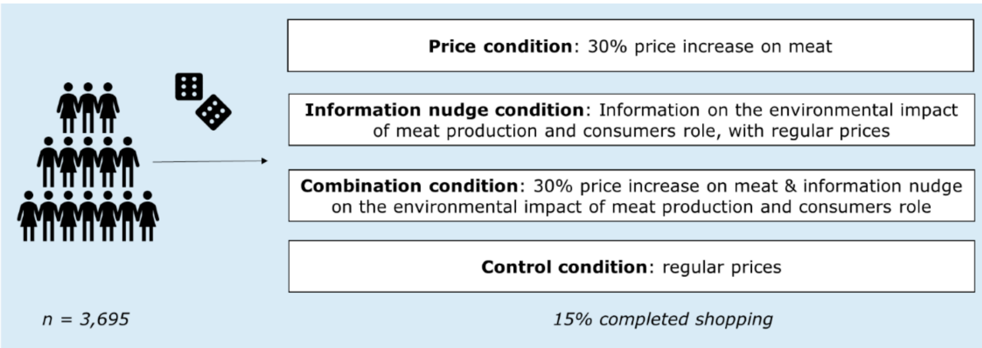

Figure 2.1 Design of the randomised controlled trial in the virtual supermarket.

[2] The ICTRP Search Portal aims to provide a single point of access to information about ongoing and completed clinical trials. It provides a searchable database containing the trial registration data sets made available by data providers around the world, meeting criteria for content and quality control.

From: The virtual supermarket: An innovative research tool to study consumer food purchasing behaviour

Figure 2.2 Screen shots of the virtual supermarket environment.
From: The virtual supermarket: An innovative research tool to study consumer food purchasing behaviour.

In order to reflect a real-world setting, participants in the Price condition and the Combination condition were made aware of the price increase of meat via a notification before entering the supermarket: "The government has increased the tax on meat in the virtual supermarket, leading to a price increase by 30% for meat" (in Dutch: In de virtuele supermarket heeft de overheid de belasting op vlees verhoogd, waardoor de prijs van vlees met 30% is verhoogd).

The information nudge during the study was formulated as follows: "The government wants to reduce the consumption of meat in the Netherlands because meat production damages the environment. You can help to reduce the environmental damage caused by meat production by purchasing less meat" (In Dutch: De overheid wil de hoeveelheid vlees die in Nederland gegeten wordt verminderen, omdat de productie van vlees een grote druk legt op het milieu. U kunt een bijdrage leveren aan het verminderen van de schade aan het milieu door minder vlees te kopen).

2.3 Results and discussion

The main result of the study is shown in Figure 2.3.

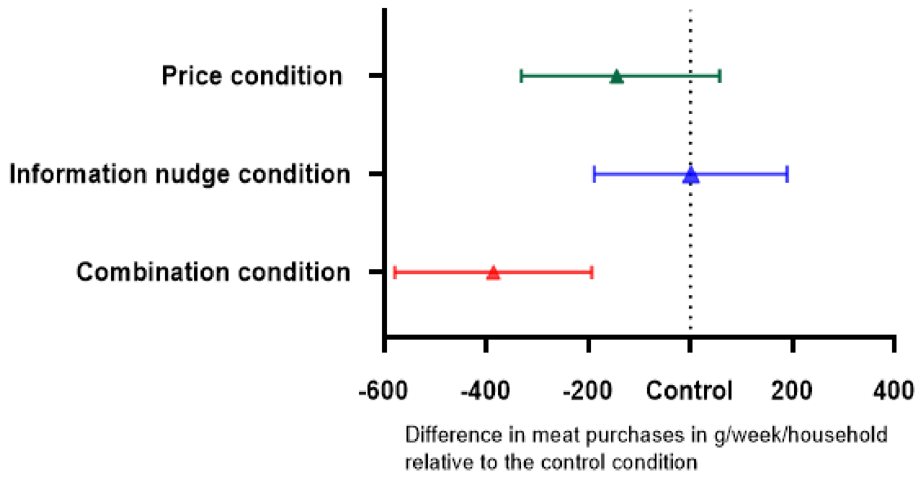

Figure 2.3 Mean difference in meat purchases (in gr/week/household) for the experimental conditions compared to the 'Control condition'.
The reference indicates the control condition. Error bars indicate 95% confidence intervals.

In the 'Combination condition', -386 gr (95% CI: -579, -193) meat was purchased compared to the 'Control condition'. In comparison to the 'Control condition', less meat was purchased in the 'Price condition' (- 44 gr (95%CI: -331, 43)), although this was not statistically significant, whereas a similar amount of meat was purchased in the 'Information nudge condition' (1 gr (95%CI: -188, 189)). More results on baseline characteristics and secondary outcome measures can be found in the journal publication.

In our study, the most pronounced decrease in meat purchases was found when applying a policy mixture of pricing and informational nudging. Pricing alone reduced meat purchases considerably, however, compared to the 'Control condition', not significantly. The information nudge in itself did not alter the amount of meat purchased. The results are in line with studies from other fields of public health food policies, which show that changing food consumption patterns through a policy mix is most effective (United Nations System Standing Committee on Nutrition, 2017; Lang and Mason, 2018; De Schutter et al., 2019), preferably combining financial incentives ed with other instruments, such as information nudges.

Politicians and policymakers may be hesitant to introduce potentially effective policy interventions, such as pricing, as they interfere with citizens' daily lives. Recent studies, however, show that a policy mix. — the systematic bundling of various policy measures — can help to mitigate the potential trade-off between political feasibility and problem-solving effectiveness (Fesenfeld et al., 2020). In the policy mix, the information nudge, as formulated in the current study, may have helped the participants to feel good about the higher price they paid for meat because of its pro-environmental nature. This is in line with a recent meta-analysis (Johnson Zawadzki et al., 2020) showing a robust, positive relation between people's pro-environmental behaviours and subjective wellbeing. Policymakers can seek these types of opportunities to design 'win-win' sustainability programmes applying a combination of policy instruments that could positively impact people, health and the environment.

3 Description of scenarios

3.1 Introduction

The first step in building a weighing framework for policy measures is defining the scenarios relating to the various policies. In this project, we focused on adjustments to the consumption and/or production of pork. Four scenarios are defined: (i) The Reference scenario; (ii) the scenario with the current production, but no pork consumption; (iii) the scenario with no production and no consumption of pork; and (iv) the scenario based on the supermarket experiment with higher pricing measures and information nudges (as described in the previous chapter). In scenarios where no pork is consumed, legumes, as a source of plant-based protein, are consumed instead.

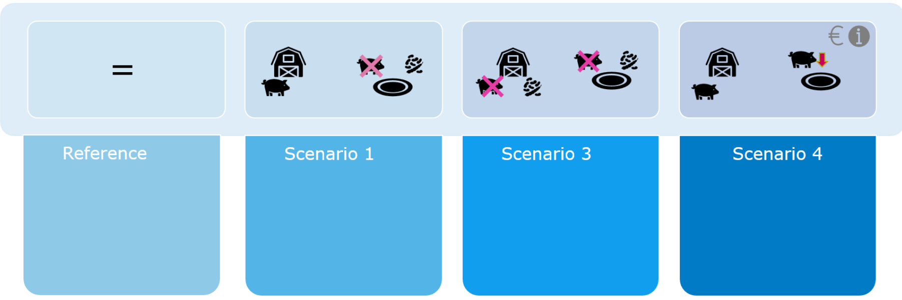

Figure 3.1 Scenarios.
Icons represent production (farm), pig/pork, consumption (plate), legumes and information plus price intervention.

3.2 Reference scenario: Current production and consumption of pork

The Reference scenario is the situation in the Netherlands with the current production of pork and the current consumption of pork and legumes, such as pulses.

Assumptions:
The average consumption of prepared pork per person = 39.3 gr/day for the population aged 1–79 years as was measured in the Dutch National Food Consumption Survey 2012-2016 (Van Rossum et al., 2020), of which 24.9 gr/day consists of processed pork

- The average consumption of prepared legumes per person = 4.7 gr/day for the population aged 1–79 years as was measured in the Dutch National Food Consumption Survey 2012-2016 (Van Rossum et al., 2020)
- The production of pork in the Netherlands = 1.53 billion kg/year as was reported by Statistics Netherlands (CBS) for the year 2018 (CBS, 2018; https://opendata.cbs.nl/#/CBS/nl/dataset/7123slac/table)

3.3 Scenario 1: Current production of pork, but no pork consumption

This scenario reflects a situation in which pork is no longer consumed in the Netherlands. Yet, the production of pork remains stable and all produced pork is exported. Legumes are consumed as a replacement for pork.

Assumptions:

- The consumption of prepared pork per person = 0 gr/day for the population aged 1–79 years.
- In the population's diet, pork is replaced by a caloric equivalent from legumes. Consumption of 39.3 gr of pork results in 67 Kcal, consumption of 61.9 gr of legumes provides the same amount of calories.
- The average consumption of prepared legumes increases per person = 66.6 gr/day. This equals the current consumption (4.7 gr/day) + the additional amount of legumes for replacing pork (61.9 gr/day).
- The ratio of plant-based versus animal-based protein consumption will improve in the Netherlands, due to a strong decrease in the consumption of pork and a slight increase in the consumption of legumes.
- The production of pork = Reference scenario = 1.53 billion kg/ year as was reported by CBS[3] for the year 2018
- All produced pork is exported
- Additionally required legumes for consumption are imported from abroad.
- Consumption of other meat products, such as poultry and beef, remains unaffected.

3.4 Scenario 2: No production and no consumption of pork

In this scenario, no production and no consumption of pork takes place in the Netherlands. In the population's diet, pork is replaced by a caloric equivalent from legumes. Land previously used for farming pigs and producing pig feed will be used for the production of legumes. The additionally produced legumes are deducted from the imported legumes. Any additionally required legumes for consumption will still be imported.

Assumptions:

- The consumption of prepared pork = 0 gr/day for population aged 1–79 years = Scenario 1.
- In the population's diet, pork is replaced by a caloric equivalent from legumes. The consumption of prepared legumes = Current consumption + additional amount of legumes for replacing pork = Scenario 1= 66.6 gr/day.
- The ratio of plant-based versus animal-based protein consumption will improve in the Netherlands, due to a strong decrease in the consumption of pork and a slight increase in the consumption of legumes.
- The production of pork = 0 kg/year.
- Land previously used for farming pigs and producing pig feed will be used for the production of legumes.
- The import of legumes minus export is 0.
- The production of legumes requires 1000 hectare for the production of 2 million kg of legumes (https://opendata.cbs.nl/#/CBS/nl/dataset/71904ned/table).

[3] StatLine (cbs.nl)

- Some pig farmers become legume farmers (25 hectares/farm). In 2018, 1540 fattening pig producers were active (and 645 other pig-related farms). It was assumed that 750 fattening pig farmers will lose their job.

3.5 Scenario 3: Higher pricing of pork combined with information nudges to consumers

On the basis of an experiment in a virtual supermarket, we defined another scenario. In this scenario, the consumption of pork decreases due to education and price policies, while the consumption of legumes remains stable. The production of pork and legumes in the Netherlands remains stable.

Assumptions:

- The consumption of prepared pork = decrease by 30% ≈10 gr, resulting in a total consumption per person of 29.3 gr/day for the population aged 1–79 years
- The percentual decrease for fresh pork is assumed to be equal to that for processed meat (3.7 gr fresh pork and 6.3 gr processed meat).
- The consumption of prepared legumes = 4.7 gr/day = Current consumption
- By decreasing the consumption of pork and slightly increasing the consumption of legumes, the ratio of plant–based versus animal-based protein will improve.
- The production of pork = production as in the Reference scenario

General assumptions

- The meat chain ends at the slaughterhouse, where pigs end up as half carcasses.
- Pulses are harvested after being dried in the pod on land.
- In the meat chain, the import and transit of meat is not taken into account.
- The industrial processing of beans and meat into preserves likewise falls outside the scope of this scenario.
- Meat contains 28 gr protein/100 grams. Legumes: (fresh) 6.5 gr protein/100 gr. We do not correct for differences in amino acid composition because the intake via other protein sources is already sufficient.
- The scenarios are handled pragmatically. Scenarios are checked for practical feasibility.

4 Sector and production chain analyses

4.1 Introduction

In order to have an overview of the impacts caused by changes in the consumption of pork and legumes, a thorough analysis of these selected protein-rich food sectors was performed. This included their full life cycle in the chain from production, via distribution, marketing, retail and consumption, to waste, and represents the Dutch situation in those sectors. The pork production sector is a good model for animal-derived proteins, while the legume production sector is a good model for plant-derived proteins. Legumes are promising substitutes for animal-derived proteins and the Dutch Health Council recommends increasing their consumption.

The analysis was two-fold: first, we identified the total pig sector (Figure 4.2) and the pulses sector (Figure 4.3) in the Netherlands. secondly, we did a life cycle analysis (LCA) on the product chains involved in the production of 1 kg of pork and 1 kg of pulses for consumption in the Netherlands. Both chains were represented in terms of both energy and material inputs, and different types of outputs, such as nutritional value, contribution to the national economy, environmental burden, burden to health or food safety issues, and socio-economic and cultural aspects.

Although there is an overlap in both visualisations, the kind of information needed and provided by either a sectoral analysis or a product analysis will differ. This is mainly caused by the complication that the 'Dutch production system' of a certain sector is altogether different from the 'Dutch consumption system' of the same sector. This is caused by the fact that in the Netherlands, many products are being imported, and many animal products are produced for export. Due to these large import and export flows in the Netherlands, one has to make clear distinctions between the 'produce' and the 'consumption' of the Netherlands. This will provide different flow charts for the 'pig sector in the Netherlands'. This phenomenon is schematically presented in Figure 4.1.

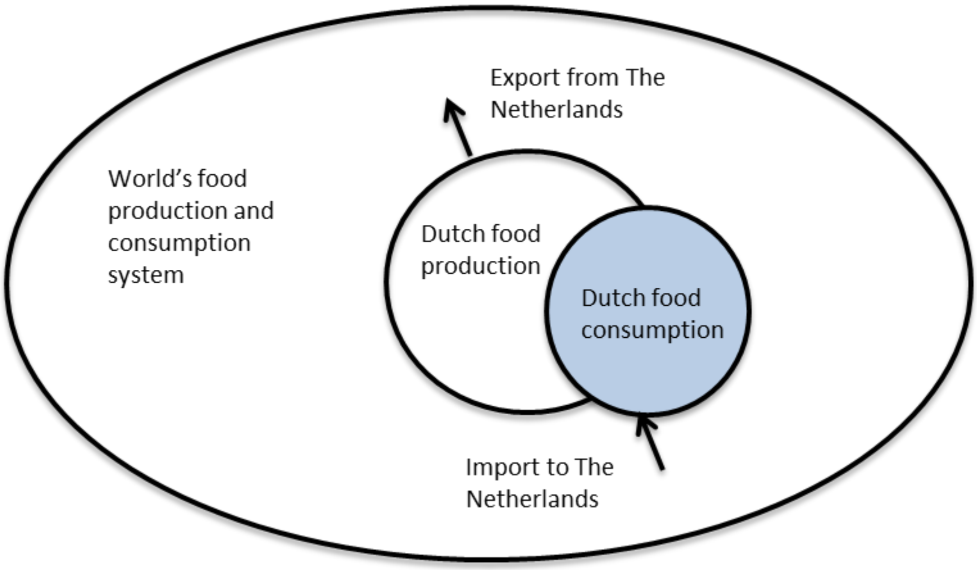

Figure 4.1 Schematic representation of the difference between 'Dutch production' of certain products/sectors and 'Dutch consumption' due to substantial import and export flows.

4.2 Pig sector

An overview of the pork sector across the product chain for the sector in the Netherlands is presented in Figure 4.2. Also, inputs (energy and materials) and outputs (emissions) relating to the sector are provided in Table 4.1.

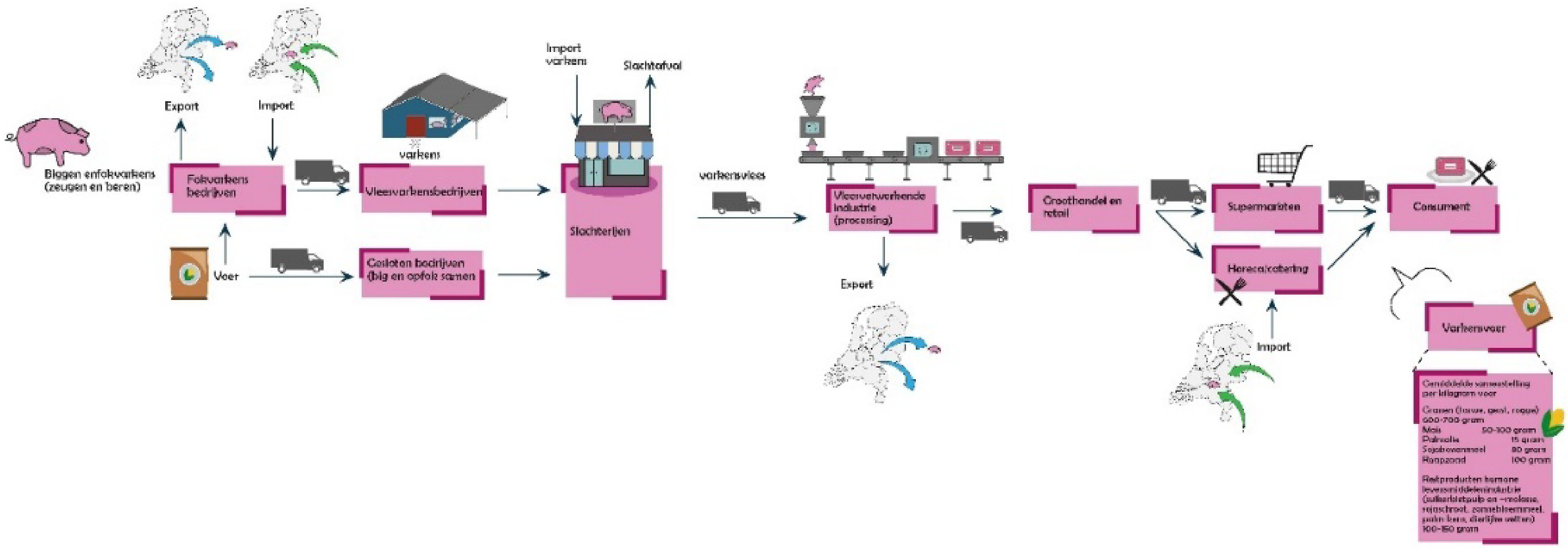

Figure 4.2 Schematic overview of the Dutch pig production chain with its main inputs and outputs.

The pork sector starts with breeding pigs, which produce piglets. In the Netherlands, about 1 million breeding pigs are present. In most cases, the breeding pigs are fed until they reach a weight of about 25 kg, after which they are moved to another farm, where they are fattened until they achieve their full weight. Also, farms exist in which both piglets and pigs are housed. At a weight of 90-120 kg, the pigs are slaughtered in the slaughterhouse. About 60% of the pigs is being consumed as meat or a meat product. The pork is distributed to supermarkets and restaurants, in the Netherlands and abroad. The Dutch consumption of pork is about 36 kg per person per year (WUR, 2018). About 67% of the Dutch pig (17%) and pork production (49%) is exported. Pigs and pork are imported as well. Dutch pigs are slaughtered in Germany, while German and Belgian pigs are slaughtered in the Netherlands. The processing of slaughter waste, dead animals and disapproved meat is regulated in the Dutch ‘Destructiewet’.

In 2019, the export value of pork was 2.3 billion euro (309 million to Germany, 1.1 billion to the rest of the EU and 864 million to the rest of the world). The import of pork only takes place from within the EU and mainly (57%) from Germany.

The average composition of 1 kg of the Dutch pig feed is:

- Cereals (wheat, barley, rye) - 600-700 gr: Europe
- Maize - 50-100 gr: the Netherlands
- Palm oil - 15 gr: non-EU
- Soybean meal - 80 gr: non-EU
- Rape seed - 100 gr: NL and EU
- Residual products from human food industry (sugar beet pulp and –molasse, soybean meal, sun kern meal, palm kernels, animal fats): 100-150 gr: the Netherlands

Over 75% of the feed is grown in the Netherlands or Europe, 25% is imported from outside Europe (NeVeDi, 2020). Resources that are imported from outside Europe are soybeans, soybean hull and palm oil products.

Emissions of particulate matter (PM10) from the pig sector amount to about 1204 tonnes per year (Emissieregistratie, RIVM). These emissions were lowered in the past decades; in 1995, the PM10 emissions were 1724 ton per year.

An overview of known figures on the Dutch pig sector is provided in Appendix A.

4.3 Pulses sector

An overview of the Dutch pulse product chain is presented in Figure 4.3. All inputs (energy and materials) and outputs (emissions) relating to the sector are provided in Appendix B.

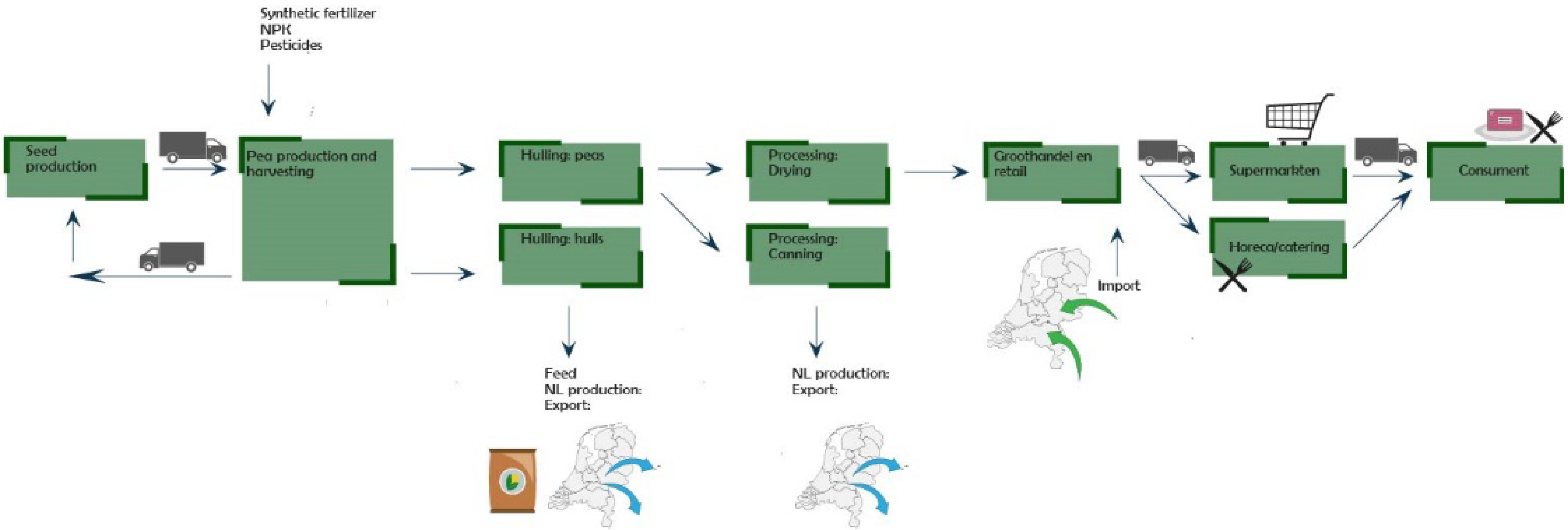

Figure 4.3 Schematic overview of the Dutch pulse product chain with its main inputs and outputs.

The pulse sector in the Netherlands is relatively small, but growing. The product chain starts with the production of seeds, out of which peas are grown. After harvesting, the peas are separated from their hulls. Hulls are used for animal feed production. The peas are being processed, either by drying or by canning. The end products are distributed to supermarkets and restaurants in the Netherlands. There is no substantial export of pulses from the Netherlands. However, the largest part of the consumed pulses is being imported, mainly from Turkey and the USA.

In the Netherlands, pulses are mainly produced in the South-West, particularly in Zeelandic Flanders ('Zeeuws-Vlaanderen' in Dutch). The crop is a leguminous plant species and, as such, is good for nitrogen fixation. The average harvest in the Netherlands is about 3 tons per hectare per year.

4.4 Life cycle assessment

The analysis of the environmental impacts of production and consumption of 1 kg of pig meat and 1 kg of pulses in the Netherlands relating to life cycle was performed using life cycle assessment methodology (LCA). Life cycle assessment is a methodological tool used to quantitatively analyse the life cycle of products / activities within the context of their environmental impact. For this purpose, specific calculation tools are being applied. In LCA, the total life cycle of a product or activity is considered; from the extraction of resource materials to the waste and waste treatment stage, also referred to as 'from cradle to grave'. LCA comprises a number of steps. The most important ones are:

- LCI – life cycle inventory. In this step, information on the use of resource materials and energy that are used within the life cycle, as well as the emission of (harmful) substances throughout the life cycle, is being collected.
- LCIA - life cycle impact assessment. In this step, the inventory data (Life Cycle Inventory results) is judged. On the basis of the LCIA, a picture is created on the environmental impact caused by the product or activity.

The result of a LCA study is an environmental profile of a product or activity: a 'score list' containing environmental effects. The environmental profile shows the largest environmental problems caused by a product, and at which stage(s) in the life cycle these problems are caused. In this way, an LCA contributes to the possible definition of management changes for improving the environmental friendliness of a product. Also, the consequences of various alternatives can be shown.

4.4.1 Pork

Figure 4.4 outlines the LCA for the production system of 1 kg of pork in the Netherlands. The life cycle chain of pork starts with the production of pig feed. In the Netherlands, pigs are mainly fed with soybean meal, palm oil, barley grain and wheat grain, which are mixed and processed into pig feed. Piglets (up to 25 kg) grow into sows and are fattened until they are ready for slaughter. In the slaughterhouse, the pigs are processed into meat.

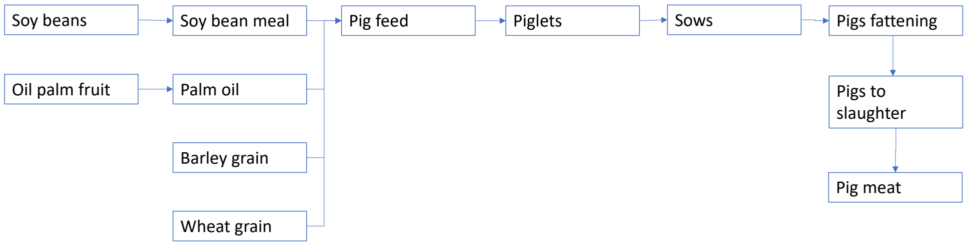

Figure 4.4 Schematic representation of the life cycle chain of pork production for the LCA calculations.

The figure shows the processes contributing >5% to the total impact. Thus, many small material flows, such as herbicide production, oat grain production and transport flows, are left out of the figure. Also, energy flows are not provided, for the sake of readability. However, these flows/inputs are incorporated in the calculations. For a complete overview of all processes, we refer to the RIVM Voedseldatabase (version 11-2-2021, Milieubelasting van voedingsmiddelen | RIVM).

In the LCA for pork, several environmental impacts were calculated that result from the pork life cycle chain. The impacts relating to the production of 1 kg of pork for the various impact categories are presented in Table 4.1.

Table 4.1 Impacts relating to the production of 1 kg of pork in the Netherlands.

Effect category	**Unit**	**Total**
Climate change	kg CO_2 eq	12.68
Terrestrial acidification	kg SO_2 eq	0.23
Freshwater eutrophication	kg P eq	0.0017
Marine eutrophication	kg N eq	0.0746
Agricultural land occupation	m^2	11.36
Water consumption	m^3	0.078

Also, the contribution by the various life cycle stages to the total impact was calculated. The figure below presents the contribution by the various life cycle stages to the total of environmental impacts (for six impact categories). It becomes clear from the figure that, out of all impact categories, the stages of feed production and pig fattening make the highest contribution to the total impact.

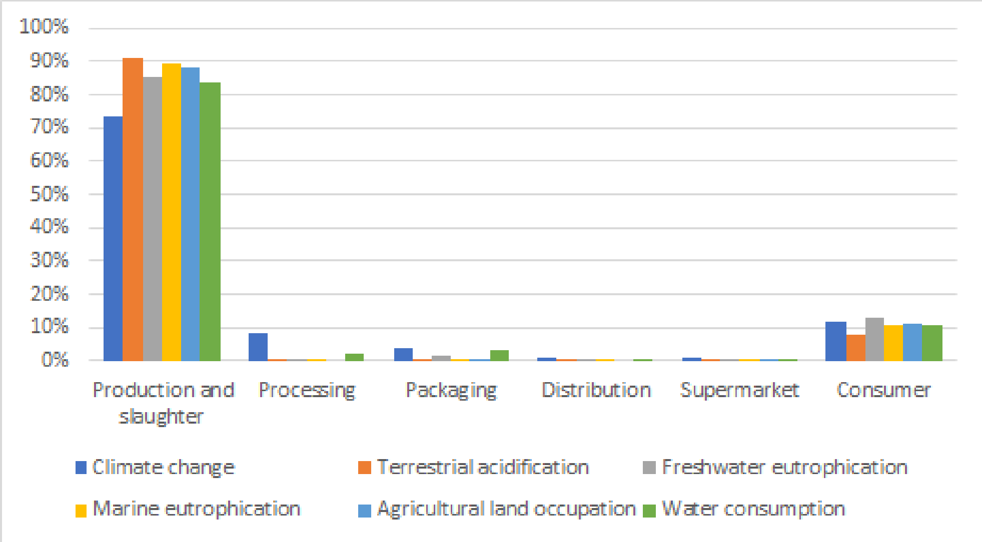

Figure 4.5 Contribution per life cycle stage to the total environmental impacts for six impact categories.

4.4.2 *Pulses*

This process describes the cultivation process of pulses in general (dry) as consumed in Netherlands. Considered activities include: start material and its production, fertiliser, lime and pesticide application rates and their production, transport, energy use for field management and irrigation. The elementary flows include field emissions to the air, water and soil, direct land use change emissions and emissions due to pesticide use and heavy metal emissions.

Crop yields are derived from FAO statistics using a 5-year average (2012-2016). Possible co-production is in line with the Agri-footprint methodology. Synthetic fertiliser use is: 20.00 kg N, 52.00 kg P_2O_5 and 80.00 kg K_2O equivalents. Specific fertiliser amounts are quantified on the basis of total NPK and relative amounts of fertiliser consumed by type for the Netherlands region (De Schutter et al., 2019). Total water use is based on the 'blue water footprint' of ‘Beans, dry in Netherlands’, which is 0.00 m^3/ton (Mekonnen & Hoekstra, 2011). We have chosen not to include 'green water footprint' of 614 m^3/ton or total rainwater of 1942 m^3/ha to the dataset.

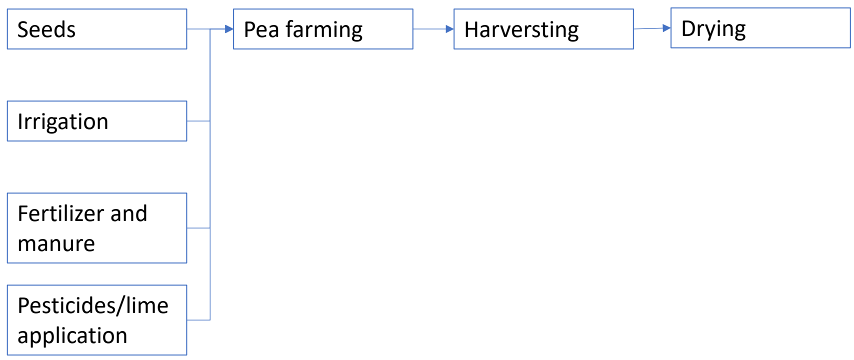

Figure 4.6 Schematic representation of the life cycle chain of dried pea production for the LCA calculations.
Processes contributing >5% on the total impact are incorporated in the diagram.

In the LCA for brown beans produced for consumption in the Netherlands, several environmental impacts were calculated that result from its life cycle chain. The impacts relating to the production of 1 kg of brown beans for the various impact categories are presented in Table 4.2.

Table 4.2 Impacts relating to the production of 1 kg of dried brown beans in the Netherlands.

Effect category	**Unit**	**Total**
Climate change	kg CO_2 eq	1.88
Terrestrial acidification	kg SO_2 eq	0.010
Freshwater eutrophication	kg P eq	0.00033
Marine eutrophication	kg N eq	0.0021
Agricultural land occupation	m^2	2.11
Water consumption	m^3	0.073

Since for all impact categories, the primary production life cycle stage contributes more than 95% to the total impacts, the distinction between life cycle stages was not visualised in this case.

5 The AHP model

5.1 Introduction

In this chapter, the methodology of the Analytic Hierarchy Process (AHP) is explained more in general (In Chapter 9, the application of the AHP model for FP4F is described). The primary goal of any MCDA, such as the AHP model, is to weigh a number of options or scenarios on different criteria in order to gain insight into the preferred option or scenario, see Figure 5.1.

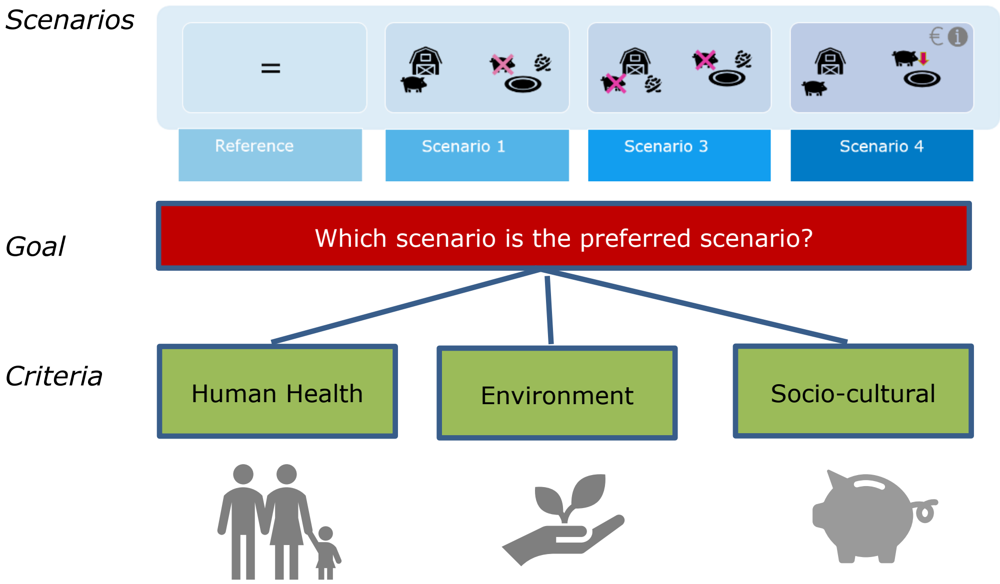

Figure 5.1 Goal and schematic setup of the AHP model.

As mentioned in previous chapters, the development of the AHP multi-criteria decision framework follows a number of steps. It starts with the description of the options or scenarios to be chosen. The next step is the identification of the various criteria and sub-categories, and when necessary, further division into sub-sub-categories. They usually follow a tree structure, such as the one in Figure 5.2.

Next to the selection of criteria (or domain), sub- and sub-subcategory, weights are assigned to each subcategory. After assigning weights to categories and subcategories and values to indicators in the AHP tree structure, the options or scenarios should be weighted in terms of the criteria. On the basis of these steps the total score for each scenario can be calculated and thus the preferred scenario can be defined.

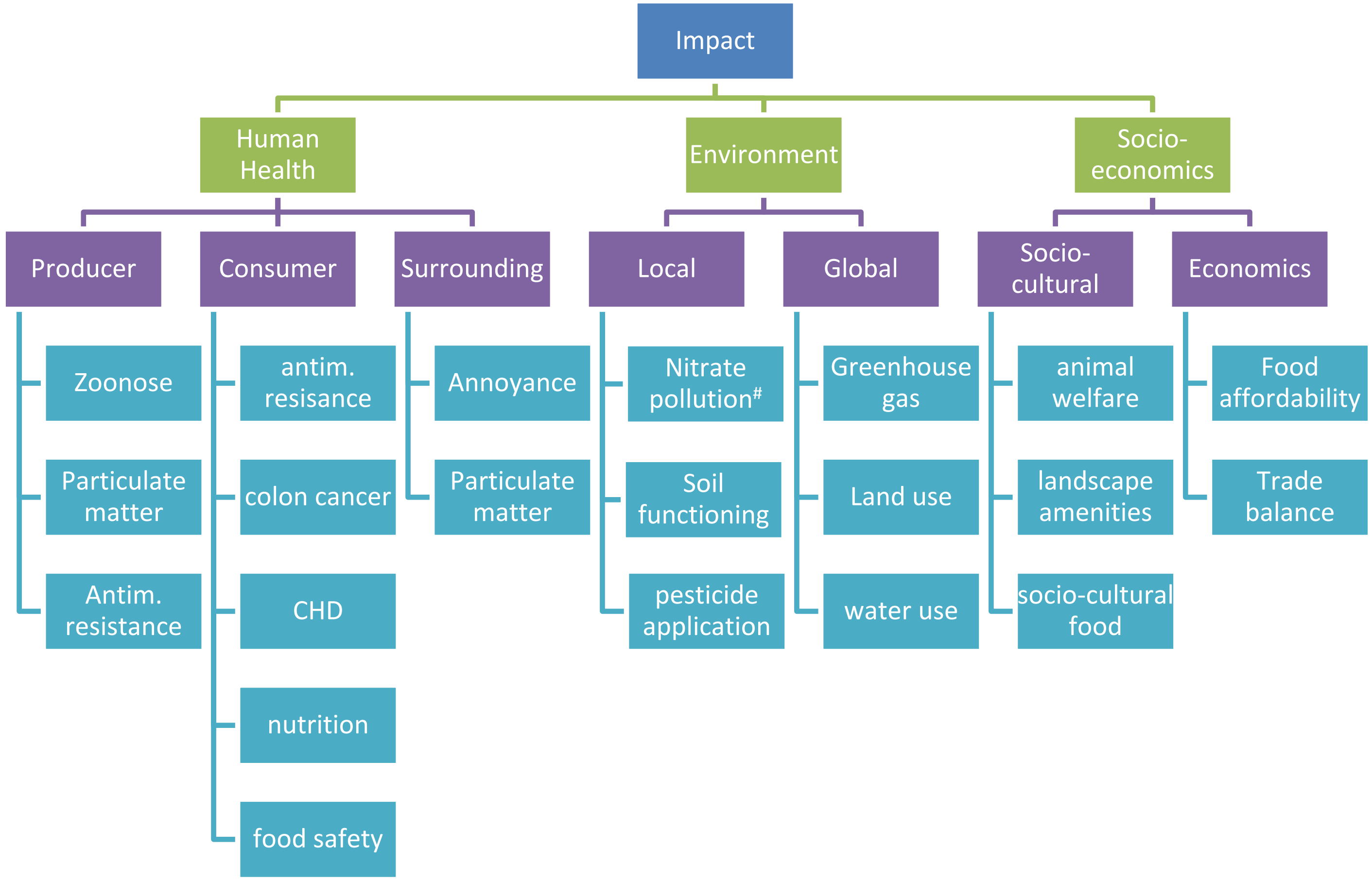

Figure 5.2 Tree structure of the criteria.
[#]: due to a lack of data, nitrate pollution was ultimately not included in the AHP model.

5.2 Weighing methodology: Analytic Hierarchy Process (AHP)

Many MCDA methods allow for the weights to be determined in a systematic way, either by the decisionmaker or through a group process. For example: a decisionmaker working in the field of public health will attach more weight to the main category of health, and less to the main categories of environment and socio-economic aspects. And within the category of health, the 'consumer' subcategory will be given more weight than 'producer'. In case of a group process, group members will have to come up and agree with weights for all categories and subcategories.
The AHP, which was developed by Saaty, is a special type of MCDA for making pairwise comparisons. The crux of the AHP is a non-linear (balanced) scale of preferences, which can assume values ranging from 1 to 9, with attached wording of the relative importance (Table 5.1).

Table 5.1 Scale of preferences developed by Saaty.

Saaty		**Balanced Saaty**	**Saaty**	**Balanced Saaty**
1	Indifference	1.00	1/1	1.000
2		1.22	1/2	0.820
3	Moderate Preference	1.50	1/3	0.667
4		1.86	1/4	0.538
5	Strong Preference	2.33	1/5	0.429
6		3.00	1/6	0.333
7	Very Strong Preference	4.00	1/7	0.250
8		5.67	1/8	0.176
9	Extreme Preference	9.00	1/9	0.111

In later psychometric research, other scale values (weight ratios) were proposed, which would fit the wording better. We use the Balanced scale (Brunelli, 2015; Ji et al., 2003; Pöyhönen et al., 1997). While the scale increases moderately at the low end, it continues to increase exponentially as preferences grow stronger. One does not have to limit oneself to the nine values, intermediate values may also be given.

The weighing must be correct for reversal: if criterion A is considered three times as important as criterion B, then B is automatically 1/3 = 0.333 times as important as A. For instance, one can fill a matrix of pairwise preferences. For three criteria, you can find an example in Figure 5.3:

	A	B	C
A	1	**3.000**	**2.000**
B	0.333	1	**0.667**
C	0.500	1.500	1

Number of Criteria: 3

Figure 5.3 Example of filling a matrix of pairwise preferences.

The main diagonal contains only the value 1: a criterion is as important as itself. Only the yellow fields are filled in. Here, it says that criterion A is 3.0 times as important as B and 2.0 times as important as C. The inverse values are in the grey fields: 1 divided by the inverse ratio.
So, if all the ratios in the yellow fields are equal to 1.000, all the criteria are equally important. In other words, we do not have a pronounced 'preference' for one or the other criterion.
Please note: In this case, the values in this 3-criteria matrix are chosen exactly in such a way that the weights are 'consistent'. So, if: w(-eight)A/w(-eight)B=3.0 and wA/wC=2.0, then wB/wC=2. / 3. = 0. 667. See also appendix III.

5.3 The priority weighing vector

On the basis of these pairwise comparisons, a priority weighing vector is calculated for all criteria. This vector represents the weights of all criteria in the consideration of the various scenarios. For instance, how important is the impact of food safety on health issues compared to the impact of stroke? This weighing factor is taken into account by considering the impacts of the various scenarios. There are several methods to determine the priority weighing factors, or the relative weights (as many as there are criteria) (Brunelli, 2015). These add up to 1.0 (100%). One very simple method is to take the geometric mean of a row of the weighing matrix (GeoMean column), to sum the geometric means and normalise this to 100% (column weights).

Figure 5.4 shows an example of priority weights based on two criteria. In this example, it can be seen that criterion B (including the grey boxes) scores relatively weakly compared to A and C. This is expressed in a low geometric mean (0.605) in the GeoMean vector. After normalisation, criterion B is given a weighing factor of 18%. Similarly, criterion A scores 55%, the highest weight.[4]

	A	B	C		GeoMean	Priority		Geometric Consistency Index			
A	1	**3.000**	**2.000**		1.8171	**0.5455**		1	1.000	1.000	0.000
B	0.333	1	**0.667**		0.6058	**0.1819**			1	1.000	0.000
C	0.500	1.499	1		0.9084	**0.2727**				1	
	Number of Criteria:	3			3.3313	1.0000				GCI:	**0.000**

Figure 5.4 Example of priority weights for three criteria based on pairwise preferences.

5.4 Scoring alternatives/scenarios

Having weighted (prioritised) criteria, we are only 'halfway' the decision problem. The main issue is the consideration of alternatives, or scenarios, in terms of the criteria. This is also achieved by means of pairwise comparisons of the scenarios for the various criteria.

So in our case, we wanted to know the preferred scenario out of the 4 options, given certain policy preferences. In the case of 4 scenarios and 20 criteria, this means 6 x 20 = 120 considerations (for each indicator, Reference scenario 0 must be compared to Scenarios 1, 2 and

[4] There are other ways to calculate the weighing vector (Brunelli, 2015). Saaty himself has always emphasised the so-called 'eigenvector' method. It has been found that this method is not resistant to the problem of rank reversal: If a criterion is added, the ranking relationships of the old criteria may not change. The geomean method is okay, for that matter, and is also easier to calculate.

3, Scenario 2 must be compared to Scenarios 3 and 4, and Scenario 3 needs to be compared to Scenario 4).
The 20 indicators are grouped into subcategories and main categories. For example: the main category Health is divided into the subcategories *producer*, *consumer* and *surroundings*. And the subcategory *producer* is divided into the criteria *zoonoses*, *particulate matter* and *antimicrobial resistance* (see Figure 5.2). Within each subcategory, pairwise comparisons are made of the various criteria within each subgroup, resulting in 3+5+2+3+3+3+2 (21) more preferences. All this is conducted by experts on the various topics.

The preferences for the three domains (meaning three pairwise comparisons, and ranking within the subcategories of producer, consumer and surroundings) need five more pairwise comparisons. All these preferences are expressed by potential decisionmakers with different perspectives (assumed).

On the basis of these pairwise considerations per decisionmaker, the total score for each scenario can be calculated. In this case, with multiple levels of consideration, the weights are multiplied by each other.

In this table, the weights of the scenarios are based on the preference domains and the subdomains. The 'Weight of criteria' column represents the result of the pairwise comparisons of the criteria for each individual criterion (standardised geometric mean). In the last column, the weights are multiplied by each other. The sums of these products are the scenario scores. The one with the highest score is the preferred scenario.

Table 5.2 Scoring of scenarios based on a virtual decisionmaker.

Priority *vs* goal		**Scenario**	**Weight of scenario**		**Weight of criteria**	**Score**
I. Human Health	A. Producer; 1. Zoonoses	0. Reference	0.237	x	0.051	0.012
		1. Scenario	0.237	x	0.051	0.012
		2. Scenario	0.289	x	0.051	0.015
		3. Scenario	0.237	x	0.051	0.012
I. Human Health	A. Producer 2. Particulate Matter	0. Reference	0.206	x	0.009	0.002
		1. Scenario	0.206	x	0.009	0.002
		2. Scenario	0.383	x	0.009	0.003
		3. Scenario	0.206	x	0.009	0.002
I. Human Health	A. Producer 3. Antimicrobial Resist.	0. Reference	0.222	x	0.051	0.011
		1. Scenario	0.222	x	0.051	0.011
		2. Scenario	0.333	x	0.051	0.017
		3. Scenario	0.222	x	0.051	0.011
I. Human Health	B. Consumer 4. colon cancer	0. Reference	0.146	x	0.026	0.004
		1. Scenario	0.337	x	0.026	0.009

Priority *vs* goal		**Scenario**	**Weight of scenario**		**Weight of criteria**	**Score**
		2. Scenario	0.337	x	0.026	0.009
		3. Scenario	0.180	x	0.026	0.005
Etcetera for the other criteria						
Total		0. Reference				20.7
		1. Scenario				24.6
		2. Scenario				33.8
		3. Scenario				20.9

6 Selection of categories, subcategories, and criteria

6.1 Introduction

The development of the AHP multi-criteria decision framework follows a set of steps of which two have been taken so far:

1. Scenario development.
2. Description of relevant sectors and production chains.

In this chapter, we continue with the third step:

3. Identification and selection of categories, subcategories, and criteria.
4. Expert opinion: effect scores.
5. Weighing factors: policy preferences.
6. Selection of preferred scenario.

Changes in the production and consumption of pork and pulses will have consequences in various domains, such as health, the environment, and socio-economic aspects.

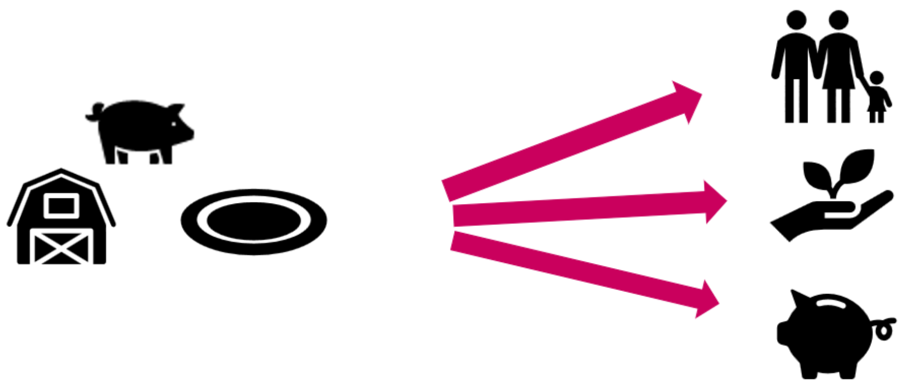

Figure 6.1 Schematic representation of indicators affecting the domains of health, the environment, and socio-economic aspects.

In this chapter, we describe the selection of subcategories (for instance, global and local in the environment category) within the three categories of health, the environment and socio-economic aspects, and criteria therein as cardinal points for our AHP framework. The next step involves the identification of criteria (in case of the category of (global) environment: climate change) and the selection of one or more relevant indicators for each criterion (regarding climate change, for instance, the emission of greenhouse gases), as well as the unit in which it is to be presented (in the case of greenhouse gases: production of CO_2 equivalents). These four steps are presented schematically in Figure 6.2, including an example with respect to the criterion of climate change.

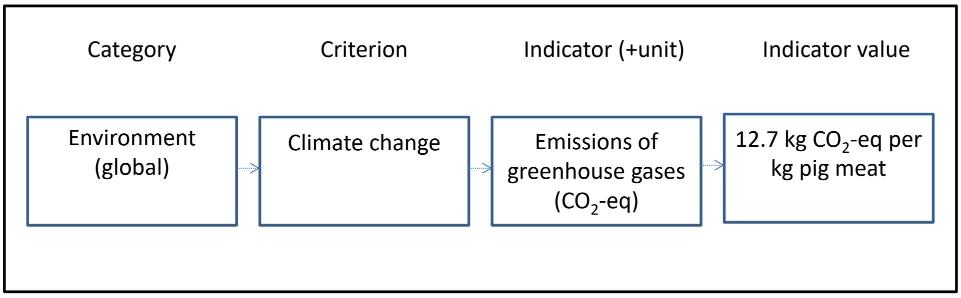

Figure 6.2. Four steps in the definition of the assessment framework: Selection of categories, criteria, indicators (and their units) and indicator values.
The four steps relating to the criterion of climate change are presented as an example. The relevant subcategory (in this case: global) is shown between brackets under Environment.

6.2 Selection of categories, subcategories, criteria and sub-criteria

First, three main categories were selected, constituting crucial themes in sustainable food system assessments. We chose to distinguish between:
I. Human Health
II. Environment
III. Socio-economics

These were subdivided into seven subcategories:
I. Human Health
   A. Producer
   B. Consumer
   C. Surroundings
II. Environment
   A. Local/regional
   B. Global
III. Socioeconomics
   A. Socio-cultural aspects
   B. Economics

Using this categorisation, we consider all relevant issues concerning food production and consumption that are being covered. Within each of the impact categories, we could distinguish several criteria. They were collected, primarily on the basis of experiences from the earlier SPR projects "V-OH – Veehouderij One Health" and "Knowledge Synthesis Safe, Healthy and Sustainable Diets", and furthermore on the basis of literature data and expert judgment by experts in different expertise fields. Initially, a list of 35 (sub-)criteria was created, see Table 6.1. Although it is impossible to be complete, we consider the table to provide a comprehensive overview of the main issues that need to be valued in order to make sustainable decisions in the food production and consumption system.

A short description of each of the 35 (sub)criteria is provided in Appendix I.

Table 6.1 Overview of all main categories, criteria and sub-criteria selected as relevant aspects to be valued in the pork and pulses production and consumption chains.

#		Main impact category	Sub category	Criteria	Sub-criteria
I	1	Health	Producer	Zoonoses (direct contact)	-
	2			Particulate matter	Pneumonia, Asthma, COPD
	3			Antimicrobial resistance (direct)	ESBL-pAmpC
	4				Antimicrobial use
	5		Surroundings	Annoyance	Odour
	6				Noise
	7			Particulate matter	Pneumonia, Asthma, COPD
	8		Consumer	Antimicrobial resistance (food): ESBL-pAmpC	-
	9			Colon cancer (food)	-
	10			Coronary heart disease (food)	-
	11			Nutrition	Proteins
	12				Calories
	13				Vitamins-Minerals
	14			Food Safety	Microbiological
	15				Chemical
II	16	Environment	Local/regional	Soil functioning	Soil structure
	17				Phosphorus loss
	18				Organic content
	19				Erosion
	20			Nitrate pollution	Nitrate pollution groundwater
	21				Nitrogen deposition (terrestrial nature)
	22			Surface water quality	Chemical water quality/pesticides
	23				Biological water quality
	24			Pesticide application	-
	25		Global	Greenhouse gas emissions	-
	26			Land use	-

#		Main impact category	Sub category	Criteria	Sub-criteria
	27			Water use	-
III	28	Socio-economics	Socio-cultural	Animal welfare	-
	29			Countryside liveability	-
	30			Landscape amenities	-
	31			Sociocultural food aspects	Convenience
	32				Culture / Habits
	33				Taste
	34		Economics	Food affordability	-
	35			Trade balance	-

6.2.1 *Justification of sub-selection*

The number of 35 (sub)criteria was practically too large to handle for visualisation and for incorporation into the model. Therefore, we selected a subset of (sub)criteria, covering the impacts on health, environment, socio-cultural aspects, and economics as well as possible. This subset contained 22 criteria. Although they are less detailed than the total of 35 criteria, together, these 22 criteria can provide a good insight into the effects that interventions in the food system may have on human health, environment, social-cultural aspects and economics at a first glance.

Thus, 13 out of 35 sub-criteria were not taken into account in the modelling sessions. We discarded the criteria that we judged to be of minor influence on the total picture, while conserving a fair distribution across the main categories, or we combined criteria:

- Odour annoyance: about 2.5% of the Dutch population experiences odour annoyance from agriculture. This can be partly ascribed to the pig sector, but is also caused by other sectors. The effects of noise annoyance from agriculture on human health are usually low. This fact, together with the relatively low percentage of inhabitants experiencing annoyance, made us decide to combine these two types of annoyance in the modelling exercises.
- Antimicrobial resistance via food: direct contact is by far the most important contact route, so the route via food was neglected in this study (Mughini Gras et al., 2019).
- Food safety: we chose to combine chemical and biological food safety aspects, whereas chemical food safety issues are rare in the selected food chains.
- Nutrition: calory intake in the Netherlands is usually high enough; there are no food scarcity issues. So the value of calories of the produced food can be neglected. However, meat is a significant source of proteins and some vitamins/minerals in the Dutch diet, so here, we focused on those nutrients. The nutrients were combined into one criterion.
- Soil functioning: it is difficult to break down and quantify various soil health issues into phosphorus loss, saturation and erosion

caused by the pig or pulse sector. It is, however, possible to qualify on the effects of the various food production systems on soil functioning in general, so these aspects were taken together.
- Surface water quality depends on many different factors, which are not all directly related to specific agricultural activities (as is ground water quality).

For 2 out of the selected 22 criteria, it was impossible within the project to derive good data for the various scenarios. This was the case for 'nitrate pollution groundwater' and 'countryside liveability'. So, although they are considered highly relevant issues, we left them out of the model assessments. This resulted in an ultimate list of 20 criteria to be incorporated into the AHP model. An overview of all sub-criteria selected for quantitative modelling assessments with AHP is listed in Table 6.2.

Table 6.2 Overview of the main categories and a subset of criteria selected for modelling assessments with the AHP model, covering the impacts on health, the environment, socio-cultural aspects and economics as well as possible.

#	**Main impact category**		**#**	**Criterion**
I	Human health	A. Producer	1	Zoonoses (direct contact)
			2	Particulate matter, COPD (direct contact)
			3	Antimicrobial resistance (direct)
		B. Consumer	4	Colon cancer (food)
			5	Coronary heart disease (food)
			6	Nutrition (proteins)
			7	Food safety (chemical and microbiological)
		C. Surroundings	8	Annoyance (odour, noise)
			9	Particulate matter, COPD
II	Environment	A. Local/regional	1	Nitrogen deposition (terrestrial nature)
			2	Soil structure
			3	Pesticide use
		B. Global	4	Greenhouse gas emissions
			5	Land use
			6	Water use
III	Socio-economics	A. Socio-cultural	1	Animal welfare
			2	Landscape amenities
			3	Sociocultural food aspects
		B. Economics	4	Food affordability
			5	Trade balance

6.3 Indicators

Indicators were selected for each of the 20 (sub)criteria, quantitative whenever possible, otherwise qualitative, or semi-quantitative. An overview of the 20 indicators and their units corresponding to the (sub)criteria is listed in Table 6.3.

Table 6.3 Overview of the main categories and a subset of criteria selected for modelling assessments with the AHP model, covering the impacts on health, the environment, socio-cultural aspects and economics as well as possible.

# (sub-) criterion	**(sub-)criterion**	**Indicator**	**Indicator unit**
I.1	Zoonoses (direct contact)	Burden of disease relating to zoonoses	DALY
I.2	Particulate matter, COPD (direct contact)	Burden of disease	DALY
I.3	Antimicrobial resistance (direct)	% of population occupied with ESBL/pAmpC	%
I.4	Colon cancer (food)	Burden of disease	DALY
I.5	Heart disease (food)	Burden of disease	DALY
I.6	Nutrient intake	Amount of intake	gr/mg and % inadequacy
I.7	Food safety (chemical and microbiological)	Burden of disease	DALY
I.8	Annoyance (odour, noise)	Burden of disease	DALY
I.9	Particulate matter, COPD	Concentration	gr/100g
II.1	Nitrogen deposition (terrestrial nature)	Amount of deposition	mg/100g
II.2	Soil structure	Organic carbon content of soil	C_{org} content
II.3	Pesticide use	Application amount	kg/ha
II.4	Greenhous gas emissions	Amount of emissions	CO_2-eq
II.5	Land use	Amount used per year	ha/yr
II.6	Water use	Amount used per year	m^3/yr
III.1	Animal welfare	Amount of Beter Leven * accreditations	%
III.2	Landscape amenities	Attractiveness	%
III.3	Sociocultural food aspects	Match with culture	%
III.4	Food affordability	Expenditure per day	euro/day
III.5	Trade balance	Change in balance	-

7 Defining Saaty scores for the selected scenarios

7.1 Introduction

The development of the AHP multi-criteria decision framework follows a set of steps, three of which have been taken so far.

1. Scenario development.
2. Description of relevant sectors and production chains.
3. Identification and selection of categories, (sub-)criteria, and indicators.

In this chapter, we continue with the fourth step:

4. Expert opinion: effect scores.
5. Weighing factors: policy preferences.
6. Selection of preferred scenario.

In the AHP framework, effects of the various scenarios are scored and compared. Effect scores are compared to a reference scenario ("business as usual") and to each other. The Reference scenario considers the overall food production system in the Netherlands. For example, the effect on food safety (indicator: burden of disease) of a scenario in which pork is no longer eaten is balanced against the burden of disease from *all foodborne* illnesses (and not from *all* illnesses).

Experts were asked to value the effects of the four scenarios on the indicators frelating to their expertise on a linear scale from 1 to 9. For each indicator, at least one relevant expert was consulted. Subsequently, values on the linear scale were transformed into balanced scores.
Indicator values and both linear and balanced scores are provided in this chapter. Balanced scores (and their inverse balanced scores) were used to fill the AHP-model.

7.2 The Reference scenario and its indicator values.

7.2.1 *Domain I: the domain of human health*

This domain includes three subcategories considering illness related to the producer, illness caused by surroundings and consumer-related illness, and is subdivided into seven sub-criteria.
The overall food-related burden of disease is estimated to be 4300 DALYs (Pijnacker et al., 2019). This burden of disease is caused, among others, by direct contact by farmers with food-producing animals and by food consumption.

food-related burden of disease (I.1)
Indicator I.1 describes the total food-related burden of disease in 2018 among farmers of animals in the Netherlands (450 DALYs). As 11% of the animal production farms produce pigs, 49 DALYs (=11%*450) are attributed to the pork production.

particulate matter (I.2)
Indicator I.2 is related to illness caused by particulate matter (PM) among farmers. The overall livestock-related burden of disease caused

by PM is 5786 DALYs per year, of which 20% is pig sector-related: 1174 DALYs/year.

antimicrobial resistance (AMR) (I.3)
The third producer-related sub-criterion I.3 is AMR. In total, 5% of the Dutch population is colonised by ESBL/pAmpC–producing *E. coli*. In 14% of the cases, this can be attributed to transmission from direct contact with livestock and through the environment. Out of that 14%, about 20% is related to the pig sector, so 2.8% of the total (Mughini Gras et al., 2019).

The domain of human health also includes consumer-related illness. We considered four consumer-related sub-criteria: colon cancer (I.4); coronary heart disease (CHD) (I.5); nutrient intake (I.6); and foodborne illness (I.7). Colon cancer (overall 90,400 DALYs per year) can be attributed to various sources. The attributable risk due to dietary factors was 79.5%. Consumption of processed meat (not of raw meat) is responsible for 6799 DALYs. An increase in legume consumption has a positive effect on health. It is estimated that the consumption of an additional amount of 67.9 gr of legumes decreases the burden of disease by 4277 DALYs.
In 2018, the number of DALYs due to CHD amounted to 271,300, while 248,000 were due to stroke (Ranglijst aandoeningen op basis van ziektelast (in DALY's) | Volksgezondheidenzorg.info).
The association between fresh and processed meat and stroke is clear. However, for CHD it is not convincing and, therefore, not taken into account. For legumes, the association between dietary fibre, stroke, and CHD is taken into account.
The annual burden of disease linked to stroke and CHD amounts to 248,000 and 271,300 DALYs, respectively. Fresh pork consumption is responsible for 2976 DALYs, processed pork for 12,648 DALYs, whereas the consumption of 67.9 gr of legumes prevents 17,856 DALYs. Pork has no effect on CHD, but legumes do have a beneficial effect. Additional consumption of 67.9 gr of legumes decreases CHD by 6.2%, or 16,303 DALYs.
Nutrient intake (B6) is the third consumer-related sub-criterion. On the basis of replacing meat by legumes, the intake of some nutrients will increase or decrease. The comparison of the scenarios only takes into account nutrients with dietary reference values and with changes over 5%. As nutrient intake is only related to the consumption of food (there are no other sources of nutrients than food), it is not necessary to distinguish between total and food-related intake of nutrients. Nutrients taken into account are: proteins (on average: 78.4 gr per day per person; 30.3 gr plant-based, 47.8 gr animal-based), dietary fibre (19.7 gr pdpp), alpha linoleic acid (1.7), vitamins B1 (2.3), B3 (22.2) and B6 (2.6), copper (1.4 mg pdpp), zinc (11.3 mg pdpp) and iron (11.3 mg pdpp).
Indicator I.7 is the fourth consumer-related criterion and concerns microbiological food safety, with burden of disease (in DALYs) as the indicator. The total food-related burden of disease is 4300 DALYs, of which 810 are related to the consumption of pork.

The last 2 sub-criteria belonging to the domain of human health are related to the surroundings: annoyance (I.8) and particulate matter

(I.9). Odour annoyance is experienced by 8.3% of the Dutch population. This annoyance is caused by BBQs, industry and agriculture. Annoyance caused by agriculture is experienced by 2.5% of the Dutch population. 80% of agricultural annoyance is related to the pig sector.
A9. People living close to livestock farms are at risk of respiratory diseases, such as chronic obstructive pulmonary disease (COPD), caused by particular matter (PM). Livestock-related PM is responsible for 5% of the burden of disease linked to COPD (5% of 18.3 – 104 DALYs). Pig farms are responsible for 3% of the burden of disease linked to COPD (Post et al., 2020).

7.2.2 *Domain II: the environmental domain*

The first environmental sub-criterion (II.1) is nitrogen deposition (terrestrial nature). In the reference scenario, the critical deposition value for nitrogen is exceeded in 60% of the Natura 2000 areas. Livestock farming is responsible for 75% of this 60%. Pig farms are responsible for 20% of the areas where the critical N deposition value is exceeded by livestock farming.
The second sub-criterion within the environmental domain is soil-structure (II.2). Soil structure comprises several aspects, such as organic carbon content, presence of small organisms, sensibility for erosion, and silting and nutrient content. In this study, the loss of phosphorus (P) with the harvesting of pig feed crops versus pulses, was applied as an indicator. This P loss is compensated in the soil, partly by the use of manure, but also by the use of fertilisers, which for P are finite. The total loss of P caused by the production of food and feed crops for the total Dutch food sector is about $1.4*10^{12}$ kg/yr; the loss of P caused by harvesting pig feed crops is responsible for $1.4 * 10^{11}$ kg/yr, which is about 24% of the total P use/loss (https://www.cbs.nl/nl-nl/onzediensten/classificaties/producten/goederenclassificatie-nst-r/goederenclassificaties/7meststoffen).

For sub-criterion II.3, pesticide use, we compared the amounts of pesticides emitted to the environment from maize (feed) to the amounts of pesticides emitted to the environment from beans. It is assumed that all maize is used for food and feed use.
In the production of maize, 15 gr/ha/year of pesticides is involved and the area used for maize is 196,000 ha (www.CBS.nl/2022/areaal-akkerbouw). In the production of beans, 11 gr/ha/year is involved (De Snoo and Vijver, 2012).
Sub-criterion II.4 refers to the emission of greenhouse gases (GHG). Agricultural activities are responsible for 14% of all GHGs in the Netherlands. Pig farming is responsible for 3% of these direct GHG emissions. An significant additional amount of GHGs is emitted during the production of pig feed. The uptake of CO_2 by legumes is considered marginal. The total emission for pork, estimated by the amount of emission per kg of pork per year (5 kg CO_2-eq), times the annual consumption in the Netherlands, is 36.6 kg/year (https://www.agrimatie.nl/SectorResultaat.aspx?subpidID=2232&sectorIS=2255&themaIS=2276) times the number of inhabitants in the Netherlands. Total pig production in the Netherlands equals total Dutch consumption ($6.38*10^8$ kg/year) times a factor 4, since 75% of all Dutch pork is produced for export. This means that CO_2-eq emissions of the Dutch pig sector are $1.3*10^{10}$ kg CO_2-eq/year, which account for

about 15% of the total GHG emissions relating to the Dutch food sector. The total Dutch food sector thus accounts for about $9*10^{10}$ kg CO_2-eq/year (https://ourworldindata.org/co2-and-other-greenhouse-gas-emissions).

For the sub-criterion II.5, the amount of land used for the Dutch pig and pulses sectors was compared to the total amount of land used for the Dutch food consumption system. For the pig sector, the amount of land used for the pig feed production abroad was also taken into account. The land use (including feed) for the total Dutch pork production per year accounts for $2.6*10^{10}$ m^2. Land use of total Dutch pulses production per year: $3.0*10^7$ m^2. If we assume an increased consumption of pulses, for external pulse production, $8.5*10^9$ m^2 would be needed. The total food footprint of the Netherlands is $1.04*10^{11}$ m^2, which means that the pig sector is responsible for 25%. The land use for the pulse sector is marginal compared to the land use for meat sector (including feed).

Sub-criterion II.6, water use, relates to the amount of water that is needed for the Dutch pig and pulse sectors compared to the water used by the total Dutch food system. Of all the water that the Dutch people consume, 85.5% is directly or indirectly needed for our food (Watergebruik | Voedingscentrum). On an annual basis, this amounts to $5.87*10^7$ m^3. For the production of 1 kg pork, 0.078 m^3 is needed (RIVM Voedseldatabase version 11-2-2021, Milieubelasting van voedingsmiddelen | RIVM), which means that with a slaughtered weight of about $1.5*10^8$ kg/year, $1.2*10^7$ m^3 water per year is applied in the pig sector. This implies that the total amount of water use in pig sector equals 20% of the total Dutch water use relating to food consumption. For an annual yield of $4.5*10^6$ kg of pulses, which is the current Dutch production plus import (personal communication landbouwcoöperatie CZAV, 2021) $9.5*10^4$ m^3 of water is used. This is marginal compared to the amount of water used in the pig sector.

7.2.3 *Domain III: socio-economic aspects*

Changes in the amounts of animal-based proteins produced and consumed do not only have consequences for our health, and the environment, they might also affect socio-cultural aspects, such as animal welfare, and our appreciation of the landscape and economic aspects. This paragraph describes the socio-economic indicators we used in our decision framework.

Indicator values

The market share of pigs and dairy cattle with the 'Beter Leven' label is used here as indicator (III.1) for animal welfare. The total number of fattening pigs in the Netherlands is 5,6 million, of which 3,7 million (66,7%) have a 'Beter Leven' quality mark (Stichting Beter Leven Keurmerk – personal communication 2021). The total number of livestock animals (pigs, cattle poultry) present in the Netherlands is about 63,6 million (Post et al., 2020), of which 37,9 million have a 'Beter Leven' label (59.5%). Saaty scores are based on two effects: the effect of a scenario on the welfare of pigs and on the welfare of the total livestock.

The attractiveness of a landscape (III.2) is subjective. Highways, trees, and buildings, for instance, all contribute to our appreciation of a landscape and might weigh differently. Citizens appreciate a landscape on the basis of the following points: variety, ruggedness, visual pollution, relief, water, vegetation, and regional identity.
Van der Wulp (2008) used the following equation to quantify the attractiveness of a landscape:

Attractiveness = 5.31 + 0.29 x naturalness – 0.15 x urbanity + 0.23 x historical characteristic – 0.09 x visual pollution + 0.03 x age (based on the average value by area).

We used visual pollution, caused by pig stables, as an indicator for landscape amenities. According to citizen consultations, pig stables contribute 17% to the decrease in valuation due to visual pollution.
For valuing food culture (III.3) we consider three aspects. We score the effect of a scenario on:

1. the number of traditional Dutch meals that contain meat;
2. dishes that contain meat and that are served on special days, such as Christmas;
3. dishes that contain meat and that are served in restaurants and bars, where the focus is on meat.

When pork is no longer used as an ingredient (scenarios 1 and 2), pork is replaced by legumes or some other non-meat food. In Scenario 3, pork consumption is 30% lower than in the reference scenario. Meals and dishes served on special days or in restaurants and bars without pork do not fit within our culture. For this reason, Saaty scores can be reciprocal.
In scenarios where pork is excluded (1 and 2) or lowered (from 39.4 to 29.3 gr in Scenario 3), meat is replaced by a plant-based protein source, in this case brown beans, while keeping the total amount of protein constant. Replacing meat by any plant-based protein source has consequences for the affordability of food (III.4). As brown beans contain less protein, its level of consumption (in gr) will increase, but brown beans are cheaper than pork. Overall, plant-based protein is cheaper than animal-based protein (per gr).

	Price per kg	gr protein/100gr
pork	€ 7.75	20.2
brown beans	€ 1.25	6.8

Therefore, replacing meat by beans results in higher food affordability. We do not correct for differences in amino acid composition or any other nutritional aspect, and prices of beans and pork remain constant.
The second economic indicator (III.5) we use for scoring scenario effects is the trade balance. The pig sector is important for the trade balance of the agricultural sector (https://www.agrimatie.nl/SectorResultaat.aspx?subpubID=2232&sectorID=2255&themaID=2276). The export value of the pig sector is around 2.5% of the total export–value in the agricultural sector. For the import value this is less than 1%. In the reference scenario, the pig sector is responsible for costs amounting to 553 million euros, while import and export contribute 2,290 million euros to the Dutch trade balance. In Scenario 1 (no consumption of pork), the level of production is constant.

Consequently, more pork is exported. Prices remain constant and pork on the plate is replaced by legumes that need to be imported. The impact on our trade balance of importing legumes is smaller than the effect of larger export of pork. In Scenario 2, where we no longer produce pigs and pork, we did not consider the effects on import of feed. And the agricultural area that becomes available is used for the production of beans.

7.3 Saaty scores in summary

In the previous paragraph, we described the various indicators that were selected for building the AHP framework. Also, we described the assumptions of the scenarios that are included and that need to be considered when scoring the scenario effects. For example: stopping the consumption of pork while keeping the production constant has consequences for the trade balance and changes the diet (we assume that pork is replaced by pulses).
Next, we contacted experts and asked them to score the effects of the various scenarios relative to the Reference scenario or relative to one of the other two scenarios. For each indictor, preferably three experts from within RIVM were contacted. The experts scored on a scale from 1 to 9, where 1 means a small or no effect and 9 means a very strong effect. Per indicator, we averaged the expert scores. In order to see whether the scores were biased (since all experts were from within RIVM), we also contacted experts from outside of RIVM to score the effects of the scenarios (on food safety). The average score of the non-RIVM experts was similar to the average score of the RIVM experts (not shown). Details on these Saaty scores are described in Appendix II. A summary of all the Saaty scores is shown in Tables 7.1 and 7.2.

Table 7.1 Saaty scores per criterion for each scenario.

#	Criterion	Scenario 1 – Ref	Scenario 2 – Ref	Scenario 2– Scenario 1	Scenario 3 – Ref	Scenario 3 – Scenario 1	Scenario 3– Scenario 2
I.1	Zoonoses (direct contact)	1	2	2	1	1	1/2
I.2	Particulate matter, COPD (direct contact)	1	4	4	1	1	1/4
I.3	Antimicrobial resistance (direct)	1	3	3	1	1	1/3
I.4	Colon cancer (food)	5	5	1	2	1/4	1/4
I.5	Heart disease (food)	4	4	1	4	1/4	1/4
I.6	Nutrient intake	1/2	1/2	1	1/2	1	1
I.7	Food safety (chemical and micro–biological)	5	5	1	2	1/4	1/4
I.8	Annoyance (odour, noise)	1	6	6	1	1	1/6
I.9	Particulate matter, COPD	1	2	2	1	1	1/2
II.1	Nitrogen deposition (terrestrial nature)	1	6	6	1	1	1/6
II.2	Soil structure	1	4	4	1	1	1/4
II.3	Pesticide use	1	2	2	1	1	1/2
II.4	Greenhouse gas emissions	1	2	2	1	1	1/2
II.5	Land use	1/2	3	4	1	2	1/3
II.6	Water use	1/2	3	2	1	2	1/3
III.1	Animal welfare	1	3	3	1	1	1/3
III.2	Landscape amenities	1	2	2	1	1	1/2
III.3	Food culture	1/4	1/4	1	1/2	1/2	2
III.4	Food affordability	4	4	1	1	1/4	1/4
III.5	Trade balance	3	1/3	5	1	1/3	3

Table 7.2 Balanced Saaty scores per criterion for each scenario.

#	Criterion	Scenario 1 – Ref	Scenario 2 – Ref	Scenario 2– Scenario 1	Scenario 3 – Ref	Scenario 3 – Scenario 1	Scenario 3– Scenario 2
I.1	Zoonoses (direct contact)	1	1.22	1.22	1	1	0.82
I.2	Particulate matter, COPD (direct contact)	1	1.86	1.86	1	1	0.538
I.3	Antimicrobial resistance (direct)	1	1.50	1.50	1	1	0.667
I.4	Colon cancer (food)	2.33	2.33	1	1.22	0.538	0.538
I.5	Heart disease (food)	1.86	1.86	1	1.86	0.538	0.538
I.6	Nutrient intake	0.82	0.82	1	0.82	1	1
I.7	Food safety (chemical and micro–biological)	2.33	2.33	1	1.22	0.538	0.538
I.8	Annoyance (odour, noise)	1	3	3	1	1	0.333
I.9	Particulate matter, COPD	1	1.22	1.22	1	1	0.82
II.1	Nitrogen deposition (terrestrial nature)	1	3	3	1	1	0.333
II.2	Soil structure	1	1.86	1.86	1	1	0.538
II.3	Pesticide use	1	1.22	1.22	1	1	0.82
II.4	Greenhouse gas emissions	1	1.22	1.22	1	1	0.82
II.5	Land use	0.82	1.50	1.86	1	1.22	0.667
II.6	Water use	0.82	1.50	1.22	1	1.22	0.667
III.1	Animal welfare	1	1.50	1.50	1	1	0.667
III.2	Landscape amenities	1	1.22	1.22	1	1	0.82
III.3	Food culture	0.53	0.53	1	0.82	0.82	1.22
III.4	Food affordability	1.86	1.86	1	1	0.53	0.53
III.5	Trade balance	1.50	0.667	2.33	1	0.667	1.50

This table shows balanced Saaty scores that were used in the modelling.

8 Defining Saaty scores for the selected criteria

8.1 Introduction

In the previous chapter, we described how we asked experts to score the (relative) effect of a scenario on a given indicator. Expert scores are the first input of the AHP framework and the lowest in hierarchy. On a next hierarchy level, indicators were grouped. With respect to consumers, health indicators, such as colon cancer, heart disease, nutrition, and food safety, were grouped, as were environmental and economic indicators. How important is one indicator within a group of criteria (subdomain) compared to another? This chapter describes the method for and results of that step.

8.2 Saaty scores for the criteria within the subdomains

To assess the relative importance of indicators with a specific subcategory, again experts were contacted. We asked them to score the relative importance of the various indicators within each subdomain. Table 8.1 shows an example how the experts judged the importance of the various criteria. The experts also judged the importance by means of pairwise comparisons and by defining Saaty scores for each comparison. A summary of all the Saaty scores is shown in Figure 8.1.

Table 8.1 Example of a sheet on which the experts should judge the importance of the various criteria within each subdomain (by marking the right cell).

	Extreme less important		*Very strong*		*strong*		*moderate*		*indifference*		*moderate*		*strong*		*Very strong*		*Extreme more important*	
Saaty:	*1/9*	*1/8*	*1/7*	*1/6*	*1/5*	*1/4*	*1/3*	*1/2*	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	
A													x					*B*
Zoonoses (direct contact)		x																Particulate matter, COPD (direct contact)
Particulate matter, COPD (direct contact)																x		Antimicrobial resistance (direct contact)
Zoonoses (direct contact)									x									Antimicrobial resistance (direct contact)

I. Human Health

A. Producer

	1.	2.	3.	GeoMean	Priority
1. Zoonoses (direct contact)	1	5.682	1.000	1.784	45.96%
2. Partic.Matter, COPD (direct c	0.176	1	0.176	0.314	8.09%
3. Antimicrobial Resist. (direct	1.000	5.682	1	1.784	45.96%
	Crit. 3			3.883	100%

B. Consumer

	1.	2.	3.	4.	GeoMean	Priority
4. Colon cancer (food)	1	0.250	9.000	2.331	1.5133	23.08%
5. Heart disease (food)	4.000	1	9.000	9.000	4.2426	64.71%
6. Food safety (chem. biol.)	0.111	0.111	1	1.000	0.3333	5.08%
7. Nutrition (proteins)	0.429	0.111	1.000	1	0.4673	7.13%
	Crit. 4				6.5566	100%

C. Surroundings

	1.	2.	GeoMean	Priority
8. Annoyance (odor, noise)	1	0.667	0.6670	40.01%
9. Particulate matter, COPD	1.499	1	1.0000	59.99%
	Crit. 2		1.6670	100%

II. Environment

A. Local

	2	3	4	GeoMean	Priority
1. Nitrogen deposition (terrest	1	0.538	4.000	1.2911	35.47%
2. Soil structure	1.859	1	4.000	1.9518	53.62%
3. Pesticide use	0.250	0.250	1	0.3969	10.90%
	Crit. 3			3.6397	100%

B. Global

	1.	2.	3.	GeoMean	Priority
4. Greenhouse gas emissions	1	4.000	2.331	2.105	59.82%
5. Land use	0.250	1	0.667	0.550	15.64%
6. Water use	0.429	1.499	1	0.863	24.53%
	Crit. 3			3.518	100%

III. Socio-Economic

A. Socio-cultural

	1	3	4	GeoMean	Priority
1. Animal welfare	1	1.500	2.331	1.5178	47.35%
2. Landscape amenities	0.667	1	1.859	1.0741	33.51%
3. Sociocultural food aspects	0.429	0.538	1	0.6134	19.14%
	Crit. 3			3.2053	100%

B. Economics

	1.	2.	GeoMean	Priority
4. Food affordability	1	2.331	2.3310	69.98%
5. Trade balance	0.429	1	1.0000	30.02%
	Crit. 2		3.3310	100%

Figure 8.1 Balanced Saaty scores per criterion within each subdomain.

9 Application of the AHP model

9.1 Introduction

Scenarios have been developed (step 1), sectors described (step 2) and criteria, (sub-) sub-criteria and indicators have been selected (step 3). In Chapter 7 (describing step 4), experts were asked to value the effects of the scenarios on given indicators (for instance, "eating less pork scores 2.33 on foodborne safety compared to the current situation"), and they were asked to attach weight to the various sub-criteria (for instance, "colon cancer is more important than food safety", scoring 2.331; Figure 8.1). All this information was assembled into an AHP model.
In this chapter, we will describe steps 5 and 6:

5. Weighing factors: policy preferences
6. Selection of the preferred scenario

If public health and the environment are most important, what would be the preferred scenario? What is the best option if all aspects are equally important? And what if socio-cultural aspects have more weight than economics? In other words: (given a specific perspective) which scenario would be the preferred option for a given stakeholder? The AHP helps to determine the preferred option. Such information can be useful for having a debate about this.

Option A *Option B*

Figure 9.1 Example of the impact of various scenarios.
Option A is the preferred option when it comes to public health and the environment.
Option B is the option of choice when all three aspects are equally important.

9.2 Building the AHP model

All the gathered information on the indicators, its balanced Saaty scores, and the pairwise comparisons of the various subcategories within each category has already been integrated into the model, which was built in Excel. (See Figure 9.2 for an example of integrating the Saaty scores for the scenarios into the model.)

I. Human Health | **A. Producer** | **1. Zoonoses (direct contact)**

	0.RefSc	1.RedVa#1	2.RedVa#2	5.ConsVoPr	GeoMean	Score
0. Referentie Scenario	1	1.000	0.820	1.000	0.9516	23.70%
1. Reductie Varkensvlees, Wel Export	1.000	1	0.820	1.000	0.9516	23.70%
2. Reductie Varkensvlees, Geen Export	1.220	1.220	1	1.220	1.1606	28.90%
3. Consumenten: Voorlichting en Prijs	1.000	1.000	0.820	1	0.9515	23.70%
	4 Criteria				4.0153	100%

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I. Human Health | **A. Producer** | **2. Partic.Matter, COPD (direct contact)**

	0.RefSc	1.RedVa#1	2.RedVa#2	5.ConsVoPr	GeoMean	Score
0. Referentie Scenario	1	1.000	0.538	1.000	0.8564	20.58%
1. Reductie Varkensvlees, Wel Export	1.000	1	0.538	1.000	0.8564	20.58%
2. Reductie Varkensvlees, Geen Export	1.859	1.859	1	1.859	1.5919	38.26%
3. Consumenten: Voorlichting en Prijs	1.000	1.000	0.538	1	0.8564	20.58%
	4 Criteria				4.1612	100%

I. Human Health | **A. Producer** | **3. Antimicrobial Resist. (direct contact)**

	0.RefSc	1.RedVa#1	2.RedVa#2	5.ConsVoPr	GeoMean	Score
0. Referentie Scenario	1	1.000	0.667	1.000	0.9037	22.23%
1. Reductie Varkensvlees, Wel Export	1.000	1	0.667	1.000	0.9037	22.23%
2. Reductie Varkensvlees, Geen Export	1.499	1.499	1	1.499	1.3548	33.32%
3. Consumenten: Voorlichting en Prijs	1.000	1.000	0.667	1	0.9038	22.23%
	4 Criteria				4.0660	100%

I. Human Health | **B. Consumer** | **4. Colon cancer (food)**

	0.RefSc	1.RedVa#1	2.RedVa#2	5.ConsVoPr	GeoMean	Score
0. Referentie Scenario	1	0.429	0.429	0.820	0.6233	14.56%
1. Reductie Varkensvlees, Wel Export	2.331	1	1.000	1.859	1.4428	33.71%
2. Reductie Varkensvlees, Geen Export	2.331	1.000	1	1.859	1.4428	33.71%
3. Consumenten: Voorlichting en Prijs	1.220	0.538	0.538	1	0.7707	18.01%
	4 Criteria				4.2796	100%

I. Human Health | **B. Consumer** | **5. Heart disease (food)**

	0.RefSc	1.RedVa#1	2.RedVa#2	5.ConsVoPr	GeoMean	Score
0. Referentie Scenario	1	0.538	0.538	0.538	0.6282	14.92%
1. Reductie Varkensvlees, Wel Export	1.859	1	1.000	1.859	1.3634	32.37%
2. Reductie Varkensvlees, Geen Export	1.859	1.000	1	1.859	1.3634	32.37%
3. Consumenten: Voorlichting en Prijs	1.859	0.538	0.538	1	0.8564	20.33%
	4 Criteria				4.2114	100%

Figure 9.2 Part of the sheet listing the input of the effects of the scenarios.

As can be seen in Figure 9.2, Scenario 2 is the preferred scenario when it comes to reducing producer-related zoonoses (28.9%), COPD/particulate matter (38,26%) or antimicrobial resistance (33.32%). For the consumer, scenarios 1 and 2 score equally with respect to colon cancer (33.71%) and heart disease (32.37%). “Business as usual” (Scenario 0) is the least preferred option.

Experts compared scenarios for all indicators and subdomains. As we have 4 scenarios and 20 indicators, the relevant experts made 20*4*3 pairwise comparisons.
As described in the previous chapter, experts also compared indicator pairs (e.g. heart disease vs colon cancer). The model calculates the priority scores for each indicator within each subdomain (see Figure 9.3). For example, for producers, the zoonoses and antimicrobial resistance indicators are equally important (45.96%), but COPD has the lowest priority (8.09%). For consumers, experts judged that heart disease is most relevant (64.71%) and food safety least (5.08%).

I. Human Health

A. Producer	1.	2.	3.	GeoMean	Priority
1. Zoonoses (direct contact)	1	5.682	1.000	1.784	45.96%
2. Partic.Matter, COPD (direct c	0.176	1	0.176	0.314	8.09%
3. Antimicrobial Resist. (direct	1.000	5.682	1	1.784	45.96%
	Crit. 3			3.883	100%

B. Consumer	1.	2.	3.	4.	GeoMean	Priority
4. Colon cancer (food)	1	0.250	9.000	2.331	1.5133	23.08%
5. Heart disease (food)	4.000	1	9.000	9.000	4.2426	64.71%
6. Food safety (chem. biol.)	0.111	0.111	1	1.000	0.3333	5.08%
7. Nutrition (proteins)	0.429	0.111	1.000	1	0.4673	7.13%
	Crit. 4				6.5566	100%

C. Surroundings	1.	2.	GeoMean	Priority
8. Annoyance (odor, noise)	1	0.667	0.6670	40.01%
9. Particulate matter, COPD	1.499	1	1.0000	59.99%
	Crit. 2		1.6670	100%

II. Environment

A. Local	2	3	4	GeoMean	Priority
1. Nitrogen deposition (terrest	1	0.538	4.000	1.2911	35.47%
2. Soil structure	1.859	1	4.000	1.9518	53.62%
3. Pesticide use	0.250	0.250	1	0.3969	10.90%
	Crit. 3			3.6397	100%

B. Global	1.	2.	3.	GeoMean	Priority
4. Greenhouse gas emissions	1	4.000	2.331	2.105	59.82%
5. Land use	0.250	1	0.667	0.550	15.64%
6. Water use	0.429	1.499	1	0.863	24.53%
	Crit. 3			3.518	100%

III. Socio-Economic

A. Socio-cultural	1	3	4	GeoMean	Priority
1. Animal welfare	1	1.500	2.331	1.5178	47.35%
2. Landscape amenities	0.667	1	1.859	1.0741	33.51%
3. Sociocultural food aspects	0.429	0.538	1	0.6134	19.14%
	Crit. 3			3.2053	100%

B. Economics	1.	2.	GeoMean	Priority
4. Food affordability	1	2.331	2.3310	69.98%
5. Trade balance	0.429	1	1.0000	30.02%
	Crit. 2		3.3310	100%

Figure 9.3 Priority scores after pairwise comparison of the indicators within each subdomain.

9.3 Virtual policymakers with different policy preferences

While the previous comparisons were made by experts, mostly using underlying data or knowledge, the priority for the various categories (human health, environment, socio-economic) and subcategories was not indicated by the experts and can be based on personal and/or political preferences. Having persons with different backgrounds fill in this part of the model may provide insight into the preferred scenario, given certain personal or professional preferences. What would be the preferred scenario for a human health policymaker, and what would be the preferred scenario for a person with a socio-economic interest? In the next section, this is illustrated for four virtual decisionmakers in order to gain insight into the preferred scenario from different points of view.

9.3.1 *"Everything is equally important"*

For this virtual policymaker, we indicated a Saaty score of 1 for all comparisons of the domains and subdomains. In other words, all the factors were equally important. See Figure 9.4 for the assumed importance of the various domains and subdomains.

FairPlay4Food (main)	I.	II.	III.
|—— I. Human Health	1	1.000	1.000
|—— II. Environment	1.000	1	1.000
|—— III. Socio-Economic	1.000	1.000	1

Crit. 3

I. Human Health	A.	B.	C.
|—— A. Producer	1	1.000	1.000
|—— B. Consumer	1.000	1	1.000
|—— C. Surroundings	1.000	1.000	1

Crit. 3

II. Environment	A.	B.
|—— A. Local	1	1.000
|—— B. Global	1.000	1

Crit. 2

III. Socio-Economic	A.	B.
|—— A. Socio-cultural	1	1.000
|—— B. Economics	1.000	1

Figure 9.4 Sheet in the AHP model for the input of the pairwise comparisons of the domains and subdomain filled in for a virtual policymaker to whom everything is equally important.

9.3.2 *"Human health is important"*

For this virtual policymaker, we assumed that human health was much more important than the environmental and socio-economic domains. Also, the environmental factors have a higher preference than the socio-economic factors (Saaty 4). Furthermore, we assumed that the health of the consumer is more important to this policymaker than that of the producer (9). Producer-related health issues were less important than surroundings-related health issues and scored with a Saaty of 0.250. Figure 9.5 shows the pairwise comparisons for this virtual policymaker.

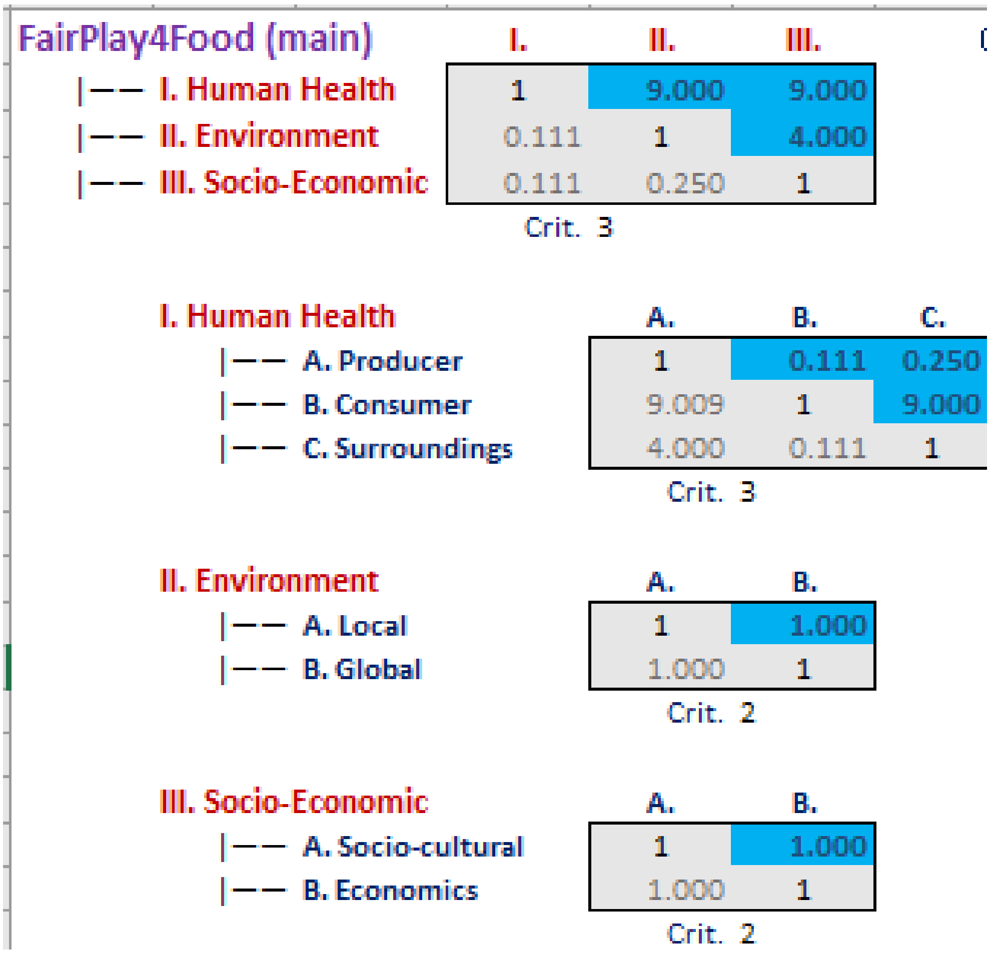

Figure 9.5 Sheet in the AHP model for the input of the pairwise comparisons of the domains and subdomain filled in for a virtual policymaker to whom human health is very important.

9.3.3 *"Environment is important"*

For this virtual policymaker, we assumed that environment was more important than the other domains. Furthermore, as environmental issues, such as countryside liveability and landscape amenities, also form part of socio-cultural aspects, socio-cultural aspects were given more weight than economics within the socio-economic domain.

FairPlay4Food (main)	I.	II.	III.
I. Human Health	1	0.250	1.000
II. Environment	4.000	1	9.000
III. Socio-Economic	1.000	0.111	1
	Crit. 3		

I. Human Health	A.	B.	C.
A. Producer	1	1.000	1.000
B. Consumer	1.000	1	1.000
C. Surroundings	1.000	1.000	1
	Crit. 3		

II. Environment	A.	B.
A. Local	1	9.000
B. Global	0.111	1
	Crit. 2	

III. Socio-Economic	A.	B.
A. Socio-cultural	1	4.000
B. Economics	0.250	1
	Crit. 2	

Figure 9.6 Sheet in the AHP model for the input of the pairwise comparisons of the domains and subdomain filled in for a virtual policymaker to whom the environment is very important.

9.3.4 *"Socio-economic aspects are important"*

For this virtual policymaker, we assumed that socio-economic aspects were much more important than the other (sub-)domains (with a Saaty score of 9 for the comparison of the socio-economic domain compared with the public health domain, and a score of 4 for the comparison with the environment. Moreover, within the socio-economic domain, we assume that the economic factors are more important to this person than the socio-cultural aspects (Saaty 4). Furthermore, in the domain of human health, maximum weight is given to the 'producer' subcategory.

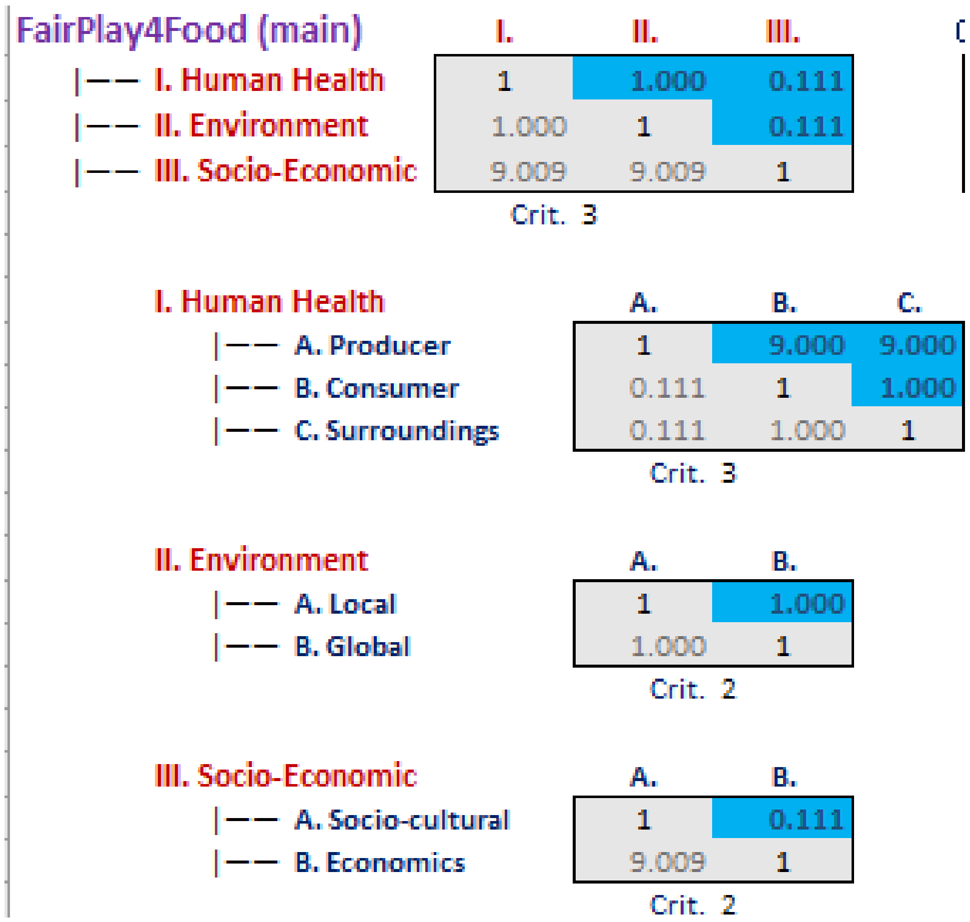

Figure 9.7 Sheet in the AHP model for the input of the pairwise comparisons of the domains and subdomain filled in for a virtual policymaker to whom socio-economic aspects are very important.

9.4 The scenario with the highest preference

On the basis of the pairwise considerations per virtual policymaker, the weights of all criteria were calculated. For example, the policymaker to whom health is important awarded the score on zoonoses a weight of 2.07% and that of particulate matter 0.36% (see Figure 9.8). By multiplying these weights by the scenario-specific criteria weights determined by the experts (Table 5.2), we could calculate the contribution by each criterion to the total score for each scenario. Thus, the total score for each scenario was calculated by summing up all the scores for each criterion. The scenario with the highest total score is the preferred scenario for that policymaker. Figure 9.9 illustrates that the contribution by zoonoses to the score of the Reference scenario amounted to 0.49 (2.07 times 23.7), while it was 0.60 (2.07 times 28.9) for the scenario with no consumption or production of pig meat.

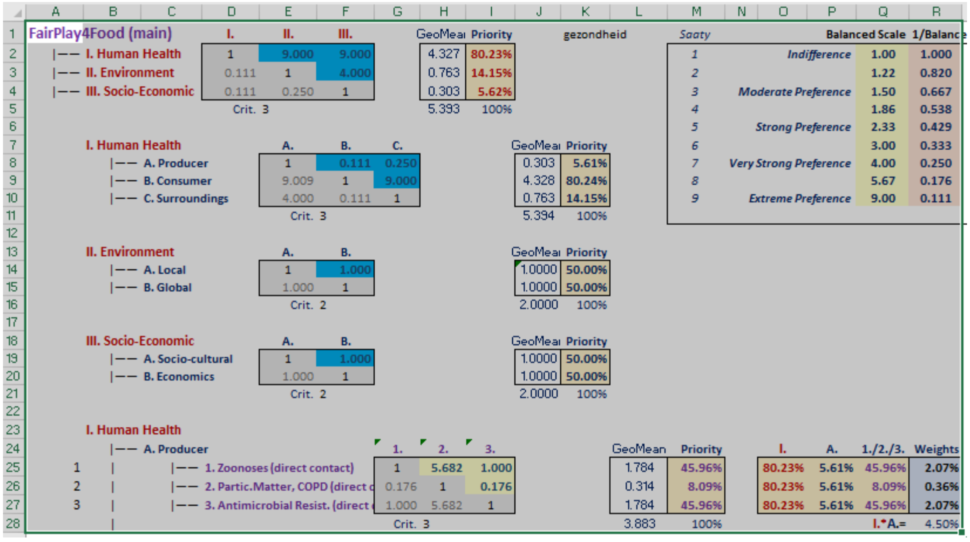

Figure 9.8 Illustration of the calculation of the weights for some indicators based on the priorities of the virtual policymaker to whom health is important.

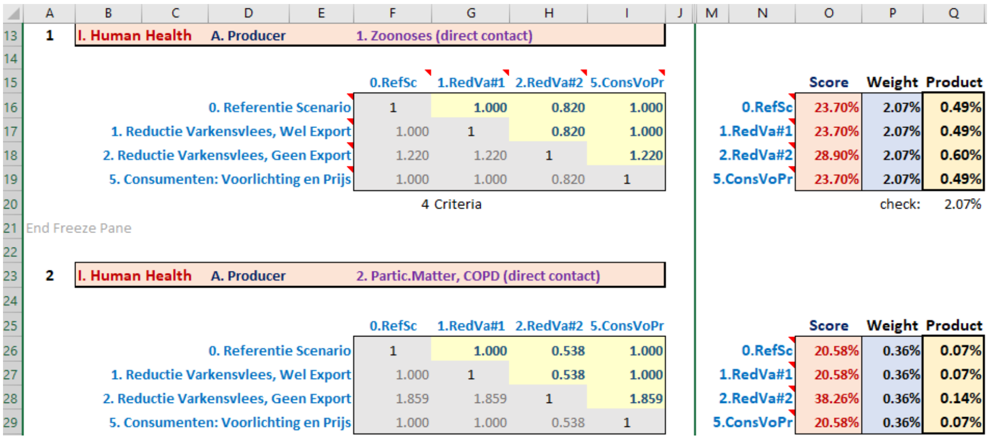

Figure 9.9 Illustration of the calculation of the contribution by some indicators to the scores for the scenarios based on the priorities of the virtual policymaker to whom health is important.

Figure 9.10 shows the preferred scenarios for the four virtual policymakers. It showed that policymakers' preferences ranged widely, but that for all virtual policymakers, the same scenario had the highest score. In all cases, our AHP model pointed to the scenario in which consumption as well as production of pork is reduced as the preferred scenario. All policymakers show a low preference for either the Reference scenario or the "taxes and nudging" scenario. For the policymaker who focused on health as well as economics, the difference between the second and third scenario was small.

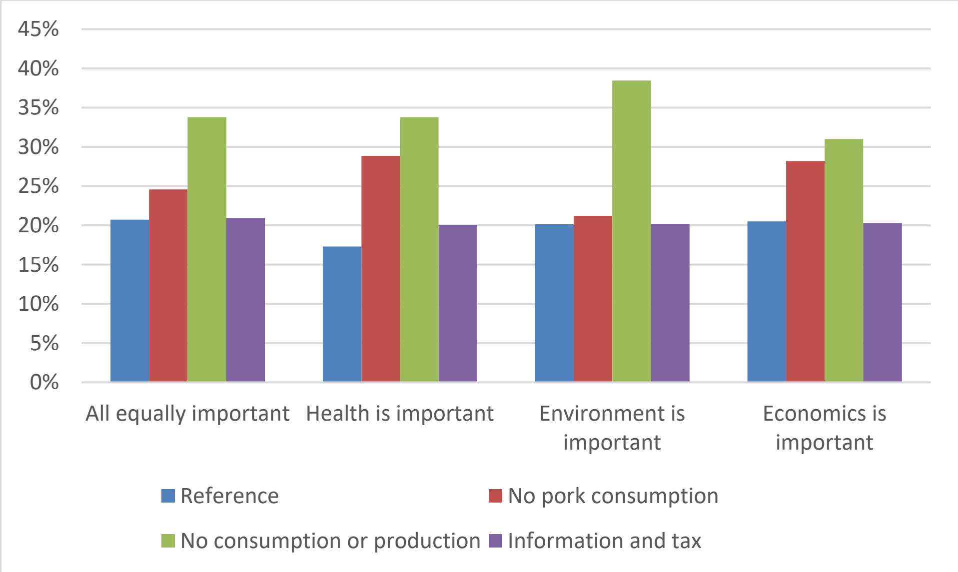

Figure 9.10 The scores for each scenario for each virtual policymaker.
The scenario with the highest score had the highest preference for all four policymakers (The green column is the highest for all policymakers).

If we look in more detail, it is interesting to see that the reason for this preference varies between policymakers (see Figure 9.11a-d). In this figure, the scores for each criterion are shown per scenario and per virtual policymaker.

Figure 9.11a shows that, for the virtual policymaker to whom all factors are equally important, the third scenario (no consumption and no production) was the preferred scenario, due to a higher score on all criteria. For the policymaker focusing more on health aspects, health aspects such as heart diseases and colon cancer contribute 13.5% and 5%, respectively to the total score. Compared to the scenario with only no pork consumption, health aspects such as COPD by particulate matter was a triggering aspect to choose for this scenario.
For the policymaker focusing on the environment, the triggering aspect was the impact of the scenario on the soil structure and the nitrogen deposition. The scores for all other scenarios were similar.

The policymaker focusing on economics also obtained the highest score for the third scenario, as shown in Figure 9.10, mainly due to the impact of this scenario on the food affordability and trade balance. However, this impact was also seen in the second scenario. The difference between the second and third scenarios was caused by a higher score on all other aspects.

Thus, from this exercise we learned that despite their different preferences, all virtual policymakers prefer the scenario in which both consumption and production of pork is reduced. All policymakers have a low preference for either the current situation, the scenario without pork consumption or the scenario with higher meat prices and information nudges. Insight into these aspects can be useful in the discussion of complex issues like this.

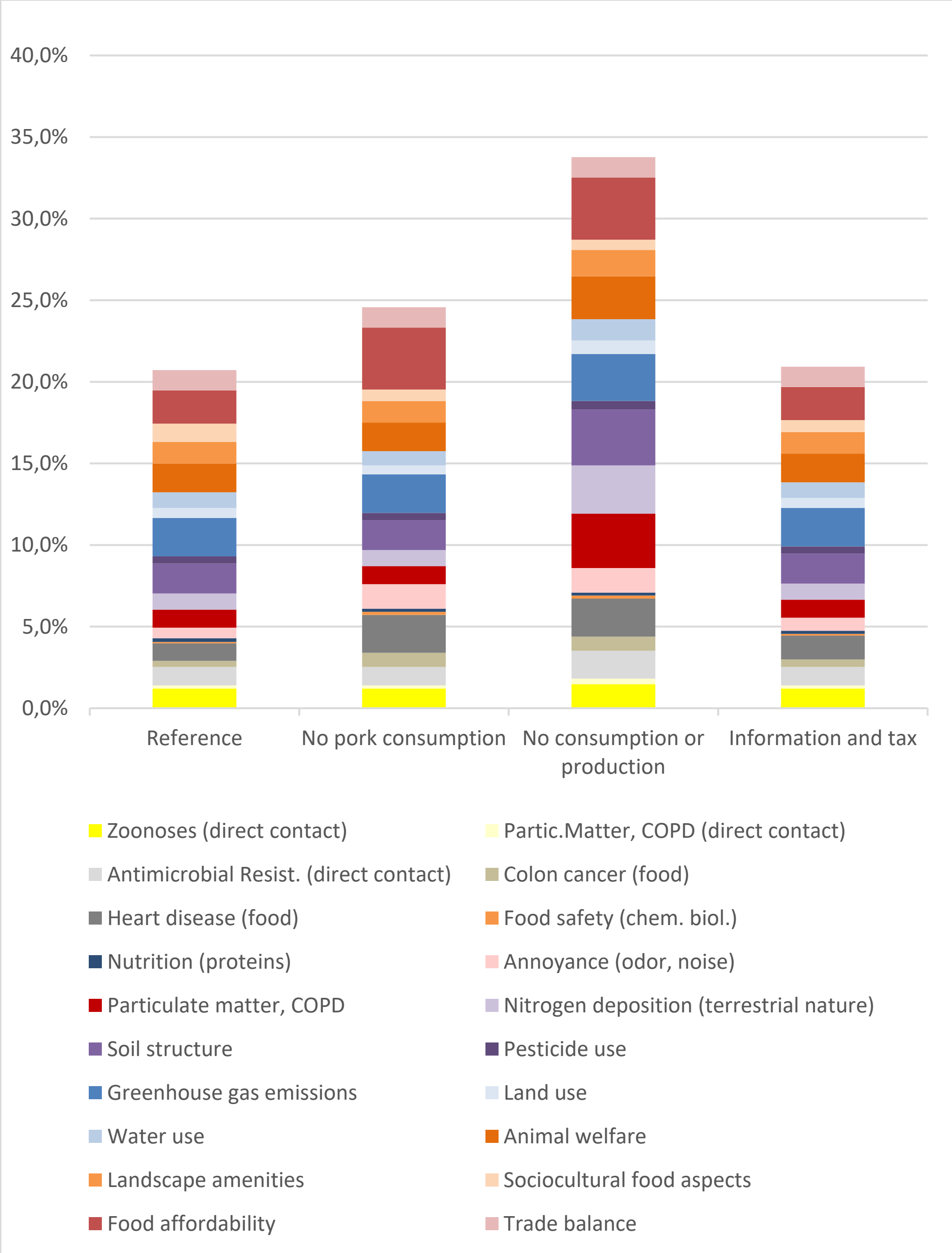

Figure 9.11a The underlying reasons for the preferred scenario for a virtual policymaker to whom all aspects are equally important.

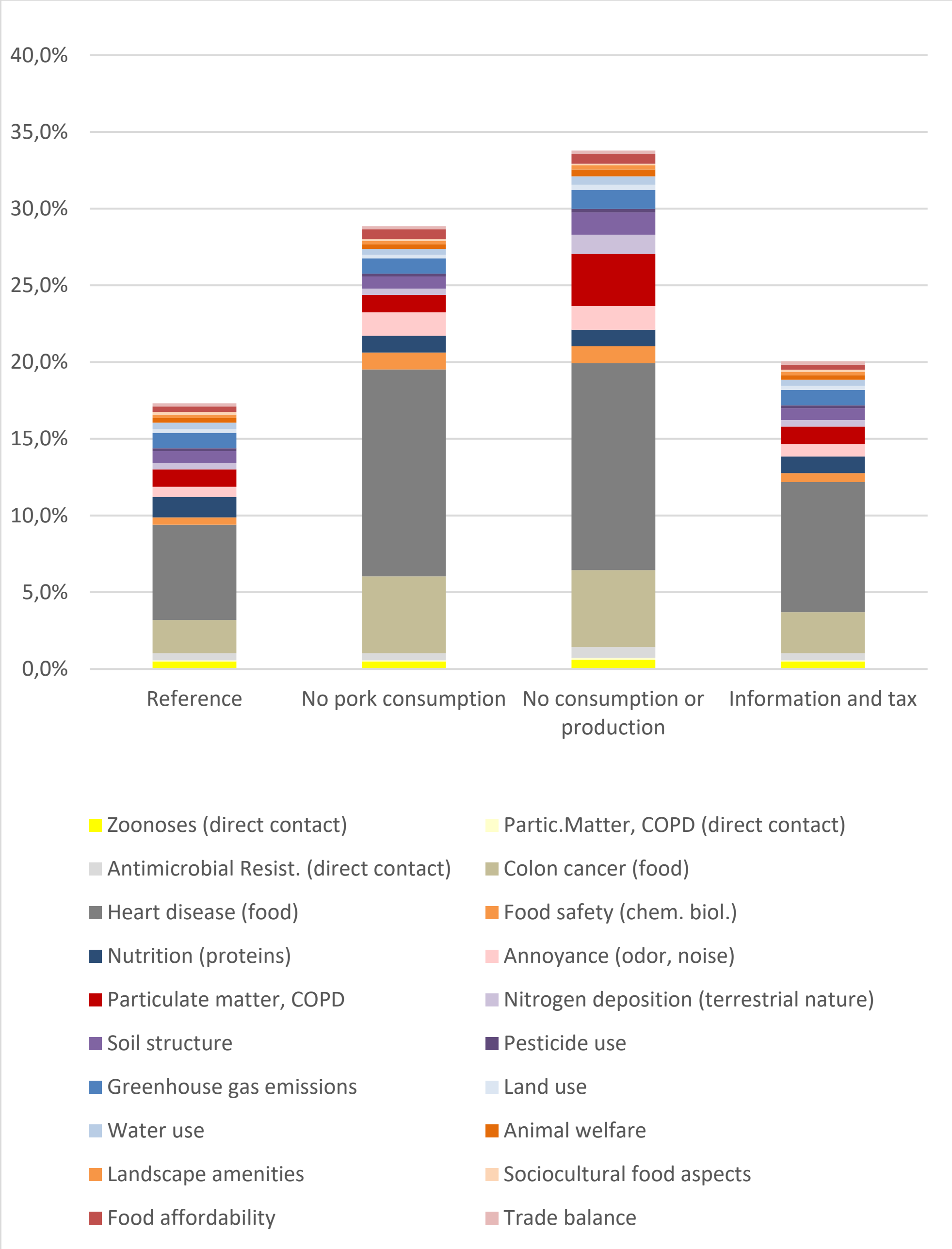

Figure 9.11b The underlying reasons for the preferred scenario for a virtual policymaker to whom human health aspects are very important.

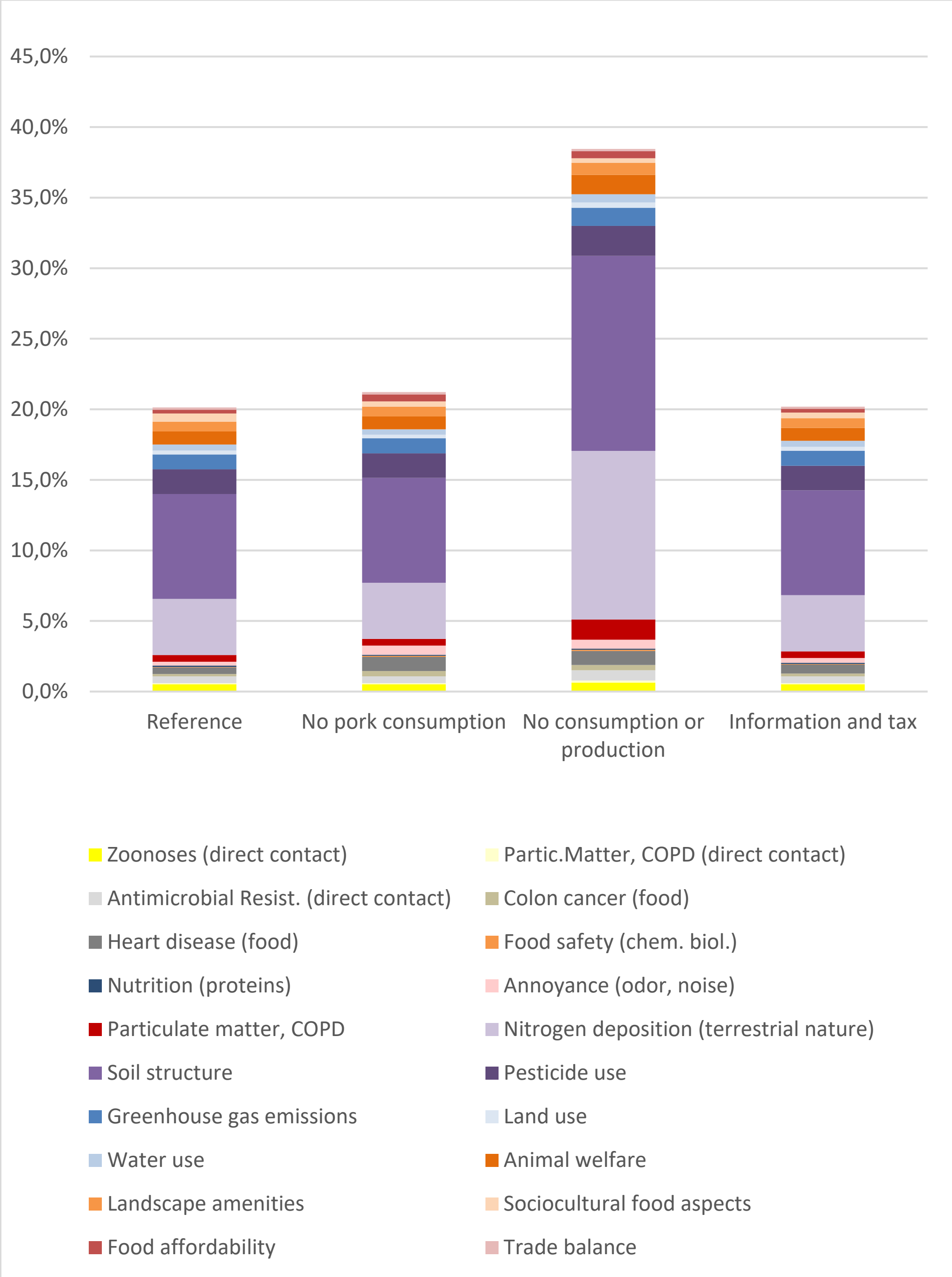

Figure 9.11c The underlying reasons for the preferred scenario for a virtual policymaker to whom environmental aspects are very important.

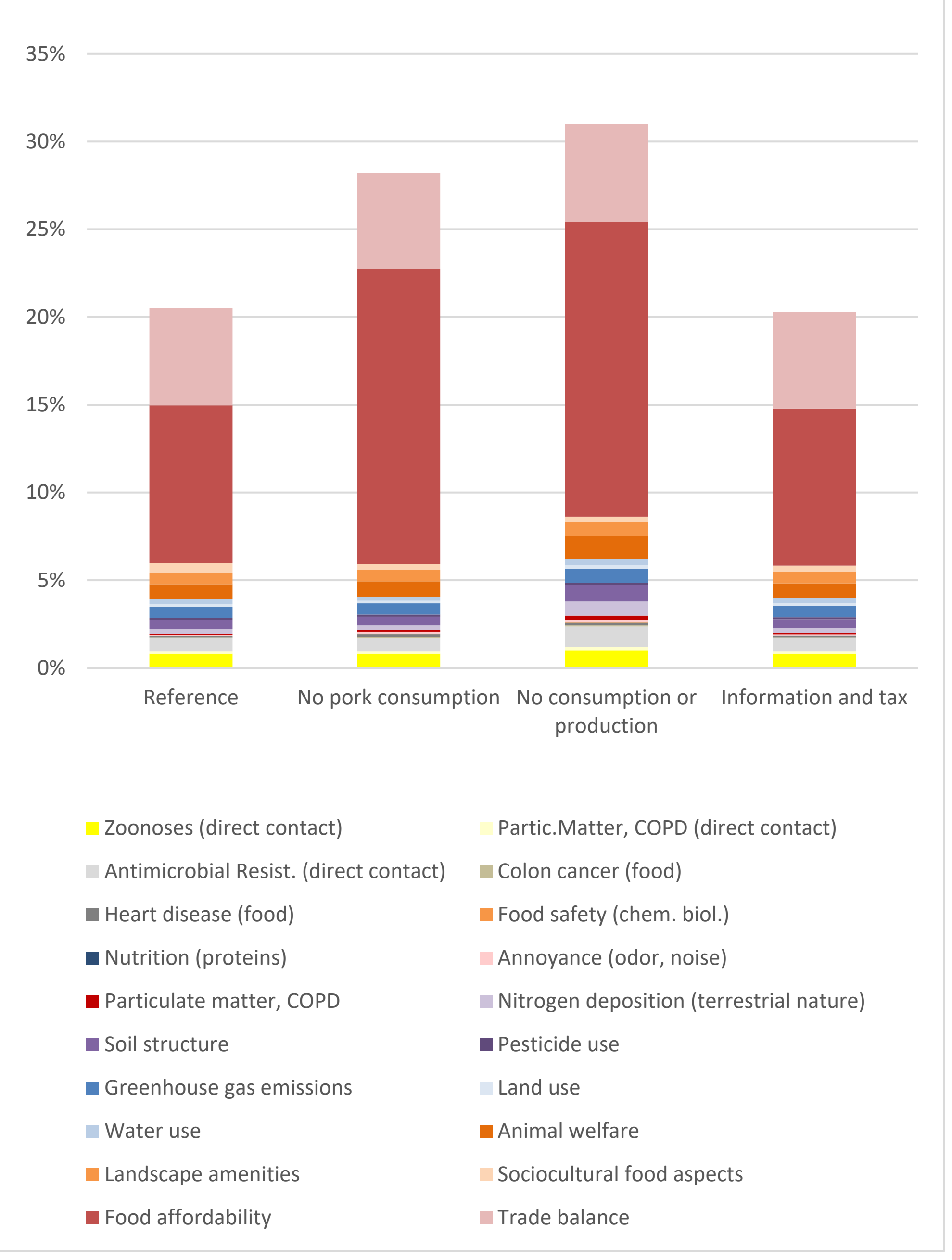

Figure 9.11dThe underlying reasons for the preferred scenario for a virtual policymaker to whom economics is important.

10 Summary, remarks, and conclusions

Measures contributing to a protein transition may have consequences in various domains. Such a transition is thought to contribute to a more sustainable food system, as the production of animal-based proteins, such as dairy, eggs, and meat, requires large amounts of water and land, as well as the import of nutrients. Additionally, the production of animal-based protein is accompanied by the production of GHGs and the disposal of unused nitrogen.
Not only does a reduction in the amount of animal protein in our diet have consequences for the environment, but human health might also be affected. Although animal products contain valuable nutrients, meat consumption is linked to, for instance, foodborne infections and colon cancer. No longer eating and/or producing animal protein will also have socio-economic consequences, both on a personal scale, for instance, food affordability, and on a national scale: a lower contribution to the trade balance and a lower number of jobs. Moreover, the way we experience our surroundings may change if stables disappear, or if fields full of maize are replaced by other crops.
The Fp4F project aims to build an integrated assessment tool for assessing the effects on human health, the environment and socio-economic aspects of possible measures contributing to a protein transition. Such a tool may enable policymakers to choose or discuss the most optimal strategy, considering human, environmental, economic, and socio-cultural aspects linked to the production and consumption of food.

We choose to study the effects of consuming pork and/or producing pigs. Pork is not the type of meat that has the largest impact on our environment (beef does), but it is consumed in larger amounts than beef, its production chain from farm to fork is relatively simple (compared with beef) and its effects have not been studied extensively. In our study, pork was replaced by pulses, which are produced in the Netherlands or, when insufficiently available, are imported from the EU. Pork was replaced on a caloric scale. Although the amino-acid composition of pulses is different from that of pork (it contains fewer essential amino-acids) pork was replaced by pulses on a caloric scale as our diet contains sufficient protein and essential amino-acids without pork.

We developed three (not necessarily realistic) scenarios that could contribute to the desired protein transition and used an AHP-integrated assessment tool to compare the effects of the three scenarios. Using expert opinions and stakeholders' preferences, the AHP tool selects the preferred scenario. The AHP tool is based on the Multi Criteria Decision Analysis methodology and was successfully used in a former study ("What is on our plate?"), where we compared the effects of less meat on human health, food safety and the environment. In FP4F we continued to explore the use of an AHP tool in decision-making and now added new socio-economic categories. The used scenarios were not necessarily realistic but were meant to show what type of measurements might be needed to comply with the intended protein transition. Strikingly, not even when we stop eating pork, the aimed protein transition from 60/40 to 40/60 animal-based/plant-based protein consumption was fully reached. It shows that a system approach is needed, and that the protein transition can only be successful if a set of measurements is taken.

When building an integrated assessment tool, the choice of (sub)criteria and indicators is important. Such indicators should be relevant to and representative of its category. Initially, we selected 35 (sub)criteria (and its indicators) for scoring the effects of the scenarios on human health, the environment, and socio-economic aspects. Unfortunately, this number of 35 (sub)criteria was practically too large to handle for visualisation and for incorporation in the model. Therefore, we selected a subset of (sub)criteria, covering the impacts on health, environment, socio-economic aspects, and economics as well as possible. We removed those criteria of which we judged (on the basis of expert opinion) that they were of minor influence on the total picture, while conserving a fair distribution over the various main categories, or we made combinations of criteria. Two sub-criteria for which no appropriate data was available were also removed. The resulting subset contained 20 (sub)criteria. Using this subset, we built the AHP tool and scored and compared the effects of the three scenarios to each other and to the current situation. Although we aimed to include a balanced set of (sub)criteria that was large enough to cover the categories, the effect of the number of included (sub)criteria and their distribution across the domains on the selection of the preferred scenario is not well understood.
Finding values for all indicators specific to the Dutch situation was not always easy. For some indicators, ready to use datasets were available, whereas for others, they were not. Here, we looked for the best practices on the basis of the available data. This means that in the results, a certain level of uncertainty is present, and that the presented numbers should be seen as an indication rather than as hard facts. The goal of this study was, therefore, to develop and demonstrate the potential of this new integrated weighing system. When this system is to be applied in real situations, more detailed data is needed, as well as the incorporation of a thorough uncertainty analysis.

The use of expert opinions enabled us to compare the effects on indicators that are difficult to compare (e.g. nutritional value vs annoyance or surface water quality vs food affordability) or for which no common unit (e.g. euros or kilograms) can be derived. For each indicator, three experts were asked to give their opinion, using a score from 1 to 9. These experts were all from within RIVM. This might bias the outcome. However, for some indicators, experts from outside of RIVM were also consulted. Their average opinion turned out not to deviate from the average opinion given by RIVM experts and their values were within the same range (not shown). The effect of the range of scores (from 1 to 9) on the final outcome also needs further research.

As a final step, we tested the integral assessment tool. We simulated a situation in which four policymakers, representing human health, the environment, economic affairs and one policymaker who considers all aspects equally important, were asked to attach weight to the main categories (for instance, environment) and subcategories (for instance,

local and global) of their interest. Subsequently, the AHP model was run to select the preferred scenario for each policymaker. Initially, these results surprised us, as we expected that (especially from an economic point of view) stopping the production of pigs would have negative effects on economics. Also, we expected that a virtual, economics-focused policymaker would prefer the reference scenario, or the scenario in which we stop eating pork while still producing pigs. However, from Figure 9.11d it becomes clear that, in the case of the virtual policymaker to whom economics are important, the preference for the "stop producing pigs, stop eating pork" scenario is, to a large extent, a consequence of an increased affordability of food, a consequence that contributes more strongly than the negative effect on the trade balance. The difference in preference with the "stop eating pork" scenario is small; in this scenario, food affordability contributes significantly to the preference, too.
Apparently, we did not fully understand the full consequences of any given scenario. Yet, it becomes clear that the application of our AHP can help (or even convince) policymakers to make unexpected choices by showing them that issues initially considered less relevant might be relevant after all.

Overall, using an expert weighing model, such as the AHP model applied here, seems to be a promising tool to analyse complex systems with aspects in various domains, such as human health, environment, and socio-economics. Thus, non-quantifiable themes can also be taken into account qualitatively, using expert opinions. It can be a helpful tool for policymakers in their decision-making and illustrates the opportunity to make policy decisions optimal for all stakeholders. However, further research is needed to optimise the model. For instance, the model could be refined, while its user friendliness could be enlarged, for example, by implementing the model as a web application. Model uncertainty on various aspects should be studied, for instance, the influence of the role of the experts and their choice on weighing factors as well as the influence of chosen indicators and their values on the various scenarios.

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Appendix I Descriptions of the (sub)criteria

For each of the (sub)criteria, suitable indicators were identified. The indicators describe the effects on each of the (sub)criteria, as quantitatively as possible, and are based on data availability. If no quantitative assessment methodology could be found, qualitative or semi-quantitative indicators were chosen. A short description of each of the initially selected 35 sub-criteria that were considered relevant for the integrated assessment framework is given below.

1 + 14. Zoonoses (direct contact and food). A zoonosis is any infection or disease that is naturally transmissible from vertebrate animals to humans and vice versa. Zoonoses are caused by all types of pathogenic agents, including viruses, bacteria, parasites, and fungi (Woolhouse and Gaunt 2007). Zoonoses can be transmitted from an infected animal to a farmer or owner via direct contact, or by the consumption of food produced from infected animals (meat, eggs, or dairy). For more information, see Post et al., 2020, Supporting Information. Consumption of products of animal origin can result in exposure to various microbiological hazards, such as bacteria (mainly Campylobacter and Salmonella), toxins (produced by B. cereus, Cl. perfringens and St aureus) and, to a much lesser extent, viruses and parasites. Beef is identified as the main source of such hazards, but pork, poultry and dairy meat are also important animal-related sources of microbiological risks (Bouwknegt et al., 2014).

2 + 7. Particulate matter: Exposure to particulate matter causes diseases. Cardiovascular diseases, respiratory diseases such as bronchitis and asthma, lung cancer, as well as low neonatal weight and post-neonatal mortality are partly attributed to exposure to particulate matter. It is the biggest contributor to the burden of disease caused by environmental factors in the Netherlands (VZinfo.nl, 2018). The average lifetime reduction that can be attributed to the particulate matter concentration in the Netherlands is estimated to be 8 months per person. For more information, see Post et al., 2020, Supporting Information.

3 + 4 + 8. Antimicrobial resistance (direct and via food). Antimicrobial resistance evolves when microorganisms are increasingly exposed to antimicrobials, resulting to reduced treatment opportunities for patients who could otherwise be treated with antimicrobials. Resistance may spread through transmission of resistant bacteria or exchange of resistance genes, potentially resulting to a global threat. Because of the potential spread of resistance, apart from antimicrobial use in humans, the use of antimicrobials in livestock is relevant to human health. It is well established that antimicrobial resistance can develop in animals (Aarestrup et al., 2001; Chantziaras et al., 2014), and several studies have shown that a reduction in the use of antimicrobials in animals may result in lower resistance in animals, and potentially in humans, too (Dorado-García et al., 2016; Tang et al., 2017). For more information, see Post et al. (2020, Supporting Information).

5. Annoyance - odour. Odour emissions from animal housing, manure storage, manure treatment, manure application, and feed production and storage may cause annoyance among local residents. Odour emissions are subject to environmental regulations regarding animal housing, prescribing minimum distances and maximum levels of odours (Wet Geurhinder en veehouderij). Apart from causing annoyance, odours are associated with lower general health and increased reporting of gastro-intestinal, respiratory, neurological, and stress-related symptoms (Hooiveld et al., 2015). Odour annoyance is indicated here as the percentage of severely annoyed persons. Indicator: Percentage of persons severely annoyed by odours from livestock production processes in the Netherlands.

6. Annoyance – Noise. Noise annoyance associated with livestock production is mainly caused by noise from the traffic involved with the transport of animals, feed, and manure. In livestock-dense areas, such traffic can cause considerable noise annoyance. Noise at night may cause sleep disturbance, which is an important effect of noise. Noise annoyance is indicated here as the percentage of persons who are severely annoyed by noise. Indicator: Percentage of persons severely annoyed by noise from livestock production processes in the Netherlands.

9. Colon cancer (food): Current research provides evidence of moderate to strong links between healthy dietary patterns and reduced risks of obesity and noncommunicable diseases, particularly cardiovascular disease, hypertension, type 2 diabetes, and certain cancers (Gezondheidsraad, 2015). A healthy diet decreases blood pressure by 2-6 mmHg, and lowers the risk of mortality, cardiovascular diseases, type 2 diabetes, and colorectal cancer by 15-25%. The Health Council of the Netherlands (Gezondheidsraad, 2015, Table 2.1) has concluded that there is convincing evidence for relations between dietary patterns and disease.

10. Coronary heart disease (CHD)/stroke: Current research provides evidence of moderate to strong links between healthy dietary patterns and reduced risks of obesity and noncommunicable diseases, particularly cardiovascular disease, hypertension, type 2 diabetes, and certain cancers (Gezondheidsraad, 2015). The Health Council of the Netherlands (Gezondheidsraad, 2015, Table 2.1) has concluded that there is convincing evidence for relations between dietary patterns and disease. One of these items is coronary heart disease and stroke.

11 + 12 + 13. Nutrient intake: Changes in the diet will result in changes in the nutrient intake. This indicator takes into account the impact of the adequacy of nutrients for the total population or for specific subgroups. For the general population. protein intake is not an issue, as the current intake is very high compared with the current guidelines. However, a recent Eu-project (PROMISS) advises a higher intake for older adults (1.0 gram/kg body weight/day) as this would be beneficial. With this reference value, a considerable part of the older adults already has an intake below that level.
The copper intake is adequate. Only among 1- to 3-year-olds, an increase might result in intakes above the upper level of 1 mg/day.

Although health risks cannot be excluded for high intake, there is no clear indication for public health problems yet.
The intake of vitamins B1, B3, B6, iron, and zinc seem adequate or is adequate for almost all age groups. There are no clear indications for health risks; as far as we know, no recent study is available on vitamin B deficiency in the general population in the Netherlands.

14 + 15. Food safety (chemical and microbiological): Consumption of products of animal origin can result in exposure to various microbiological hazards, such as bacteria (mainly Campylobacter and Salmonella), toxins (produced by B. cereus, Cl. perfringens and St aureus) and, to a much lesser extent, viruses and parasites. Beef is identified as the main source of such hazards, but pork, poultry and dairy meat are also important animal-related sources of microbiological hazards (Bouwknegt et al., 2014).
In the Netherlands, the burden of disease due to pathogens linked to the consumption of pork is 810 DALYs, about 20% of the total burden of disease associated with the consumption and production of food–producing animals (4300 DALYs; Pijnacker et al., 2019).
Incidence figures of clinical diseases due to exposure to chemicals present in food are sparsely available because the health effects of almost all chemicals are a-specific. The few cases are not likely to be related to pork consumption.

16 + 17 + 18 + 19. Soil functioning:
Soil structure/degradation: With soil degradation, the soil quality decreases due to soil erosion, salinisation, nutrient depletion, and desertification. This is an increasing problem in agricultural areas, particularly in Africa, parts of South America and Southeast Asia. One of the causes of soil degradation is that modern agricultural techniques remove an increasing amount of nutrients and organic matter from the soil.
Phosphorus loss: Due to the harvesting of crops, loss of phosphorus occurs. Apart from nitrogen and potassium, phosphorus is an important nutrient for agricultural crops (Hollander et al., 2015).

20. Chemical surface water quality / Nitrate pollution groundwater: Nitrate leaching is an important environmental indicator because of the role nitrate plays in eutrophication and (drinking) water quality. Nitrate leaching is not a simple indicator. There are a number of routes that link nitrate leaching on farmland to pig farms. One route is directly via pig manure as a fertiliser, both around the pig stables and on agricultural land where the manure is applied. The second is indirect via the (residual) flow of agricultural crops, such as pig feed. The last (and smallest) flow is in the form of nitrogen deposition following emission to the air. Concentrations of nitrate in groundwater depend on many non-linear and sometimes opposing influences. Examples of these influences are soil type, groundwater level, precipitation, temperature, crop type, organic matter content and composition, type of manure, amount of manure, time and method of application, and the presence of denitrifying bacteria.
21. Nitrogen deposition (terrestrial nature): The OPS (Operational Priority Substances) model calculations show that the critical deposition value is exceeded in 60% of the Dutch Natura 2000 areas. It can be

deduced from the emissions (emission factors) that 20% of agricultural emissions can be traced back to pig farming.

22 + 23. Surface water quality (chemical and biological): In agriculture, many pesticides are applied. Pesticides may be used to eradicate weeds and pests on grassland and cropland that is used for the production of livestock feed. During and after application, these substances may end up in or on soils, in groundwater, of in surface waters, depending on the properties of the substance, management factors and environmental factors. Locally, these emissions may cause (eco)toxicological pressure on the local ecosystems, terrestrial as well as aquatic. Different types of crops require different types and amounts of pesticides. The effect of pesticide application depends on the type of pesticide and on the amount that finally ends up in the environment.

24. Pesticide application: In agriculture, many pesticides are applied. Pesticides may be used to eradicate weeds and pests on grassland and cropland that is used for the production of livestock feed. During and after application, these substances may end up in or on soils, in groundwater, or in surface waters, depending on the properties of the substance, management factors, and environmental factors. Locally, these emissions may cause (eco)toxicological pressure on the local ecosystems, terrestrial as well as aquatic. Different types of crops require different types and amounts of pesticides. The effect of pesticide application depends on the type of pesticide and on the amount that finally ends up in the environment.

25. Climate change: Emissions of greenhouse gases (GHGs) resulting from human activities lead to increased global warming (climate change). As a measure for climate change, the amount of emitted GHGs is usually used. The most important emissions in the food life cycle are CO_2, CH_4, and N_2O. In this study, all emissions are recalculated into CO_2 equivalents (CO_2-eq) according to the IPCC-guidelines.

26. Land use: Land use is defined as the number of square meters of land area that is needed per year for the total supply chain of food products, including land used for food production abroad. In LCA, a distinction is usually made between two mechanisms: 1) use of a certain area of agricultural land, 2) transformation of a certain area of (natural) land to make it suitable for agriculture and food production processes.

27. Water use: Water use is defined as the amount of blue water that is consumed in the full life cycle of a product. It thus covers irrigation water, including the amount of irrigation water that is evaporated or discharged to rivers and the sea, as well as the water that is eventually incorporated into products. Also, the amounts of water needed in the processing, transport, retail, consumer and disposal phases are taken into account. Direct rainwater input (green water) is not incorporated.

28. Animal welfare: Animal welfare is a sustainability indicator that overlaps with both environmental and social sustainability. Animal welfare is the physical and psychological wellbeing of animals, which means that animals are free of hunger, thirst, physical discomfort, pain, and illnesses. But also that they are able to conduct their natural behaviour and that they are free from stress and fear. In the Netherlands, several labels exist that inform the consumer about the living circumstances of the animals in their animal products. A widespread label is 'Beter Leven' with *, ** or ***. The market share of meat and dairy sold with this 'Beter Leven' label is used here as an indicator for animal welfare.

29. Countryside liveability: Countryside liveability means the presence of local markets for agricultural products and the presence of utilities such as schools, shops, public transport, etcetera. We focus on the concept of 'liveability' of De Leede, (1993). The following aspects can be distinguished:

- Subsistence security (having a job and income).
- Residential climate (valuation of home and living environment).
- Social climate (valuation of social contacts).
- Care situation (nature and level of the facilities present).
- Administrative climate (the involvement of residents in local decision-making).

If pig farmers stop their business, this will lead to a decline in livelihoods on the short term. However, the income in pig farming has been uncertain and low in recent years, so that in the long run, there may be new and better prospects for farmers. Especially if their follow-up activities focus more locally. Hard to estimate. The valuation of the living environment can increase if large polluting companies disappear.

30. Landscape amenities: The removal of the natural habitats of many flora and fauna species is an emerging problem resulting from the intensification of agricultural activities: Large monocultures are formed, causing tree groups, field borders, bushes, shrubs, relief, etcetera to disappear. The 'landschapsbeleving' or countryside appreciation of people recreating in the countryside also decreases. The characteristics of the landscape, of which literature fas established that they influence the valuation of the landscape, have been derived from existing national databases and included in a GIS application, the Experience GIS. The Experience GIS was recalibrated in 2006 on the basis of the results of a survey among 4500 Dutch people for the Belevingswaardenmonitor Nota Ruimte 2006 (Van der Wulp, 2008). In that survey, various population groups were interviewed about the experience and appreciation of 300 areas marked on a map of 5 to 10 km^2. This has resulted in the following equation:
Attractiveness = 5.31 + 0.29 x naturalness – 0.15 x urbanity + 0.23 x historical characteristic – 0.09 x horizon pollution + 0.03 x age (based on the average value by area). Source: https://www.clo.nl/indicatoren/nl1023–belevingskaart–van–het–nederlandse–landschap.)

31 + 32 + 33. Food culture (convenience, taste and habits): Our food culture stands for the attitudes and beliefs relating to our food habits but also for how we look at our food system. Our food culture determines what we eat and produce, but also the feasibility of shifts in our diet (culturally acceptable).

34. Food affordability: The Agrifoodmonitor concludes that affordability is one of the main motives for buying agricultural food products (Onwezen et al., 2016). Changes in food prices result in changes in opportunity costs of food consumption in terms of real income and substitution effects for consumers. A food affordability index is the ratio of average wages, usually of unskilled or low-skilled labourers, to the price of one individual food item or a combination of items (Dorward, 2013). As we want to compare products, the affordability index is calculated as: Percentage of total household income spent on protein = total protein expenditure / (per capita average wage in the lowest income group - total protein expenditure).

35. Trade balance: Trade balance stands for the net import/ export per agricultural product. While the agricultural sector is only a very small part of the Dutch economy, the agricultural sector is very important for trade. Some recent numbers: Dutch exports of agriculture-related products had an estimated value of 94.5 billion euros in 2019. This makes the Netherlands the second largest exporter of agricultural products worldwide (www.agrimatie.nl). Dutch imports of these products have a value of 64.1 billion euro in 2019, resulting in a trade surplus. It is important to realise that mainly raw materials (such as feed) and semifinished products are imported and semifinished, and that end products are exported. About 75% of the import and export take place within the EU (Jukema et al., 2020).
A country that imports more goods and services than it exports in terms of value has a trade deficit or a negative trade balance. Conversely, a country that exports more goods and services than it imports has a trade surplus or a positive trade balance.
A trade review is often seen as an indication that a country is competitive on the world market. This can be due to good quality or low price (https://www.cbs.nl/nl–nl/nieuws/2015/29/nederland–heeft–zevende–handelsoverschot–in–de–wereld). In 2018, the value added generated within the Dutch economy as a result of goods and services exports abroad approximated 262 billion euros, accounting for 34% of the Dutch GDP. A trade surplus can be seen as a proxy for other macro-economic indicators (e.g. GDP-growth, employment, price-stability, buying power). There are 2.4 million jobs involved in goods and services exports, representing 32% of total employment in the Netherlands in 2018 (https://www.cbs.nl/–/media/_pdf/2020/36/nederland–handelsland–2020.pdf). A trade surplus will mean that more income and employment are associated with international trade. A trade surplus generally makes the euro currency stronger. In the longer run, a sustained trade surplus would mean that exported products become relatively more expensive than products of competitors. This correction mechanism would ultimately reduce the competitiveness of the economy and reduce exports until an equilibrium is reached. A negative trade balance is associated with short term loss of employment, income, and average buying power due to rising prices of imported goods.

Appendix II Saaty scores of all indicators

Indicator values

Originally, we identified and selected 35 (sub-)criteria and indicators for building the framework. However, we were not able to find reliable data for all (sub-)criteria and indicators,. In this appendix II, we give the values for the ultimately selected 20 indicators.

Zoonoses (criterion 1 and 7)

Indicator values
The total food-related burden of disease among farmers of animals in the Netherlands is estimated to be 450 DALYs. As 11% of the animal production farms producing pigs, 49 DALYs (=11%*450) are due to pork production. The burden of disease linked to the consumption of food is 4300 DALYs (Pijnacker et al., 2019).

Reference scenario + Scenario 1
On the production side, there is no effect on the burden of disease in Scenario 1; as the production is kept stable, the burden of disease relating to the pig sector is still 49 DALY due to contact with animals. At the consumer side, the total burden of disease relating to consumption in Scenario 1 drops to 3490 (4300-810) DALYs.

Scenario 2:
There is an effect on the burden of disease relating both to pig farmers and pork consumption. The number of infectious diseases decreased as the pig sector stopped. Thus, the decrease in DALYs is 49 due to contact with animals and 810 as part of the original 4300 DALYs due to consumption of pork.

Scenario 3
In Scenario 3, the production of the pig sector is kept stable. Thus, the burden of disease due to food-related pathogens in the pig sector remains stable.
In Scenario 3, meat purchases drop by 30%, of which 10% is pork. We only consider the effects on pork-related indicators. As the meat production is kept stable, this drop in pork purchases affects consumers: 10% fewer DALYs (10% of 810 DALYs relating to the consumption of pork). 4300-81 = 4219 DALYs in total.

Saaty scores

- Saaty Scenario 1 – Reference scenario: no difference = 1.
- Saaty Scenario 2 – Reference scenario/Scenario 1: a decrease in DALYs by 49. By the experts this difference is considered to be small = 2: meaning that Scenario 2 is considered to be the preferred scenario.
- Saaty Scenario 3 – Reference scenario/Scenario 1: The production in the pig sector is stable. Thus, no difference is observed. Saaty = 1.

- Saaty Scenario 3 – Scenario 2: no decrease in DALYs by 49 is seen in Scenario 3. The experts consider this difference to be small = 2; Thus, Saaty = 1/2.

Consulted experts: Rob de Jonge, Eric Evers, Jurgen Chardon, Roan van Pijnacker.

Particulate matter (PM)

Indicator values
The average lifetime reduction that can be attributed to the particulate matter concentration in the Netherlands is estimated to be 8 months per person.

Reference scenario + Scenario 1+ Scenario 3:
In Scenario 1 and Scenario 3, the production of the pig sector is kept stable. Thus, the burden of disease due to PM remains stable.

- Livestock-related concentration: 0.69 µg.m–3.
- Pig sector-related concentration: 0.14 µg.m–3.
- Livestock percentage of total PM concentration: 3.75%.
- Pig sector percentage of total livestock PM concentration: 20%.
- Livestock-related burden of disease due to PM: 5786 DALYs/year.
- Pig sector-related burden of disease due to PM: 1174 DALYs/year.

Scenario 2:
There is an effect on the burden of disease due to PM if the pig sector stopped; therefore, the livestock-related values also decrease. See Post et al. (2020). Total PM concentrations and the burden of disease are related to the life-stock sector. If we remove the PM and the burden of disease caused by pigs:

- Livestock-related concentration: 0.550 µg.m–3.
- Pig sector-related concentration: 0 µg.m–3.
- Livestock percentage of total PM concentration: 2.99%.
- Pig sector percentage of total livestock PM concentration: 0%.
- Livestock-related burden of disease due to PM: 4615 DALYs/year.
- Pig sector-related burden of disease due to PM: 0 DALY/year.

Saaty scores

- Saaty Scenario 1 – Reference scenario: no difference = 1
- Saaty Scenario 2 – Reference scenario/Scenario 1: We relate this score to the total livestock production of PM, we see a reduction by 20%, which we consider to be a significant/strong reduction. Moreover, locally, the effects will be very strong, so we score at Saaty = 4.
- Saaty Scenario 3 – Reference scenario/Scenario 1: The production of the pig sector is stable. Thus, no difference is observed. Saaty = 1.
- Saaty Scenario 3 – Scenario 2: we see a reduction by 20% in Scenario 2, which we consider to be a significant/strong reduction. Moreover, locally, the effects will be very strong, so we score at Saaty = 4 for Scenario 2 versus Scenario 3. Thus Saaty = 1/4.

Consulted experts: Anne Hollander, Pim Post (indirectly: Hendrika A.M. Sterk, Susanna Rutledge-Jonker, Wilco de Vries, Henk Hilderink).

Antimicrobial resistance (direct)

Indicator values
Reference scenario + Scenario 1 + Scenario 3:
Out of the 5% of the Dutch population that is colonised by ESBL/pAmpC–producing E. coli, 14% can be attributed to transmission from direct contact with livestock and through the environment. Out of that 14%, about 20% is related to the pig sector, so 2.8% of the total. The remaining particularly chicken, but also sheep and other cattle (Mughini Gras et al., 2019).
In Scenario 1 and Scenario 3, the production of the pig sector remains stable. Thus, the antimicrobial resistance remains stable.

- % Dutch population colonised with ESBL/pAmpC–producing E. coli: 5%.
- % of colonisation attributable to cattle: 14%.
- % of cattle attribution related to pigs: 20%.
- % of colonisation attributable to pigs: 2.8%.

Scenario 2:
There is an effect on the antimicrobial resistance if the pig sector stops.

- % Dutch population colonised with ESBL/pAmpC–producing E. coli: 4.86%.
- % of colonisation attributable to cattle: 11.2%.
- % of cattle attribution related to pigs: 0%.
- % of colonisation attributable to pigs: 0%.

Saaty scores

- Saaty Scenario 1 – Reference scenario: no difference = 1
- Saaty Scenario 2 – Reference scenario: If 2.8% of the resistance disappears due to absence of pigs, the contribution by cattle to the total Dutch resistance becomes 11.2%, and the total value decreases from 5% to 4.86% of the population. We consider this to be Saaty = 3.
- Saaty Scenario 2–Scenario 1: If 2.8% of resistance disappears due to absence of pigs, the contribution by cattle to the total Dutch resistance becomes 11.2%, and the total value decreases from 5% to 4.86% of the population. We consider this to be Saaty = 3.
- Saaty Scenario 3 – Reference scenario/Scenario 1: no difference = 1;
- Saaty Scenario 3 – Scenario 2: we see a reduction by 2.8% in Scenario 2, which we consider to be a Saaty = 3 for Scenario 2 versus Scenario 3. Thus Saaty = 1/3.

Consulted expert: Lapo Mughini-Gras.

Colon cancer (food)

Indicator values
On the basis of GBD 2017, Colorectal cancer collaborators, the attributable risk due to dietary factors was 79.5% (not including the risk of smoking and physical activity).

Reference scenario:
- Fresh pork consumption = 14.4 gram;
- Processed pork consumption 24.9 gram;
- DALYs due to colon cancer = 90,400;
- DALYs attributable risk due to food factors is 79.5%.

Scenario 1 and Scenario 2:
In Scenario 1 and Scenario 2, no pork will be consumed. This will lower the DALYs due to colon cancer. This number is based on the following assumptions:
- Fresh pork consumption = 0 gram (reduction by 14.4 gram);
- RR for colon cancer for fresh meat = 1;
- Decrease in Fresh pork has no effect on DALYs;
- Processed pork consumption = 0 gram (reduction by 24.9 gram);
- RR for processed meat = 1.17 per 50 gram;
- Decrease by 24.9 gram means a decrease in the number of cases of colon cancer by 7.5% (=exp((24.9/50*ln(1.17))*100));
- Decrease in processed meat results in a decrease in DALYs by 7.5% ➔– 6799 DALYs;
- Legume consumption = 67.9 gram (increase in fibre by 4.6 gram);
- RR for colon cancer for total fibre = 0.90 per 10 gram fibre;
- Increase in legumes means a decrease in the number of cases of colon cancer by 4.7% (4.6/10*ln(0.90));
- Increase in legume consumption results in a decrease in DALYs by 4.7% ➔– 4277 DALYs.
- We assume that the impact is independent: No consumption of pork and an increase in legumes will result in a decrease in the number of cases of colon cancer by 11.9% ➔– 10,754 DALYs. This is 15% (10754/(79.5*90400)) of the DALYs relating to food factors.

Scenario 3:
In this scenario, the consumption of pork will decrease by 10 gram.
- Fresh pork consumption = 10.7 gram (reduction by 3.7 gram).
- RR for colon cancer for fresh meat = 1.
- Decrease in Fresh pork has no effect on DALYs.
- Processed pork consumption =18.6 gram (reduction by 6.3 gram).
- RR for processed meat = 1.17 per 50 gram.
- Decrease by 6.3 gram means a decrease in the number of cases of colon cancer by 2% (=exp((6.3/50*ln(1.17))*100))
- Decrease in processed meat results in a decrease in DALYs by 2% ➔–1781 DALYs. This is 2% of the DALYs relating to food factors.
- There is no effect on the consumption of pulses, as we assume that the intake will not change.

Saaty scores
- Saaty Scenario 1 – Reference scenario: A decrease by 15% is considered to be Saaty 5.
- Saaty Scenario 2 – Reference scenario: A decrease by 15% is considered to be Saaty 5.
- Saaty Scenario 2 – Scenario 1: No difference.

- Saaty Scenario 3 – Reference scenario: A decrease by 2% is considered to be Saaty 2.
- Saaty Scenario 3 – Scenario 1/Scenario 2: A smaller decrease by (15-2)% is considered to be Saaty 4. In which Scenario 1 or 2 is the preferred scenario. Thus, Saaty is 1/4.

Consulted experts: Ido Toxopeus, Marga Ocké, Jolanda Boer, Caroline van Rossum.

Coronary heart disease /stroke (food)

Indicator values
In 2018, the number of DALYs due to CHD was 271,300, while 248,000 was due to stroke. (Ranglijst aandoeningen op basis van ziektelast (in DALY's) | Volksgezondheidenzorg.info).
However, the association between meat and CHD is not convincing, whereas it is for stroke. Therefore, the DALYs associated with stroke are used for this indicator. For legumes, the association between fibre and CHD is taken into account.

Reference scenario
- Fresh meat: 14.4 gram; processed meat: 24.9 gram
- Legumes: 4.7 gram
- DALYs due to stroke = 248,000
- DALYs due to CHD= 271,300

Scenario 1 and Scenario 2:
In Scenario 1 and Scenario 2, no pork will be consumed and more legumes will be consumed. This will lower the DALYs due to stroke. This number is based on the following assumptions:
- Fresh pork consumption = 0 gram (reduction by 14.4 gram)
- RR for stroke for fresh meat = 1.1 per 110 gram
- Decrease in Fresh pork means a decrease in number of cases by 1.2% (14.4/110*ln(1.1))
- Processed pork consumption = 0 gram (reduction by 24.9 gram)
- RR for processed meat = 1.11 per 50 gram
- Decrease by 24.9 gram means a decrease in number of cases by 5,1% (24.9/50*ln(1,11).
- Legume consumption = 67.9 gram (increase in fibre by 4.6 gram)
- RR for stroke for total fibre = 0.85 per 10 gram fibre
- Increase in legumes means a decrease in the number of cases of stroke by 7.2% (4.6/10*ln(0.85))
- We assume that the impact is independent: No consumption of pork and an increase in legume consumption will result in a decrease in the number of cases of stroke by 13% ➔– 32,228 DALYs.

CHD
In Scenario 1 and Scenario 2, no pork will be consumed and more legumes will be consumed. This will lower the DALYs due to CHD. This number is based on the following assumptions:
- There is no association between pork consumption and CHD (not convincing)

- Legume consumption = 67.9 gram (increase in fibre by 4.6 gram)
- RR for CHD for total fibre = 0.91 per 7 gram fibre
- Increase in legumes means a decrease in the number of CHD cases by 6.2% (4.6/7*ln(0.91)). This amounts to 16,303 DALYs.
- An increase in Legumes will result in lower LDL cholesterol (130 gram legumes corresponds with a decrease in LDL by 0.2 mmol. This effect is not taken into account.
- We assume that the impact is independent: No consumption of pork and an increase in legumes will result in a decrease in the number of cases of stroke by 13% and cases of CHD by 6.2% ➔– 48,531 DALYs (9.3% of the DALYs due to stroke and CHD).

Scenario 3:
Stroke

- In this scenario, the consumption of pork will decrease by 10% and the consumption of legumes is stable.
- Fresh pork consumption = 10.7 gram, decrease by 3.7 gram
- RR for stroke for fresh meat = 1.1 per 110 gram
- Decrease in Fresh pork means a decrease in the number of cases of stroke by 0.3% (exp(3.7/110*ln(1.1)))*100).
- Processed pork consumption = 18.6 gram, decrease by 6.3 gram
- RR for processed meat = 1.11 per 50 gram
- Decrease in processed meat consumption means a decrease in the number of cases by 1.3% (exp((6.3/50*ln(1,11))*100).
- Legume consumption is stable, thus no changes in DALYs due to changes in legume consumption.
- We assume that the impact is independent: No consumption of pork will result in a decrease in the number of cases of stroke by 1.6% (0.3+1.3) ➔– 4033 DALYs. This is 0.9% of the total DALYs due to stroke and CHD.

CHD

- In Scenario 3, the legume consumption remains stable. This means no changes in the DALYs due to CHD.

Saaty scores

- Saaty Scenario 1 – Reference scenario: A decrease by 9.3% is considered to be Saaty 4.
- Saaty Scenario 2 – Reference scenario: A decrease by 9.3% is considered to be Saaty 4.
- Saaty Scenario 2 – Scenario 1: No difference.
- Saaty Scenario 3 – Reference scenario: A decrease by 0.9% of DALYs is considered to be no difference. Saaty 1
- Saaty Scenario 3 – Scenario 1: A smaller decrease by 9.3-0.9% is considered to be Saaty 4; in which Scenario 1 is the preferred Scenario.
- Saaty Scenario 3 – Scenario 2: A smaller decrease by 9.3-0.9% is considered to be Saaty 4; in which Scenario 2 is the preferred Scenario.

Consulted experts: Ido Toxopeus, Marga Ocké, Jolanda Boer, Caroline van Rossum.

Nutrient intake

Indicator values
Scenario 1 and Scenario 2
On the basis of the replacement of meat by legumes, the intake of some nutrients will increase or decrease. Only the nutrients with dietary reference values and with changes larger than 5% are taken into account in the comparison of the scenarios.

- The protein intake will decrease slightly (by about 4 gram=5%).
- The intake of fibre will increase: this effect is already being taken into account in the other indicators.
- The copper intake will increase by 0.11 mg/day.
- In scenarios 1 and 2, the intake of alpha linoleic acid will increase compared to the Reference scenario (0.1% of in total 1.7 mg day).
- In scenarios 1 and 2, the intake of vitamin B1 will decrease by 0.18 mg/day.
- In scenarios 1 and 2, the intake of vitamin B3 will decrease by 1.9 mg/day.
- The intake of vitamin B6, will decrease by about 6% (1.84 mg/day). For adult women and for men aged 71-79, low intakes were already observed in VCP 2012-2016.
- The intake of zinc will decrease by about 5% (0.64 mg/day).
- The intake of iron will increase by about 10% (1.1 mg/day). This might have a positive effect, as for children aged 1-13, the median iron intake was below the AI, and for girls or women of productive age (14-50), a high prevalence of low intakes was observed (which is even expected to be underestimated).
- In summary, for most nutrients, the change in intake would not affect the nutritional value of the diet. Only for older adults there might be an effect as their protein intake will become lower.

Scenario 3
In Scenario 3, the impact was not observed for all relevant nutrients. However, the protein intake will also decrease slightly (by about 8%). Thus, in this scenario, too, a higher percentage of older adults might have a low intake of protein, which might affect their health.

In summary, the changes are as follows:

	mean	% Change in Scenarios 1 and 2	% Change in Scenario 3
protein	78.4	-5.3	-7.6
- plant	30.3	12.6	-
- animal	47.8	-16.6	-12.4
ALA	1.7	7.3	-0.2
fibre	19.7	25.3	-0.1
Copper	1.4	7.6	-1.5
Iron	11.3	9.6	-2.3
Zinc	11.3	-5.3	-6.9
Vitamin B1	2.3	-7.6	-7.9
Vitamin B3	22.2	-8.3	-6.7
Vitamin B6	2.6	-6.3	-5.1

Saaty scores

- Saaty Scenario 1 – Reference scenario: a small difference with the Reference scenario as the preferred scenario; Saaty = 1/2
- Saaty Scenario 2 – Reference scenario: a small difference with the Reference scenario as the preferred scenario; Saaty = 1/2
- Saaty Scenario 2 – Scenario 1: No difference; Saaty = 1
- Saaty Scenario 3 – Reference scenario: with the Reference scenario as the preferred scenario; Saaty = 1/2
- Saaty Scenario 3 – Scenario 1: the impact is comparable; no difference; Saaty = 1
- Saaty Scenario 3 – Scenario 2: the impact is comparable; no difference; Saaty = 1

Consulted experts: Ido Toxopeus, Marga Ocké, Jolanda Boer, Caroline van Rossum.

Food safety (chemical and microbiological)

Indicator values
Reference scenario

- In the Reference scenario, the burden of disease due to pathogens in pork amounts to 810 DALYs. In total, the burden of disease linked to the consumption of food is 4300 DALYs.

Scenario 1 and Scenario 2:

- As the consumption of pork stopped in Scenarios 1 and 2, the decrease in DALYs is 810 DALYs.

Scenario 3

- As the consumption of total meat dropped by 30%, the DALYs due to a decrease in pork consumption also amount to 30%* 810 DALYs.

Saaty scores

- Saaty Scenario 1/Scenario 2 – Reference scenario: In both scenarios, the burden of disease will decrease by 810 DALYs.

Thus, Scenario 1 and Scenario 2 are preferred over the reference scenario. According to experts, the impact of 810 DALYs out of the total of 4300 DALYs, the difference is considered to be a Saaty of 5.

- Saaty Scenario 2 – Scenario 1: The decrease is similar in both scenarios: Thus Saaty = 1.
- Saaty Scenario 3 – Reference scenario: The production of the pig sector is stable. However, the consumption decreased by a small percentage and thus, the number of DALYs decreased too (243 DALYs). This difference is considered to be a Saaty of 2. In which Scenario 3 is the preferred scenario.
- Saaty Scenario 3 – Scenario 2/Scenario 1: In Scenarios 1 and 2, the burden of disease will decrease by more DALYs. 810 DALYs was considered to be 5. This amounts to 70% of 810, which is considered to be 4. With Scenarios 1 and 2 as the preferred scenarios.

Consulted experts: Rob de Jonge, Roanne Peijnenburg, Jurgen Chardon.

Annoyance (odour)

Indicator values
Reference scenario + Scenario 1+ Scenario 3:
In scenarios 1 and 3, the production of the pig sector is kept stable. Thus the annoyance remains stable.

- % of Dutch population encountering odour annoyance (BBQ, industry, agriculture): 8.3%.
- % of Dutch population encountering odour annoyance from agriculture: 2.5%
- % of odour annoyance from agriculture relating to the pig sector: 80%.

Scenario 2:
There is an effect on the odour annoyance if the pig sector stops. No additional effects relating to increased pulses consumption are expected.

- % of Dutch population encountering odour annoyance (BBQ, industry, agriculture): 6.3%.
- % of Dutch population encountering odour annoyance from agriculture: 0.5%.
- % of odour annoyance from agriculture related to the pig sector: 0%.

Saaty scores

- Saaty Scenario 1 – Reference scenario: no difference. Thus Saaty = 1.
- Saaty Scenario 2 – Reference scenario/Scenario 1: Substantially lowering of odour annoyance due to agriculture. Lowering by 80%. Judged to be Saaty = 6.
- Saaty Scenario 3 – Reference scenario/Scenario 1: The production of the pig sector is stable. Thus no difference is observed. Saaty = 1.
- Saaty Scenario 3 – Scenario 2: The noise in Scenario 2 is lower than that in Scenario 3. A similar difference as in Scenario 2 compared to the reference scenario; thus Saaty = 1/6.

Consulted experts: Pim Post, indirectly Ric van Poll.

Particulate matter, COPD

Indicator values
According to Post et al., 2020, the following numbers of exposed persons were estimated:

- Number of persons living within 500 m from any livestock farm: 3,544,336 (21%) in 2015.
- Percentage of persons living within 1000 m from more than 11 farms: 16% (sd: 0.1%) in 2015.
- Percentage out of those persons living within 1000 m from more than 11 farms that live within 500 m from a livestock farm: 94% (sd: 2%) in 2015.

The burden of disease for lower respiratory infections was about 487➔102 DALYs in 2015. The burden of disease for COPD was about 18.3➔104 DALYs in 2015, and this burden would nearly be 5% lower if no livestock farms would be present.

Reference scenario + Scenario 1+ Scenario 3:
In scenarios 1 and 3, the production of the pig sector is kept stable. Thus the particular matter causing COPD remains stable.

- % of Dutch population encountering COPD: 18.3 ➔ 104 DALYs, out of which about 5% related to livestock farms
- % of COPD related to pig sector: 3%.

Scenario 2:
There is an effect on COPD (DALYs) as the pig sector stopped.

- % of Dutch population encountering COPD: 17.8 ➔ 104 DALYs.
- % of COPD related to the pig sector: 0%.

Saaty scores

- Saaty Scenario 1 – Reference scenario: no difference = 1
- Saaty Scenario 2 – Reference scenario/Scenario 1: Slightly lower COPD due to no agriculture. Judged to be a Saaty = 2.
- Saaty Scenario 3 – Reference scenario/Scenario 1: The production of the pig sector is stable. Thus, no difference is observed. Saaty = 1.
- Saaty Scenario 3 – Scenario 2: The COPD due to agriculture is lower in Scenario 2 than in Scenario 3. A similar difference as in Scenario 2 compared to the reference scenario; thus Saaty = 1/2.

Consulted experts: Pim Post (indirectly Henk Hilderink, Marie-Jose Mangen, Lenny Hogerwerf).

Nitrogen deposition (terrestrial nature)

Indicator values
Reference scenario
In the reference scenario, the critical deposition value for nitrogen is exceeded in 60% of the Natura 2000 areas.

Scenario 1:
In Scenario 1, as in the reference scenario, the critical deposition value is exceeded in 60% of the Natura 2000 areas.

Scenario 2:
In Scenario 2, the reduction in deposition from livestock farming is less than 20%, because a correction needs to be made for animal manure that is no longer exported, as is the case in the reference scenario. The application emissions were corrected. To this end, it has been assumed that spreading 1 kg-N chicken or cattle manure produces the same application emissions as spreading 1 kg-N pig manure. It has also been assumed that the ratio of application emissions to total emissions per animal species is the same.

The ratio of application emissions in the total animal emissions is 42/108 (mln kg N/mln kg N). The change in application emissions compared to the export situation and to the situation without pig manure is assumed to be equal to the ratio of exported animal manure to pig manure, which is 49/96 (mln kg N/mln kg N). Correction amounts to: (60%*25%)+(60%*75%*(100%-20%+X%))=Y%

In which the increase in deposition due to an export stop, as a result of the application emissions of previously exported chicken, cattle and horse manure is as follows:
X%=20%* 42/108*49/96=3.81%

This would amount to: (60%*25%)+(60%*75%*(100%-20%+3.8%))=52.8%

Thus, the critical deposition value is exceeded in 52.8% of the Natura 2000 areas. Compared to the reference situation, this is a reduction by (60-52.8)/60= 12%.

- KDW exceeding non-livestock farming is 25% of 60%.
- KDW exceeding livestock farming is 75% of 60%.
- Pig farming's share in livestock farming emissions is 20%.
- This would amount to

: (60%*25%)+(60%*75%*(100%-20%))=51%

Saaty scores
Saaty Scenario 1 – Reference scenario: no difference = 1
Saaty Scenario 2 – Reference scenario: Saaty = 6. (Mean of 5, 7, 5, 6, 5)
Saaty Scenario 2 – Scenario 1. Saaty = 6.
Saaty Scenario 3 – Reference scenario/Scenario 1: Saaty = 1
Saaty Scenario 3 – Scenario 2: Saaty = 1/6.

Consulted experts: Rob Maas, Roy Wichink-Kruit, Albert Bleeker, Mike Wit, Timo Brussée and Addo van Pul.

Soil structure

Indicator values
The average composition of 1 kg of the Dutch pig feed is:

- Cereals (wheat, barley, rye) – 600-700 gram: Europe

- Maize – 50-100 gram: the Netherlands
- Palm oil – 15 gram: non-EU
- Soybean meal – 80 gram: non-EU
- Rape seed – 100 gram: NL and EU

Reference scenario + Scenario 1 + Scenario 3:
- Phosphorus losses by harvesting of soybean: 5.97 kg P/ton yield
- Phosphorus losses by harvesting of maize: 0.72 kg P/ton yield
- Phosphorus losses by harvesting of wheat: 3.37 kg P/ton yield

Scenario 2:
In Scenario 2, the pig sector stopped in the Netherlands, thus there is an impact on the animal feed cultivation.

Saaty scores
- Saaty Scenario 1 – Reference scenario: no difference = 1.
- Saaty Scenario 2 – Reference scenario: Strong increase in soil structure. Saaty = 4.
- Saaty Scenario 2 – Scenario 1: Strong increase in soil structure. Saaty = 4.
- Saaty Scenario 3 – Reference scenario/Scenario 1: no difference. Saaty = 1.
- Saaty Scenario 3 – Scenario 2: Strong increase in soil structure in Scenario 2, So Saaty = ¼.

Consulted experts: Anne Hollander, Michiel Zijp.

Pesticide use

Indicator values
For this study, we compared the amounts of pesticides emitted to the environment from maize (feed) to the amounts of pesticides emitted to the environment from beans (Emissions of pesticides to surface water and their changes (De Snoo and Vijver, 2012).

Reference scenario + Scenario 1 + Scenario 3:
- Emissions from maize: 15 gr/ha/year
- Maize areal 196,000 ha (CBS, 2020).
- Emissions from maize: 2940 kg/ha/year

Scenario 2:
Shift in acreage maize>beans: 197,000 ha
Emissions from beans: 11 gr/ha/year
If the maize areal shifts to beans: 4 gr/ha/year fewer emissions

If the maize area shifts to beans, emissions decrease to 2156 kg/ha/year, which is a 27% decrease.

Saaty scores
- Saaty Scenario 1 – Reference scenario: no difference = 1.
- Saaty Scenario 2 – Reference scenario: Slightly lower pesticide emissions to surface water. Saaty = 2.
- Saaty Scenario 2 – Scenario 1: Slightly lower pesticide emissions to surface water. Saaty = 2.

- Saaty Scenario 3 – Reference scenario/Scenario 1: no difference. Saaty = 1.
- Saaty Scenario 3 – Scenario 2: slightly lower pesticide emission to surface water. So Saaty = 1/2.

Consulted experts: Ton van der Linden, Anne Hollander.

Greenhouse gas emissions

Indicator values

The total emissions for pork is estimated by the amount of emission per kg of pork per year, times consumption in the Netherlands times number of inhabitants in the Netherlands times a factor 4 (assuming that 75% of Dutch production is for export). The assumptions are:

- CO_2 emissions 1 kg pork: 5 kg CO_2-eq (Database milieubelasting voedingsmiddelen | RIVM\
- Number of kg of pork consumption pp/year in the Netherlands: 36.6 kg/year (Agrimation, see the Figures table for Pig sector figures)
- Number of inhabitants of the Netherlands: 1.74E+07 persons (CBS, January 2020)
- Annual pork consumption in the Netherlands: 6.37E+08 kg/year

Reference scenario + Scenario 1+ Scenario 3:

- % CO_2 emissions of the Dutch pig sector directly: 8.1E+09 kg CO2-eq/year.
- % CO_2 emissions from Dutch agriculture compared to the Dutch total: 14%.
- % of emissions by pigs: 3%.
- CO_2 emissions including global feed production for meat consumed in the Netherlands: 3.2E+09 kg CO_2-eq/year.
- CO_2 emissions including global feed production: 1.3E+10 kg CO_2–eq/year.
- Uptake of CO_2 by legumes: marginal.

Scenario 2:

- As the production of pork stops, the emission will decrease slightly.

Saaty scores

- Saaty Scenario 1 – Reference scenario: no difference = 1
- Saaty Scenario 2 – Reference scenario: Slightly lower CO_2 emissions. Saaty = 2.
- Saaty Scenario 2–Scenario 1: Slightly lower CO_2 emissions. Saaty = 2.
- Saaty Scenario 3 – Reference scenario/Scenario 1: no difference. Saaty = 1.
- Saaty Scenario 3 – Scenario 2: slightly lower CO_2 emissions in Scenario 2. So Saaty = 1/2.

Consulted expert: Pim Post.

Land use

Indicator values
Reference scenario /Scenario 3
- Land use per kg pork production per year including feed: 10 m^2
- Land use (including feed) total Dutch pork production per year: 2.6E+10 m^2
- Land use total Dutch pulses production per year: 3.0E+07 m^2

Scenario 1:
- Current land use for pig and pig feed production will remain the same.
- Replace pork consumption by legumes based on caloric value: 120 vs 242 = consume 2.02 times as much weight in legumes as in pork.
- Land use external pulse production for Dutch consumption per year, based on increased consumption amounting to 61.9 gr/day: 8.5E+09 m^2

Scenario 2:
- Land use (including feed) Dutch pork production per year: 0 m^2
- Land use external pulse production for Dutch consumption per year, based on increased consumption of 61.9 gr/day: 8.5E+09 m^2

Saaty scores
- Saaty Scenario 1 – Reference scenario: Slightly higher land use for the consumption of legumes in Scenario 1: Saaty = 1/2.
- Saaty Scenario 2 – Reference scenario: lower land use in Scenario 2 (no pork, but slightly more for legumes). Saaty = 3.
- Saaty Scenario 2 – Scenario 1: lower land use in Scenario 2 (no pork and similar for the legumes. Saaty = 4.
- Saaty Scenario 3 – Reference scenario: no difference, same production. Saaty = 1
- Saaty Scenario 3 – Scenario 1: Slightly higher land use in Scenario 1. Saaty = 2.
- Saaty Scenario 3 – Scenario 2: Lower land use in Scenario 2; Saaty = 1/3.

Consulted experts: Pim Post, Anne Hollander.

Water use

Indicator values
- Water use (global) for production of 1 kg pork = 0.078 m^3 (RIVM statline).
- Water use for pig + peas from the Netherlands including feed: 1.21E+08 m^3/year.
- Water use per person per year for pig + peas: 69.7 m^3/ year.
- Water use for total food per person per year: 1345 m^3/ year.

Reference scenario
- a slaughtered weight of 1,535,180,000 kg results in the use of 119,744,040 m^3 water per year.

- For production of 1 kg of dried legumes = 0.073 m^3 water is required.
- Conversion factor dry:fresh legumes = 1:2.2.
- So, for 1 kg of fresh beans 0.073/2.2 = 0.033 m^3 of water is needed.
- Annual yield (own table legumes) = 4,500,000 kg (landbouwcoöperatie CZAV) + import, so a total of 954,900 m^3 of water. Total = 1,21E+09 m^3/year.

Scenario 1:

- Current water use for pig production will remain the same.
- Replace pork consumption by legumes based on caloric value: 120 vs 242 = consume 2.02 times as much weight in legumes as in pork.
- Extra water needed for this: 53,104,639 m^3/year: 797,966,025 kg = Dutch consumption of pigs.
- So x 2.02 = 609,231,484 kg Dutch consumption of pods as a replacement based on calories = 53,104,639 m^3 extra water needed in this scenario.

Scenario 2:

- Extra water is needed for the consumption and production of legumes, but less water is needed for the production of pork. In total, less water is used.
- Extra water is needed for the consumption of legumes = 53,104,639 m^3 extra water (as in Scenario 1).
- Reduction in water use, as it is not needed for production of pork = 119,744,040 m3 water.
- Net less water: 119,744,040 – 53,104,639 = 57,639,401 m^3 water.

Scenario 3:

- There is no effect on the production and thus on the water use. Thus the situation is similar to the reference scenario.
- The effect on the change in consumption is assumed to be 0.

Saaty scores

- Saaty Scenario 1 – Reference scenario: Slightly higher water use for the consumption of legumes: Saaty = 1/2.
- Saaty Scenario 2 – Reference scenario: Less water use for the production of pork, but more water needed for the consumption/production of legumes. Net less water. Saaty = 3.
- Saaty Scenario 2 – Scenario 1: less water use than in Scenario 1 due to no production of pork. But more water is needed for the production of legumes. In total, the water use is less than in Scenario 1. Saaty = 2.
- Saaty Scenario 3 – Reference scenario: Saaty = 1.
- Saaty Scenario 3 – Scenario 1: more water is needed for the consumption of legumes in Scenario 1. Saaty = 2.
- Saaty Scenario 3 – Scenario 2: more water is used for the production of pork, but less water is needed for the consumption/production of legumes; in total, the water use in Scenario 3 is higher , Saaty = 1/3.

Consulted expert: Anne Hollander.

Animal welfare

Indicator values

The market share of meat and dairy sold with this 'Beter Leven' label is used here as indicator for animal welfare.

- Number of pigs in the Netherlands with 'Beter Leven' quality mark: 3,757,205 (Source Stichting 'Beter Leven' Keurmerk, personal communication)
- Total number of porkers ('vleesvarkens' in Dutch) (CBS) amounts to 5,630,909.
- Percentage = 66.7%.
- Total amount of livestock in the Netherlands = 63,617,970 (Post et al., table SuppA1_4, see Indicator ValuesScenarios201018.xls).
- Total number of pigs with Beter Leven label is 37,900,000. Percentage = 59.5%.

Reference scenario + Scenario 1 + Scenario 3:

- Percentage of pigs with Beter Leven quality mark: 66.7%
- Percentage of cattle with Beter Leven quality mark: 58.9%

Scenario 2:

- Percentage of pigs with Beter Leven quality mark: 0%
- Percentage of cattle with Beter Leven quality mark: 58.9%

Saaty scores

- Saaty Scenario 1 – Reference scenario: no difference. Saaty = 1.
- Saaty Scenario 2 – Reference scenario: Fewer animals. Saaty = 3.
- Saaty Scenario 2–Scenario 1: Fewer animals. Saaty = 3.
- Saaty Scenario 3 – Reference scenario= no difference. Saaty = 1.
- Saaty Scenario 3 – Scenario1: no difference. Saaty = 1.
- Saaty Scenario 3 – Scenario 2: Fewer animals in Scenario 2: Saaty = 1/3.

Consulted expert: Anne Hollander.

Landscape amenities

Indicator values

A survey by Van der Wulp (2008) has resulted in the following equation:

- Attractiveness = 5.31 + 0.29 x naturalness – 0.15 x urbanity + 0.23 x historical characteristic – 0.09 x visual pollution + 0.03 x age (based on the average value by area). Source: https://www.clo.nl/indicatoren/nl1023–belevingskaart–van–het–nederlandse–landschap.)

Reference scenario + Scenario 1+ Scenario 3:

- Residents' appreciation of the current landscape is based on the following points: Variety, Ruggedness, Horizon Pollution, Relief, Water, Vegetation, Regional Identity. Horizon pollution = pig stables contribute 17% to the decrease in valuation due to horizon pollution according to resident consultations.

Scenario 2:
- Disappearance of decrease in horizon pollution due to pig stables: with 17%. However, it is assumed that this is a short-term effect.

Saaty scores
- Saaty Scenario 1 – Reference scenario: no difference. Saaty = 1.
- Saaty Scenario 2 – Reference scenario: Slightly higher landscape appreciation. Saaty = 2.
- Saaty Scenario 2–Scenario 1 Slightly higher landscape appreciation. Saaty = 2.
- Saaty Scenario 3 – Reference scenario= no difference. Saaty = 1
- Saaty Scenario 3 –scenario1= no difference. Saaty = 1.
- Saaty Scenario 3 – Scenario 2: Lower landscape appreciation in Scenario 3: Saaty = 1/2.

Consulted expert: Anne Hollander.

Food culture

Indicator values
Reference scenario:
- Food culture: The traditional Dutch diet/meal contains meat ++
- Dishes on specific days, such as Christmas, are focused on meat ++
- In restaurants and bars, the focus is on meat: ++ (greendish.com)

Scenarios 1 + 2:
- In Scenario 1 or 2, the consumption of pork is replaced by legumes or other food.
- Food culture: The traditional Dutch diet/meals do not consist of pork. This does not fit in with the current culture --
- The same for dishes on specific days, such as Christmas –, and in restaurants -.

Scenario 3
- In Scenario 3, the consumption of pork is somewhat reduced (30%).
- Food culture: The traditional Dutch diet/meal contains no pork. This does not fit in with the current culture -
- The same for dishes on specific days, such as Christmas, and in restaurants -

Saaty scores
- Saaty Scenario 1 – Reference scenario. Scenario 1 does not fit in with the current food culture . Saaty = 1/4.
- Saaty Scenario 2 – Reference scenario: Scenario 2 does not fit in with the current food culture. Saaty = 1/4.
- Saaty Scenario 2 – Scenario 1. no differences, Saaty = 1.
- Saaty Scenario 3 – Reference scenario: In Scenario 3, the consumption of pork is somewhat reduced; Saaty = 1/2.
- Saaty Scenario 3 – Scenario1/Scenario 2: Scenario 1 is much more extreme than Scenario 3. Saaty =2.

Consulted expert: Anne Hollander.

Food affordability

Indicator values
- 100 gram product Gram protein Price per kg
- Pork 20.2 € 7.75
- Brown beans 6.8 € 1.25

Reference scenario:
- Daily Pork consumption = 39.4 gram containing 8 gram protein.
- Price per kg pork = 7.75 euro per kg; brown beans =1.25 euro per kg.
- Price per gram protein: for pork: (100/20.2)* (775/1000) = 3.8 ct ; and for brown beans: (100/6.8)*(125/1000) = 1.8 ct per gram.
- Total expenditure on pork protein: 8*3.8=0.30 euro

Scenarios 1 + 2:
In scenarios 1 and 2, the expenditure on pork decreases to zero, while the consumption of legumes increases.
- Pork consumption = 0 gram.
- Legume consumption = 61.9 gram per person.
- Total extra expenditure on protein from beans per person = 61.9*6.8/100*1.25 = 0.085 euro per day (this means a daily saving of 0.22 euro).
- Affordability for low-income groups will increase.
- Food will become cheaper.
- The assumption is that the extra supply and consumption does not affect the prices of pork and beans.

Scenario 3
- Pork will become more expensive (30%).
- Pork consumption is decreased to 29.3 gram.
- Total expenditure on protein per person = 29.3*20.2/100*7.75*1.30 in euro/day.
- An assumption was that the expenditure was similar. Thus , the price increase is compensated by lower meat consumption.
- Hardly any effect on the affordability.

Saaty scores
- Saaty Scenario 1 – Reference scenario: Saaty = 4
- Saaty Scenario 2 – Reference scenario: Saaty = 4
- Saaty Scenario 2–Scenario 1: Saaty = 1
- Saaty Scenario 3 – Reference scenario: Saaty = 1
- Saaty Scenario 3 –scenario1/Scenario 2: Saaty = 1/4

Consulted experts: Arianne de Blaeij, Rob Maas.

Trade balance

Indicator values
Reference scenario:
- The pig sector in 2019: 553 million (net import) / 2290 million (net export) =0,24

- The export value of the pig sector is approximately 2.5% of the total export value in the agricultural sector. The import value is less than 1%.
- The pig sector is important to the trade balance of the agricultural sector. https://www.agrimatie.nl/SectorResultaat.aspx?subpubID=2232&sectorID=2255&themaID=2276

Scenario 1

- In Scenario 1, the export of pigs increases as the production is kept stable and the consumption decreases.
- We assume that there is an international market for all pork to compensate for the loss of domestic sales.
- It is uncertain what will happen to the price.
- Assuming that the price remains equal, the trade balance will be more positive.
- Extra legumes need to be imported, but the impact on the trade balance is less than the increased export of pork.

Scenario 2:

- In Scenario 2 the production of meat in the Netherlands stops. Thus, the export also stops, as does the import.
- No production implies no import as well
- In total, this would have a negative impact on the trade balance (although less pig feed needs to be imported either, while beans can be produced domestically instead of pig feed).

Scenario 3:

- In Scenario 3 , we assume that the higher price does not have an impact on the trade balance.

Saaty scores

- Saaty Scenario 1 – Reference scenario: The trade balance is positive in Scenario 1. Saaty =3
- Saaty Scenario 2 – Reference scenario: The trade balance is more negative in Scenario 2 compared to the reference scenario. Saaty =1/3
- Saaty Scenario 2 – Scenario 1: Saaty = 5
- Saaty Scenario 3 – Reference scenario: Saaty = 1
- Saaty Scenario 3 – Scenario1: Saaty = 1/3
- Saaty Scenario 3 - Scenario 2: Saaty = 3

Appendix III The Geometric Consistency Index (GCI)

Although in pairwise weighing, it is not necessary, and even questionable, to be completely consistent down to the umpteenth decimal place, it is possible to calculate an index, which is a measure of the inconsistency. Moreover, you don't want criterion A to dominate over B; B clearly has priority over C and C is extremely preferable to A.

An index for the geometric mean is the Geometric Consistency Index (GCI) (Brunelli 2015). In the following Table, the GCI is calculated using the previous A-E table:

	A	B	C	GeoMean	Weights	Geometric Consistency Index			
A	1	3.000	2.000	1.817	54.5%	1	1.000	1.000	0.000
B	0.333	1	0.667	0.606	18.2%		1	1.000	0.000
C	0.500	1.500	1	0.909	27.3%			1	
	Number of Criteria:	3		3.331	100.0%			GCI:	0.000

	A	B	C	GeoMean	Weights	Geometric Consistency Index			
A	1	3.000	2.000	1.817	49.9%	1	2.381	0.420	1.505
B	0.333	1	9.000	1.442	39.6%		1	2.381	0.753
C	0.500	0.111	1	0.382	10.5%			1	
	Number of Criteria:	3		3.641	100.0%			GCI:	2.258

In the ideal, completely consistent case, the GCI is 0.0. It is hard to say, what is still acceptable, but values below 1.0 do seem acceptable.
In the following example, we compare the first consistent A-B-C pairwise trade-off to an inconsistent trade-off. You can see that the GCI = 0.0 in the first case, and 2.258 in the second.
Another way to see the (in-)consistency is that in the first case, the Weights vector has the same proportions as the values in each column of the A-B-C pairwise trade-off matrix. In the second case, none of this holds true.

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