Legume Futures

Legume-supported cropping systems for Europe

Legume Futures Report 4.6

Social Cost-Benefit Analysis of Legumes in Cropping-Systems

Prepared by:

Tom Kuhlman and Vincent Linderhof

LEI

March, 2014

Legume-supported cropping systems for Europe (Legume Futures)
is a collaborative research project funded from the European Union's Seventh Programme
for research, technological development and demonstration under grant number 245216
www.legumefutures.de

Legume Futures

Legume-supported cropping systems for Europe (Legume Futures) is an international research project funded by the European Union through the Framework 7 Programme (FP7) under grant agreement number 245216 (FP7-KBBE-2009-3). The Legume Futures research consortium comprises 20 partners in 13 countries.

Disclaimer

Copyright

Citation

Please cite this report as follows:

Kuhlman, T., Linderhof, V., 2014. Social Cost-Benefit Analysis of Legumes in Cropping-Systems. Legume Futures Report 5. Available from www.legumefutures.de

CONTENTS

FOREWORD

Legume Futures, "Legume-supported crop rotations for Europe", is an international research project funded under the European FP7 programme. It has 20 partners in 13 countries. The project aims to develop and assess legume-supported cropping systems that improve the economic and environmental performance of farming in Europe.

This report is part of the socio-economic research in Legume Futures which aimed to assess the economic effect of including legumes in farming systems both in relation to the internal (economic) effects for the farmer and the external effects, especially on the environment. It builds on Legume Futures Report 4.5 (Impacts of legume scenarios). That report described said impacts, here we are concerned with valuing them, in order to help policy-makers arrive at a judgment on the most advantageous course of action.

The report also describes the method of social cost-benefit analysis, for the benefit of those readers who are not familiar with it. There is ample literature on this topic, but much in a concise form accessible to laymen. In a project such as Legume Futures, most participants fall into that category. Beyond mere description, the report looks critically at the method, in order to make possible users aware of its limitations as well as its usefulness.

Tom Kuhlman,

The Hague, Netherlands,

15 December 2013

1. INTRODUCTION

The cultivation of legumes is expected to bring environmental benefits. One of the tasks in Legume Futures is to assess how these environmental benefits compare to social and economic costs and/or benefits – in other words, whether these environmental benefits of legumes are worth pursuing. Other research in Legume Futures leading has explored the benefits from the farmer's point of view. The impact on greenhouse gas emissions was also examined. Legume Futures Report 4.5 presents a number of possible policies to promote legumes with their effects simulated by means of scenario modelling. The research reported here was an overall assessment of the effects of these policies from a societal point of view.

This assessment was done by means of social cost-benefit analysis (SCBA), which is one way of doing it. Hence, the following chapter explains what SCBA is, how it relates to other possible methods, and what this means for assessing the impact of said policies. Chapter 3 presents the SCBA itself. In Chapter 4 conclusions are drawn and recommendations formulated for policies on legumes.

2. WHAT IS SOCIAL COST-BENEFIT ANALYSIS?

There are, one may say, two kinds of cost-benefit analysis. One is carried out by firms in order to see whether a possible course of action yields enough profit to justify the cost. The other is done on behalf of public entities, usually by independent researchers, to assess the pros and cons of a policy, a programme or a project in terms of the public interest. This latter kind, social cost-benefit analysis, is built on the first type, but uses additional methods. Hence, we begin by explaining what cost-benefit analysis in general entails, i.e. the private kind (section 2.1), before proceeding to a description of the social kind (section 2.2).

Social cost-benefit analysis may be regarded as one form of impact assessment, one that, for all its complexity, results in a single figure upon which a decision may be based. This is both a strength and a weakness. The downside is that not all values can be expressed in figures; and even when they can, not everyone will agree on how these values have been decided upon. Section 2.3 addresses those issues.

2.1. Private cost-benefit analysis

Before a firm undertakes a new project, it is common practice to examine the likely return on the investment. When the project is financed by a bank, such ex-ante evaluation is usually a requirement. Cost-benefit analysis is a method of conducting such research. The essence of the method is that an anticipated flow of costs over different years is compared to an anticipated flow of revenues. These two flows are asynchronous, which is the essence of investment: in routine operations one may calculate profits by the difference between revenue and expenditure on a yearly basis, but an investment means that one spends money in one year in order to obtain a return in a later period.

This difference in time between the two flows makes it necessary to discount them, that is to say, the costs and benefits must be revalued in order to account for the fact that income received today does not have the same value as that same income in the future – not even after correcting for inflation. Postponing the gratification of a desire till next year represents a sacrifice, and that sacrifice is expressed as a cost. It is calculated by reducing the value of a particular amount of expenditure or revenue by a certain rate, called the discount rate. That rate represents the sacrifice an entrepreneur makes by not having (or using) the money right away. Conversely, it is the rate at which he would want the money to increase if it is to be worth the postponement. If it is his own money, he could use the interest he could otherwise get at the bank as his discount rate. If he borrows the money from the bank, his discount rate will be the interest rate he pays on the loan.

This brings us to a second important feature of cost-benefit analysis (next to discounting): opportunity cost. Strictly speaking, in cost-benefit analysis it is not the cost in money that counts, but what the entrepreneur sacrifices in terms of alternative opportunities. We assume that he wants to use the productive resources available to the firm in the most profitable way possible. For instance, if land is currently not used, the opportunity cost of that land to the project will be zero. If labour has to be used differently in the project, the opportunity cost of that labour is not the wages paid, but the loss of the revenue which those workers would otherwise produce.

So, what a cost-benefit analysis entails is:

(1) Identify and quantify the resources needed for the project;

(2) Value these resources in terms of opportunity costs;

(3) Arrange them in a time-line and discount them according to the year in which they occur;

(4) Calculate the flow of expected revenues, set them in a time-line and discount them;

(5) Add all discounted revenues for all the years in which the effect of the project is likely to be felt, and subtract the discounted costs.

The result is the Net Present Value (NPV) of the project, i.e. the total of discounted revenues minus the total discounted cost. In principle, if the NPV is greater than zero, one could decide to undertake the project. Usually, however, an investor would demand that the NPV is high enough to offset his risk. The NPV is really the break-even point between profit and loss. An alternative yardstick for assessing the attractiveness of a proposed project is the Internal Rate of Return (IRR): the discount rate at which the NPV is zero. This can be used when the unknown variable is the discount rate: the entrepreneur is not sure what rate to apply. He can then consider whether the IRR of the investment is favourable compared to the inflation rate and the IRR of alternative investment opportunities.

2.2. Social cost-benefit analysis

Private cost-benefit analysis can also be used by a public agency. For instance, before undertaking a project, the government might want to know how much additional tax revenue would flow into its coffers as a result of the added economic growth which the project is supposed to cause. Or, if the project is, say, a railway, how much revenue could be realized from ticket sales on the new line. However, in doing so the government would really be addressing not an economic problem but a financial one: how to pay for the project. A project can be beneficial to society irrespective of whether the government can recoup its expenditure. The essence of social cost-benefit analysis (SCBA) is that it should state whether society as a whole, on balance, benefits.

Some SCBA practitioners see these benefits in terms of income and expenditure. The increase in gross domestic product (GDP) is an obvious one, but one may also measure, say, a positive impact on health as a decrease in medical costs or, more expansively, as the additional production gained from disability-adjusted years of life. In environmental economics, the impact of a project on the environment can be expressed as changes in the essential services provided to humans by ecosystems: oxygen and water, plant nutrients in the soil, climate regulation, sundry raw materials, genetic diversity, etc.[1]

However, there are also costs and benefits that cannot be directly converted into money or do not directly impinge on our physical survival. These are things that many people value, but which they do not buy in a market: a beautiful landscape, a rare species, employment (for its own sake, rather than just as a source of income), social equality or freedom. Since people are willing to sacrifice (i.e. incur costs) in order to keep or obtain these things, they may be included in a social cost-benefit analysis. We propose to call this extended SCBA, as distinct from 'simple' SCBA, where only strictly 'economic' costs and benefits are considered. We will recognize here the elements of sustainability: beside economic growth (profit), we should look at the effects on different groups in society (people) and on the environment (planet). If we are to add up these differential benefits and subtract the relevant costs, we need to try and find monetary values for them and apply weights expressing their respective social priorities.

There are different methods for doing so. One is contingent valuation: you ask people how much they value, say, an extra day off, access to a recreation facility (for which they do not have to buy a ticket) or an attractive landscape. You may ask them how much they would be willing to pay for such services if they had to. For impact on health, we may use the cost of medical services due to a predicted negative effect on health; or alternatively, disability-adjusted life years: the value of loss of health expressed in terms of what a worker would have produced if the health impact had not occurred. Policy-

[1] Costanza, R., d'Arge, R., De Groot, R., Farber, S., Grasso, M., Hannon, B., Limburg, K., Naeem, S., O'Neill, R.V., Paruelo, J., Raskin, R.G., Sutton P., Van den Belt, M., 1997. The value of the world's ecosystem services and natural capital, Nature, 387, pp. 253-260.

makers (or those who follow them critically) may also arbitrarily assign weights to such things as more jobs, or an improved position of women. Sometimes market values may also be used even where the effect one wants to measure is not a market product: an increase in greenhouse-gas emissions can be expressed in terms of what these emissions would cost on an emission-rights market.

A crucial issue in social cost-benefit analysis is the discount rate of which we spoke in the previous section. To a firm, it expresses the sacrifice made of forgoing immediate profits in the interest of higher profits later. In social cost-benefit analysis it expresses how much policy-makers care about future generations. If one is highly concerned about the long term, one would apply a low social discount rate, i.e. benefits in the future carry almost as much weight as benefits today. On the other hand, uncertainty about the future may induce policy-makers to use a higher rate: problems of today may be solved as has happened so often in the past,[2] or something else may happen which makes our efforts today fruitless anyway. Many governments use a standard social discount rate, and how high it should be is often a thorny issue. Social discount rates proposed and applied vary from 1-10%.[3]

There is another way in which SCBA differs (or ought to do so) from private cost-benefit analysis: the treatment of spill-over effects, or externalities as they are called by economists. A project may have unintended effects on its environment. These can be negative, such as pollution, or positive, such as providing training to a local workforce. These effects need not concern the planners of the project, as long as they do not have to pay for the negative effect nor extract any revenue from the positive one. In social cost-benefit analysis, however, these externalities are an essential part of the study.

In a feasibility study of proposed public policies which require certain behaviour on the part of the private sector, both private and social cost-benefit analyses are needed: the former for assessing the difference in income to a private actor following the policy as compared to what that actor would earn if he would not do so; hence, private cost-

---

[2] A well-known example is the concern over dwindling forests in England in the 16th and 17th century, wrongly ascribed to the use of vast quantities of charcoal for smelting iron ore. That resource was no longer needed once the coke-fired blast furnace came into use in the early 18th century. Today there is more forest cover in Britain than in the 19th century (cf. Saito, O., 2009. Forest history and the Great Divergence: China, Japan, and the West compared. Journal of Global History 4:3, 379-404).

[3] The Stern Review (Stern, N., 2006. The Economics of Climate Change, Cambridge University Press) uses a discount rate of 1.4%. More usual rates are quoted in Bos, E.J., 2007. Integrating Ecology in Social Cost-Benefit Analysis, Ph.D. dissertation, Shaker Publishing, Maastricht. For a comprehensive view on social discounting, see Harrison, M., 2010. Valuing the Future: the social discount rate in cost-benefit analysis, Visiting Researcher Paper, Australian Government, Productivity Commission, available at www.pc.gov.au/__data/assets/pdf_file/0012/96699/cost-benefit-discount.pdf.

benefit analysis can calculate the extent of incentives needed to make actors (in this case farmers) behave the way we want. The latter is needed to assess whether the cost of providing those incentives (whether sanctions or subsidies) is worthwhile.

2.3. A critical look at social cost-benefit analysis

The principal criticism that has been levelled at SCBA is that it attempts to put prices on things that cannot be priced.[4] Or, in James Cameron's words: "Not everything that can be counted counts, and not everything that counts can be counted."[5] Such critics reject that contingent valuation can give reliable information on the value of such things as biodiversity. More in particular, they claim that it leads to systematic under-valuation of public goods in general.[6]

A second criticism refers to the uncertainties in both costs and benefits. Climate change, for instance, will have large impacts on our future ability to produce food and energy, but we cannot say how large. Hence, we should avoid or diminish this risk at all cost.

Discounting also comes in for criticism. It is argued that we have an obligation to preserve natural resources for future generations, and we do not have the right to value, say, biodiversity in the future lower than today. Why should the welfare of a future generation count for less than the present one?[7]

These criticisms convince some that it is better to use other methods of ex-ante evaluation. Such methods typically use a number of different criteria, rather than attempting to reduce all considerations to a single number. Such methods include integrated impact assessment,[8] in which social, environmental and economic impacts

---

[4] E.g. Ackerman, F., Heinzerling, L., 2004. Priceless: On Knowing the Price of Everything and the Value of Nothing, The New Press, New York.

[5] Cameron, W.B., 1963. Informal Sociology: A Casual Introduction to Sociological Thinking, Random House, New York.

[6] Graves, P.E., 2003. Valuing public goods, Challenge: The Magazine of Economic Affairs, Vol. 46.

[7] A good discussion on the topic of social discounting can be found in Van Liedekerke, L., 2004. Discounting the Future: John Rawls and Derek Parfit's Critique of the Discount Rate, Ethical Perspectives 11:1, 72-83.

[8] European Commission, 2009. Impact Assessment Guidelines, SEC(2009) 92, available at http://ec.europa.eu/smart-regulation/impact/commission_guidelines/commission_guidelines_en.htm.

are considered independently; and multi-criteria analysis,[9] which is a formal method of operational research in which different criteria are explicitly recognized.

While the above critiques are certainly justified, it would be wrong to discard social cost-benefit analysis. People (including policy-makers) make choices all the time in which they implicitly compare costs and benefits, even though these calculations are often not recognized.[10] Applying formal SCBA helps in making the process of decision-making more transparent, by revealing the considerations made and the weights they are given. In doing so, it opens up the process for criticism, therewith providing an opportunity for improving it. SCBA should not, however, be regarded as an objective process.

A real danger in applying SCBA is that its outcome is taken at face value, without studying the assumptions and subjective valuations that have been used in the process. Where there is great doubt concerning the impacts, how they can be valued and compared, it may be better to use SCBA only for those aspects of an impact assessment where there is some confidence on the quantities and values involved. SCBA then becomes one part of an impact assessment process.

One important (and contested) premise in SCBA is that one good may be substituted for another one. By expressing values in terms of prices, we may decide how much of one good is equivalent to how much of another one. That notion may be rejected for some values, such as freedom or biodiversity, as we may refuse to entertain any notion that these would be diminished (even though our actual behaviour may reveal that we do put a price on them). In such situations, a helpful notion can be the distinction between 'strong' and 'weak' sustainability – where we see sustainability in general as a goal of any proposed action.[11] Strong sustainability refers to such absolute values as mentioned above, on which no price can be put. Weak sustainability refers to those aspects where substitutability applies. Looking at environmental concerns, we may cast such things as clean air and biodiversity into the former category; the depletion of fossil fuel sources falls under weak sustainability, as we can in principle replace them by other sources of energy. In this way, concerns of strong sustainability can impose conditions on the solutions we are seeking: we set out minimum standards that any solution must be capable of achieving. In this way, we create a 'sustainability space', within which we

---

[9] Department for Communities and Local Government, 2009. Multi-criteria analysis: a manual, London, available at www.communities.gov.uk.

[10] Even the value of human life is included in cost-benefit calculations, although the calculators will deny that they do so. An example is given in Lomborg, B., 2013. Introduction, in Lomborg, B., (Ed.), Global problems, smart solutions.Costs and benefits, Cambridge University Press, pp. 1-18.

[11] Ayres, R.U., Van den Bergh, J.C.J.M., Gowdy, J.M., 1998. Viewpoint: Weak versus Strong Sustainability, Tinbergen Institute Discussion Papers, 98-103/3, Amsterdam.

can seek optimum solutions on the basis of maximum efficiency. Inside that space, we can apply SCBA with less controversy.

3. A COST-BENEFIT ANALYSIS OF LEGUMES

This chapter begins with the identification of the various effects of legumes in farming systems, the negative as well as the positive ones. This is done in section 3.1, which is mainly based on a study conducted by the Legume Futures consortium for the European Parliament.[12] Next, these effects must be quantified, which is done in sections 3.2 through 3.5 for the main types of impact.

The remainder of the chapter is dedicated to the valuation of said effects, with special attention to establishing an appropriate discount rate, to a suitable price for greenhouse-gas emissions, and to the environmental impact of nitrogen excess. The final section presents the outcome of the analysis.

3.1. Identifying the benefits and costs

3.1.1. Benefits

The primary benefit of growing legumes is that they can fix nitrogen in the soil – or rather, that they act as hosts to *Rhizobia* bacteria which do this. Among higher plants, legumes can virtually be equated with biological nitrogen fixation: there are some species of legumes which do not have this propensity as well as some non-legumes that do, but neither group contains any species that are important in agriculture.

From biological nitrogen fixation flow other benefits: the need to apply nitrogen through chemical fertiliser is eliminated or strongly reduced, and because of the nitrogen left in the soil there is also less need of nitrogen fertilisation for the succeeding crop. The reduced application of nitrogen fertiliser – to the extent that chemical fertilisers are used rather than organic manure – means a reduction in greenhouse gases, a saving in the consumption of fossil energy, and a reduction of air pollution from the production of said chemical fertilisers. Since fossil energy is mostly imported, there is an additional benefit in that it decreases energy dependence.

Less nitrogen fertiliser also leads to less excess nitrogen on farmland. This excess nitrogen occurs in various compounds, most importantly as nitrous oxide (N_2O), which is a potent greenhouse gas, and nitrate in groundwater, which eventually ends up as a

[12] Bues, A., Preiβel, S. Reckling, M., Zander, P., Kuhlman, T., Topp, K., Watson, C., Lindström, K., Stoddard, F.L., Murphy-Bokern, D., 2013. The environmental role of legumes in the new Common Agricultural Policy. European Parliament, Brussels, Policy Department B: Structural and Cohesion Policies, document IP/B/AGRI/IC/2012-067.

nutrient in surface water where it causes eutrophication. That in turn can lead to disturbances in natural ecosystems with the attendant consequences for biodiversity. Nitrate in drinking water also has adverse effects on human health. Furthermore, nitrous oxide, in addition to its role in climate change, is also an important factor in the depletion of the stratospheric ozone layer.[13]

There are two other impacts of nitrogen that need to be considered: ammonia (NH_3) and nitrogen oxides (NO and NO_2, collectively known as NO_x). Both are gases emitted into the atmosphere, and both cause damage to forests and other natural habitats (acid rain). Also, both have adverse effects on human health, on stone (monuments) and on steel (cars, bridges). We include the effect of NO_x in the impact of fertiliser production, but not in other aspects of agriculture: although these oxides are produced as a result of the operation of tractors and farm machinery, these are not substantially different in systems with and without legumes. As for NH_3 emissions from farming, these are mostly caused by animal manure, but also chemical fertilisers can lead to NH_3 losses. This is mainly a problem with urea, particularly under no-till systems when it remains on the surface.[14] Hence, legumes may also lead to some abatement of NH_3 emissions.

On the other hand, it must be noted that legumes do not always lead to less nitrogen surplus. Because the crop itself has a low C:N ratio, residues left on the land (for instance as green manure) contain much nitrogen, some of which will be emitted into the atmosphere as N_2O and a large fraction will be leached as nitrate into the groundwater.[15] This latter effect in particular is perhaps the main environmental downside of legumes.[16]

The study by Bues et al. (2013) also mentions some additional benefits of legumes, outside the changes in nitrogen balance:[17]

- They mobilize phosphate reserves in the soil, leading to lower phosphate need for the succeeding crop;

---

[13] Ravishankara, A.R., Daniel, J.S., Portmann, R.W., 2009. Nitrous Oxide (N_2O): The Dominant Ozone-Depleting Substance Emitted in the 21st Century, Science, 326:5949, pp. 123-125.

[14] Mikkelsen, R., 2009. Ammonia Emissions from Agricultural Operations: Fertilizer, Better Crops, 93:4, pp. 9-11.

[15] Williams, M., Stout, J., Crass, S., Fischer, J., Böhm, H., Murphy-Bokern, D., Kuhlman, T., Stoddard, F.L., Lindström, K., Watson, C., Pappa, V., Topp, K., Reckling, M., Preiβel, S., Bues, A., Zander, P., 2014. Policy implications of the environmental effects of legume cropping. Legume Futures Report 3.8. Available from www.legumefutures.de.

[16] Geoff Squire, in a presentation to the Legume Futures Stakeholders' Workshop, Edinburgh, 22 January 2014.

[17] Some of these effects are not due to the legumes as such, but due to the recommended practice of growing legumes in a crop rotation system.

- They increase the organic matter content of soils, leading to lower soil erosion, increased water retention capacity, and higher storage of carbon in the soil;
- By increasing the agro-biodiversity and by the increase in soil organic matter, overall above- and below-ground biodiversity (including pollinating insects) is enhanced;
- Due to rotation, less pesticides needed in the cropping system, leading to less water pollution and supporting biodiversity.

Furthermore, legumes grown in Europe (including soybean) substitute for imported soya. This can bring considerable benefits, especially where soya imports are hampered by GMO regulations (see Legume Futures Report 4.5): not only a higher degree of food self-sufficiency, but also less pressure on global land use since soya cultivation in Argentina and Brazil occurs directly or indirectly at the expense of natural areas.[18]

3.1.2. Costs

However, legume cultivation also incurs costs, and these are borne by farmers. Although there are cases where legumes are grown profitably, in general the area under legumes is low (except in organic farming), because the revenue from legumes tends to be lower than that for competing crops. There are several reasons for this:

- The yield of grain legumes is lower than that of most cereals. This is not an accidental but a fundamental characteristic of legumes: their high protein content means that less of their energy can be dedicated to carbohydrates and biomass in general.
- Not only is the yield lower, but it is also more variable. This is due to the high incidence of diseases, vulnerability to weather conditions, and the fact that legumes do not compete easily with weeds. Forage legumes, although they have a high protein content, yield less energy than fertilised grass.
- Many farmers are unfamiliar with the management of legumes, which has happened as a result of the decline in these crops: much knowledge has been lost. Moreover, farmers often have little confidence that legumes can do well.
- For the same reasonss, there is in many cases a lack of suitable cultivars, and also a lack of markets at reasonable distance.

It will be understood that some of these drawbacks are not immutable. After all, as we have seen above, the decrease in legume cultivation is at least partially a result of EU policies favouring cereals over legumes. The lower yields of legumes are also partially

[18] Fearnside, P.M., 2001. Soybean cultivation as a threat to the environment in Brazil, Environmental Conservation 28 (1), 23–38.

caused by these policies: yields have grown far less for legumes than for wheat (Figure 1), which is probably due to lower incentives for increasing legume productivity.

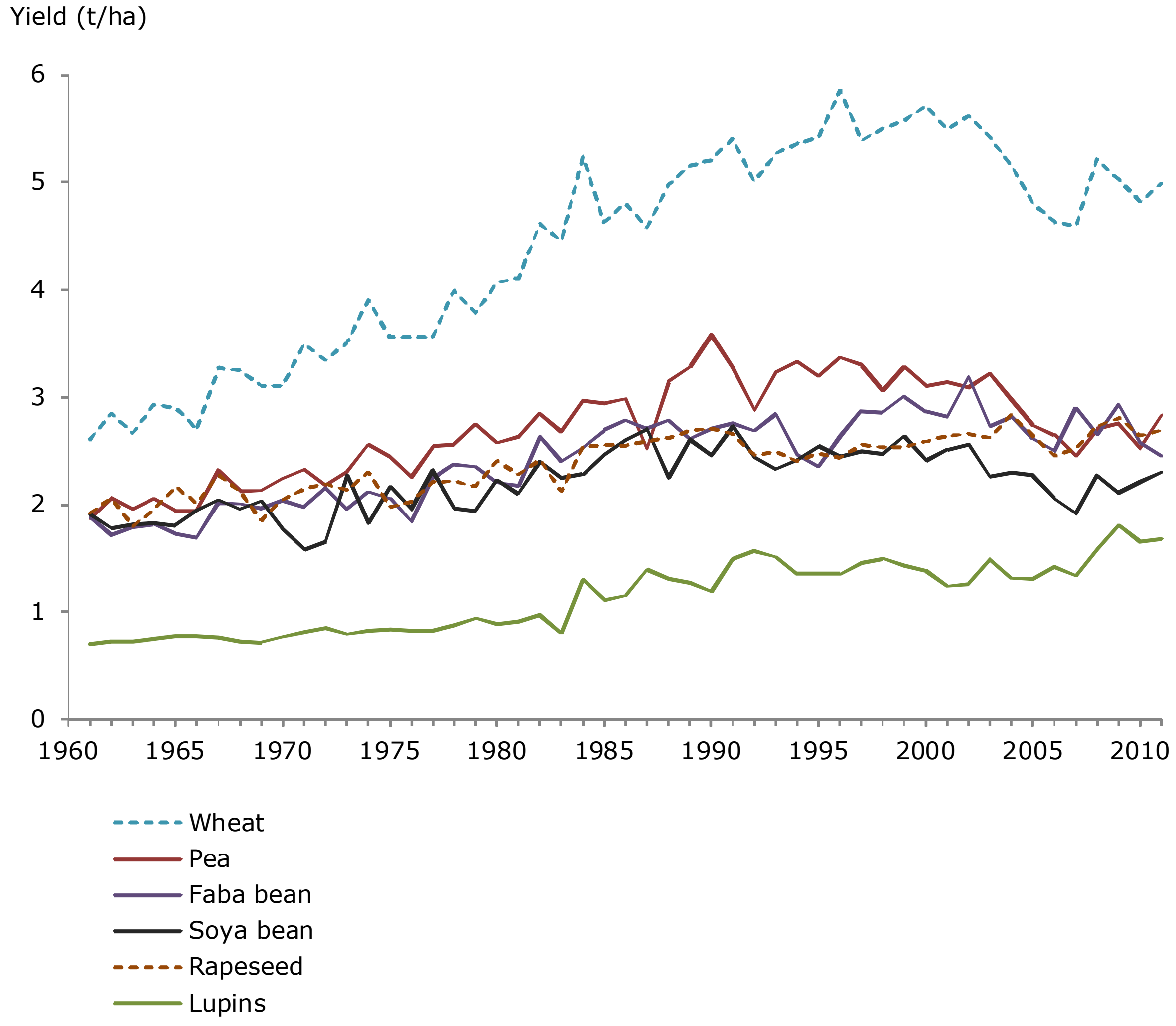

Figure 1. Average yields of wheat and main grain legumes across the EU-27

3.2. Quantifying the costs and benefits

The impact of a particular scenario, such as those described in Legume Futures Report 4.5, can be complex, as changes in legume cultivation may have effects on animal production and on trade in vegetable proteins. In this section, however, we are concerned only with the direct effects of cultivating legumes, per hectare. These effects are in principle also quantified by the model CAPRI used in D4.5, but some of them are not and others need to be further refined.

We shall assume two different situations: one for the incorporation of grain legumes into an arable rotation cycle, and one where forage legumes are intersown with grass. For grain legumes, we suppose a rotation system where pulses are grown once every four years and wheat the rest of the time, as compared to wheat alone. For forage, we use the same scenario as in Legume Futures Report 4.5: clover on 25% of grassland and forage crops combined, compared with non-leguminous forage crops and fertilised grassland. In the present section we shall only quantify the environmental impact of legumes, not the economic one. This is because the latter can be directly converted into money units (i.e. gross margin at farm level), whereas the former cannot.

3.2.1. Reduction of greenhouse-gas emissions

According to the CAPRI database (see Table 2 in Legume Futures Report 4.5), pulses use 12 kgs of nitrogen from chemical fertilisers per hectare, as compared to 123 for soft wheat. For the year in which the legumes are grown, this represents a saving of 111 kg N. In addition there is the saving of N fertiliser for the succeeding crop. Figures for this vary wildly, but we may use a conservative figure of 30 $kg.ha^{-1}$ for the first year.[19] For the second year we shall assume a saving of 10 $kg.ha^{-1}$, and no saving for the third. This means a total saving over the four-year cycle of 151 $kg.ha^{-1}$, or an average of 38 kgs per year.

Concerning grassland, an average of 98 $kg.ha^{-1}$ of N is applied on intensive grassland and 42 kgs on extensive pasture. If the percentage of clover is increased from 5.2% (presently) to 25% under the clover scenario, this will cause the amount of nitrogen applied to be reduced by 24.3 kgs on intensive and 10.4 kgs on extensive grassland.[20]

Assessing how much this means in terms of greenhouse-gas emissions requires a technical digression. Nitrogen in chemical fertilisers is mostly in the form of either ammonium nitrate or urea, or a combination of both. All use ammonia as a raw material. The production of ammonia involves large carbon dioxide emissions: 2.2 kg per kg of N under the modern steam-reforming process for extracting hydrogen from natural gas. Alternative technologies for obtaining hydrogen produce even larger emissions: 2.7-2.8

[19] Kirkegaard, J., Christen, O., Krupinsky, J., Layzell, D., 2008. Break crop benefits in temperate wheat production. Review. Field Crops Research 107, 185–195.

[20] Figures calculated from the CAPRI database, supposing that the additional clover itself does not need any N fertiliser; that 25% of this saving can be added for the surplus nitrogen brought into the soil through the clover; and that these savings can be deducted from mineral fertiliser rather than from manure (which accounts for slightly over half the total N added to the soil).

kg.[21] 2.33 kg is mentioned as an average figure for Europe, and this is the figure we shall use.[22]

Ammonium nitrate is made from ammonia and nitric acid. The manufacture of that compound does not produce carbon dioxide, but it does have nitrous oxide (N_2O) as a by-product. That is a much more potent greenhouse gas than carbon dioxide, and its emissions from nitric acid production amount to 9 kg CO_{2e} (carbon dioxide equivalents) per kg N. This can be reduced to 2.5 kg with non-selective catalytic reduction (NCSR) technology. However, only a small minority of plants use this technique.[23] An estimate from the fertiliser industry is much lower: 6-8 kgs of N_2O per tonne of acid.[24] This is equivalent to 1.3-1.8 g of N_2O per kg N, which means 410-550 g $CO_{2\text{-}e}$ per kg N. Considering that, on the one hand, the aforementioned figures are gleaned from several sources, but, on the other hand, they are rather old and progress may have been made, we shall assume a figure of 5 kg CO_{2e} per kg N as a total for the production of ammonium nitrate, incorporating both ammonia and nitric acid.

The other principal N fertiliser compound, urea, makes up 15% of the total quantity, according to the CAPRI database. This produces lower emissions, because the CO_2 from ammonia production is partially reused. Hence net emissions here are much lower: 900-1700 g per kg N. Although ammonium nitrate and urea are the most important forms of N fertiliser, there are two others of some importance, namely calcium ammonium nitrate (CAN) and urea ammonium nitrate (UAN). Their greenhouse-gas emissions are estimated at, respectively, 3-9.5 kg and 2-4 kg CO_{2e} per kg N, again depending on the technology.[25] If we take the means of the three forms mentioned last and we assume shares in total N fertillizer use of 15% for urea, 65% for ammonium nitrate, 15% for UAN and 5% for CAN, we arrive at a rough estimate of 4.2 kg CO_{2e} per kg of N. This is a somewhat conservative figure, as Wood & Cowie in their review study give estimates for Germany (dating from the late 1990s) of 5.3-7.6 kg. The two main types of N fertiliser and their environmental effects are shown in Figure 2.

---

[21] UN Industrial Development Organization/International Fertilizer Development Centre, 1998. Fertilizer Manual, Kluwer Academic Publishers, Dordrecht, Netherlands, p. 515.

[22] Kongshaug, G. 1998. Energy Consumption and Greenhouse Gas Emissions in Fertilizer Production. IFA Technical Conference, Marrakech, Morocco, 28 September-1 October, 1998; quoted by Wood, S., Cowie, A., 2004. A Review of Greenhouse Gas Emission Factors for Fertiliser Production, Research and Development Division, State Forests of New South Wales, p. 8.

[23] Kongshaug 1998, op. cit.

[24] International Fertilizer Association: http://www.fertilizer.org/ifa/HomePage/SUSTAINABILITY/Climate-change/Emissions-from-production.html.

[25] Kongshaug 1998, op. cit.

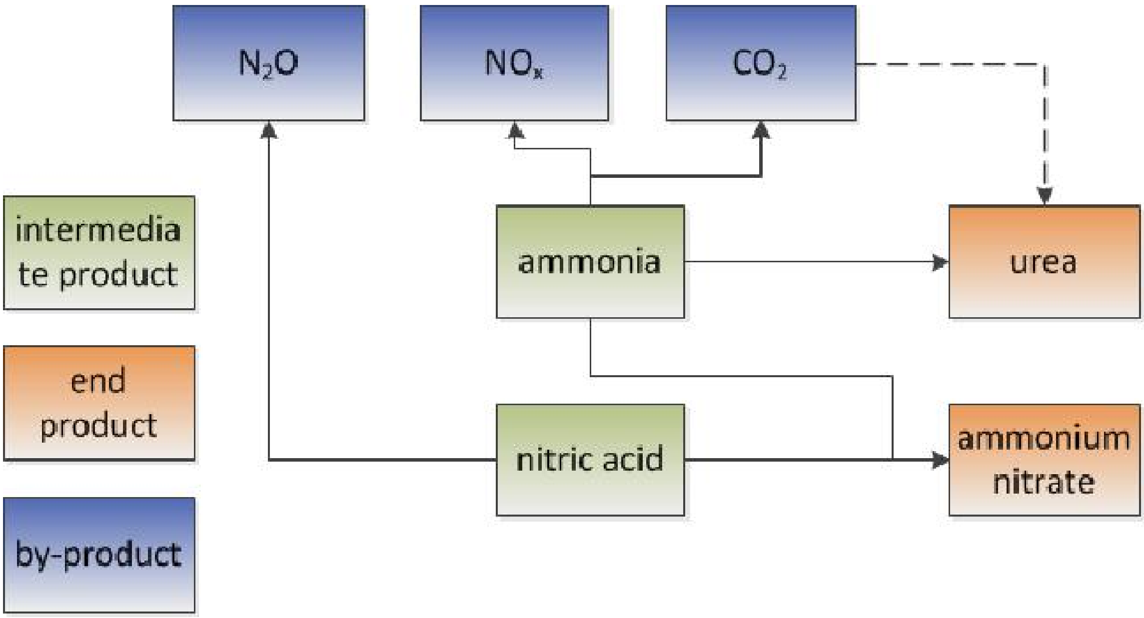

Figure 2. Environmental effects of N fertiliser

Armed with this estimate, we may conclude that the reduced amount of mineral N fertilisers in legume systems leads to a reduction in greenhouse-gas emissions of 159 kg $CO_{2e}.ha^{-1}.yr^{-1}$ for grain legumes in rotation with wheat in a four-year cycle, as compared to a wheat monoculture. For forage legumes, the reduction in emissions is estimated at 74 kg.$CO_{2e}.ha^{-1}.yr^{-1}$ in comparison with fertilised pure-grass stands.

In addition to the lower greenhouse-gas emissions from using less N fertiliser, N_2O emissions from the field are also reduced. According to CAPRI, soft wheat produces an average of 2.71 kg.ha^{-1} of N_2O, including both direct emissions from fertiliser application and crop residues, as well as indirect ones from ammonia and leached nitrates. For pulses this figure is only 0.53 kg.ha^{-1}, a saving of 2.18; that is equivalent to 650 kg CO_{2e}, or 163 kg.$ha^{-1}yr^{-1}$ over our four-year cycle.[26] Apparently the greenhouse effect of nitrous oxide is slightly larger than that of N fertiliser production. We must remember that 1 kg N contained in nitrous oxide produces no less than 465 kg CO_{2e}, whereas the production of N fertiliser produces only 4.2 kg of CO_2 per kg N.

For forage legumes, replacing fertilised pure grass stands with unfertilised or modestly fertilised stands of grass with a 25% share of forage legumes would result in a significant reduction of N application, through inorganic fertiliizers or manure.

[26] This is related to the emission factor for N2O emissions, i.e. the proportion of nitrogen added to the soil which is emitted as N2O. That factor is taken by IPCC as 1.25% for mineral fertiliser. For biological nitrogen fixation, it is estimated by Legume Futures at an average of 0.11% (Williams et al. 2014, op. cit., p. 11).

Considering that a large share of the nitrogen applied on grassland is supplied by anumal manure, we estimate a reduction of 24 $kg.ha^{-1}$ of N on intensive grassland and 11 kg on extensive pasture, meaning savings in greenhouse gases of 85 and 36 kg $CO_{2e}.ha^{-1}$ respectively. The savings in N_2O emissions from forage legumes are highly uncertain,[27] but we shall assume that they are similar to those for grain legumes. Hence, for an increase in the share of clover from 5% to 25% we arrive at savings of 0.35 $kg.ha^{-1}$ of N on intensive and 0.06 kg on extensive grassland, equivalent to, respectively, 105 and 19 kg CO_{2e}.

A third factor in the greenhouse effect is the carbon sequestration under legumes. Quantitative data on this are scarce, but a study over a 15-year period showed that, where N was derived from legumes rather than inorganic fertiliser, soil organic carbon eventually was 750 $g.m^{-2}$ higher – or 7.5 $t.ha^{-1}$.[28] Similar results were obtained in a large-scale survey in France: 10 t.ha-1 over a 20-year period.[29] This is equivalent to 1.83 $t.CO_2.ha^{-1}.yr^{-1}$, however the effect is cumulative: low in the initial years and gradually rising. For our test case of pulses once every four years as compared to wheat alone, it would amount to 460 $kg.ha^{-1}.yr^{-1}$, and for clover in grassland the effect would be about the same. Thus, C sequestration may have the largest effect on the reduction of greenhouse gas emissions – although only when legumes are included in cropping-plans for an extended period of time.

Total reduction in global warming potential from all three sources (saving in N fertiliser, reduction of N_2O emissions, and increased C sequestration) then comes to 1975 $kg.CO_{2e}.ha^{-1}.yr^{-1}$ for our wheat-and-pulses rotation and 1347 kg for the grass-and-clover pasture (taking the average of intensive and extensive grassland; respectively compared to wheat monoculture and pure-grass swards. The figures are presented in Table 1.

---

[27] Crews, T.E., Peoples, M.B., 2004. Legume versus fertilizer sources of nitrogen: ecological tradeoffs and human needs, Agriculture, Ecosystems and Environment, 102, 279–297.
[28] Drinkwater, L.E., Wagoner, P., Sarrantonio, M., 1998. Legume-based cropping systems have reduced carbon and nitrogen losses, Nature 396, 262-265.
[29] Jensen, E.S., Peoples, M.B., Boddey, R.M., Gresshoff, P.M., Hauggaard-Nielsen, H., Alves, B.J.R., Morrison, M.J., 2011. Legumes for mitigation of climate change and the provision of feedstock for biofuels and biorefineries. A review, Agron. Sustain. Dev., 32:2, 329-364.

Table 1. Greenhouse gas emissions under different regimes

	all figures in kg.ha^{-1}						
cropping/forage system	**N fertiliser (inorganic)**	**GHG emissions from fertiliser in CO_{2e}**	**N_2O emissions**	**N_2O expressed as CO_{2e}**	**additional C sequest-ration**	**SOC expressed as CO_{2e}**	**total GHG effect of legumes (CO_{2e})**
wheat	123	517	2.71	808			
pulses	12	50	0.53	158	1,833	6,722	
rotation *	85	357	2.17	645	458	1,681	
reduction in GHG		160		163		1,681	2,004
grass (permanent, intensive)	46	193	2.30	685			
grass with 25% clover	22	92	1.95	580	367	1,344	
grass, extensive	20	84	0.85	253			
grass, extensive with 25% clover	9	38	0.79	234	183	672	
reduction in GHG, average		74		62		1,008	1,144

* Rotation scheme, first one year pulses and then three years wheat. Including the N-fertiliser reduction of succeeding crops.

3.2.2. Reduction of eutrophication and pollution through reactive nitrogen

As mentioned in section 3.1.1, nitrate leaching can be a problem in legume systems. Although leaching during growing legumes is low (as long as the application of N fertiliser is appropriate), crop residues can cause increased leaching – higher even than when no legumes are grown. In New Zealand, leaching under white clover (pure stand) was found to be 10 kg.ha^{-1} (compared to 5 kg on lightly grazed pasture), and under peas it was no less than 90 kg.ha^{-1} (compared to 60 kg under wheat).[30] However, pure stands of clover cannot really be compared with clover in a grass sward. If the comparison is between fertilised pure grass and unfertilised grass with clover as a source of nitrogen, then one would expect less N leaching in the latter case. This was indeed found to be the case in the UK: 55 kg N under conventional management, 16 kg under a grass-clover mixture.[31]

---

[30] Adams Pattinson, J.A., Pattinson, J.M., 1985. Nitrate leaching losses under a legume-based crop rotation in Central Canterbury, New Zealand. New Zealand Journal of Agricultural Research, 28:1, 101-107. The research was conducted on deep löss soils with varying drainage conditions.
[31] Jarvis, S.C., 2000. Progress in studies of nitrate leaching from grassland soils. Soil Use and Management, 16, 152-56.

This points to a possibility to reduce nitrate leaching under legumes: intercropping. Indeed, in the Legume Futures project it was found that intercropping faba bean with oat during the winter season (when seepage takes place) reduced leaching from 41 $kg.ha^{-1}$ of N_r (reactive nitrogen, in this case in the form of NO_3) to 16 kg.[32]

For the purpose of this analysis, we shall assume two variants: one in which the net effect of legumes on leaching is 30 $kg.ha^{-1}$ of N_r above that of wheat, i.e. an average of 7.5 kg per year for a four-year rotation; and another where a saving of 7 kg $N.ha^{-1}$ is assumed.[33] This is for grain legumes. for forage legumes, we shall assume a saving of 39 $kg.ha^{-1}$ based on the above-quoted figure.

For NH_3 emissions, we have not been able to find any data that can serve as average quantities for arable land under legumes or non-legume crops – only that the magnitudes are highly variable.[34] In the absence of data, we shall assume provisionally that 10% of fertiliser applied is lost in the form of NH_3. Growing legumes then means a saving of 11 kg N for the year in which they are grown, and no saving in the succeeding year, i.e. 5.5 kg.ha-1.yr-1 for a two-year cycle. This is equivalent to 13.5 kg NH_3.

That is the situation for grain legumes. Forage legumes lead to larger savings. How high these are depends heavily, like many of the quantities we talk about, on soil conditions, fertilisation levels and drainage.

3.2.3. Other environmental effects of legumes

Soil erosion: The increase in soil organic matter, noted in section 3.2.1, also leads to lower soil erosion – both wind and water erosion. This is because organic matter acts as a binding force for soil particles and because it increases water infiltration, therewith reducing surface runoff; the improved water retention capability of the soil, by the way, is an additional benefit of soil organic matter.

Quantification of this effect is tenuous, however: the extent of soil erosion differs enormously from one location to another and depends on many factors besides soil organic matter. The latter is one component of the factor soil erodibility, which is one of five factors in the Revised Universal Soil Loss Equation.[35]

Phosphorus mobilisation: An Australian study found that wheat grown without phosphate fertiliser after faba bean produced 41% more dry mass than without a

---

[32] Williams et al., 2014, op. cit., p. 13.
[33] Crews, T.E., Peoples, M.B., 2004. Legume versus fertilizer sources of nitrogen: ecological tradeoffs and human needs, Agriculture, Ecosystems and Environment, 102, 279–297, p. 283.
[34] European Environment Agency, 1999. Emission Inventory Guidebook, Copenhagen.
[35] Cf., for instance, http://35.8.121.139/rusle/kfactor.htm

preceding legume crop.[36] This was due to P mobilised by the legume. It is difficult to generalize this figure, but as a rough guess it should save some 10 $kg.ha^{-1}$ for the three years of wheat succeeding the legume crop, or 3.3 $kg.ha^{-1}.year^{-1}$. This is equivalent to 7.6 kg of P_2O_5, a common form of phosphate fertiliser. As regards forage, given that – under the relevant scenario - we increase the percentage of clover in grassland from 5 at present to 25, we assume a saving of 6 $kg.ha^{-1}$ for intensive and 3 kg for extensive grassland.

Biodiversity: Field studies and literature review undertaken during the Legume Futures project suggests that legume-supported cropping systems can have a negative as well as positive impact on invertebrate biodiversity, both above- and below-ground. The impact is generally positive, however. Quantification is virtually impossible, because of the problem of an appropriate index for overall biodiversity. As for floral biodiversity, field surveys showed 133 different species of vascular plants in legume-supported treatments, as compared to 107 for cropping-plans without legumes.[37]

Then there is the effect that a crop rotation involving legumes needs **less pesticides** than a monoculture of wheat. This is not so much an effect of legumes themselves as of the fact that rotation tends to reduce the incidence of pests, as the buildup in the soil of pests adapted to a particular crop is interrupted. We shall abstain from attempts to quantify this effect which is highly dependent on local conditions and crop management, but it needs to be considered when balancing the costs and benefits of legumes.

Finally, the saving on nitrogen fertiliser achieved by growing legumes also decreases the emission of **noxious gases** (other than greenhouse gases) during the process of fertiliser manufacturing. These include nitrogen dioxide and sulphur dioxide. However, these emissions are quite small: less than 1 kg of NO_2 and 0.2 kg of SO_2 per tonne of ammonia under the most common and most modern (steam reforming) process of ammonia manufacturing; under the older process of partial oxidation of fuel and coal oxidation emissions are higher but still modest: 1.8 kg of NO_2 and 3 kg of SO_2 per tonne of ammonia. More NO_2 emissions are produced by nitric acid manufacturing, another component of N fertiliser: 6-9 kg per tonne of nitrogen.[38] Converting ammonia into nitrogen and combining these figures, we can estimate the total emission of NO_x (i.e.

---

[36] Nuruzzaman, M., Lambers, H., Bolland, M.D.A., Veneklaas, E.J., 2005. Phosphorus uptake by grain legumes and subsequently grown wheat at different levels of residual phosphorus fertiliser. Austr. J. Agricult. Res. 56, 1041-1047.

[37] Cass, S.L., Williams, M., Stout, J., 2014. Influence of legume-supported cropping systems on floral biodiversity – initial findings of the Legume Futures pan-European study. Unpublished paper, Legume Futures project.

[38] Fertilizer Manual, op. cit., p. 513-14.

nitrogen monoxide and nitrogen dioxide) from N fertiliser manufacturing at 5 kg N_r per tonne of N. We shall disregard SO_2 emissions.

Figure 3 summarizes the quantifiable environmental effects of legume-supported cropping and forage systems.

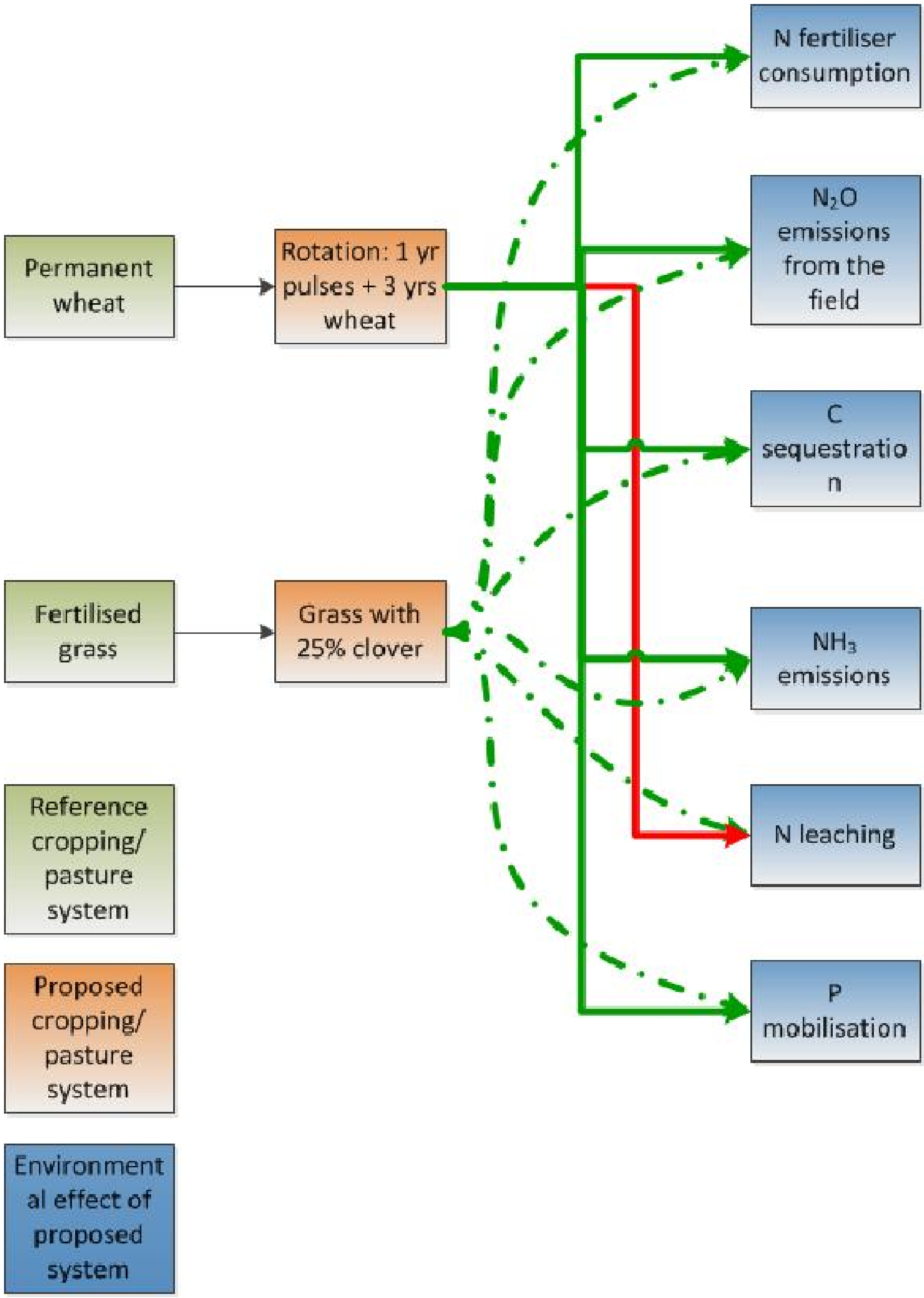

Figure 3. Quantifiable environmental effects of legumes

3.3. Valuation of costs and benefits

3.3.1. Climate change mitigation

Our task here is to set a shadow price for greenhouse-gas emissions, i.e. a price that reflects the damage done by these emissions, now and in the future. It will be understood that, since much of this damage takes place over a long period, the price is critically affected by the discount rate applied. One option could be to take the market price. The EU Emissions Trading Scheme is the largest market for emission rights in the world. However, it has been plagued by numerous problems: primarily over-allocation of free credits which reduced the need for companies to buy additional emission rights,[39] but also fraud.[40] The price reached a peak of €30 per tonne of CO_2 equivalents in 2006, but then fell to almost zero in 2007. It recovered in 2008 but then fell again in succeeding years, and in late 2013 it was just below €5. Several other countries have introduced or are considering emission-trading schemes (China, some states in the U.S., Australia and New Zealand). Prices there range from €4-10, with the (proposed but now defunct) Australian scheme projecting a fixed price of €16.60.

It is widely believed that all of these prices are below what is required to offset the damage from greenhouse gases. The IMF, for instance, considers $25 per tonne (or €18) to be an appropriate price.[41] What the right price should be depends to a large extent on one's views regarding the importance of climate change, and on whether mitigating climate change should purely consider its probable impact on future income or also on such harder-to-price values like biodiversity. We shall use the IMF price as one alternative in our analysis, based on a more conservative view of how much should be invested in mitigating climate change.

A more radical view is expressed in the Stern Review,[42] which estimates the social cost of carbon at $85 per tonne of CO_2. Using the exchange rate of 2007 and average inflation rates in the EU over 2006-2013, this means €72 in today's money. We shall use that price as the other alternative, based on the idea that climate change is a very serious threat and that large sacrifices in income are justified to counteract it. Actually,

---

[39] The Economist, 20 April 2013. ETS, RIP?

[40] Dutch Emissions Authority, 2011. Study report: Risks of fraud in the emissions trading system, available at https://www.emissieautoriteit.nl.

[41] Litterman, B., 2013. What Is the Right Price for Carbon Emissions? Energy & Environment, Summer 2013, pp. 38-43.

[42] Op. cit., see note 3.

Stern argues that we need to sacrifice about 1% of GDP annually to avoid losses of 5% later on.

3.3.2. The value of reactive nitrogen

In this section we attempt to determine the social value of reducing the amount of excess nitrogen leaching (in the form of nitrates) and emissions (in the form of NH_3 and NO_x), as described in section 3.1.1 and quantified in section 3.2.2. We may call this reactive nitrogen, or N_r. Nitrogen is, of course, an essential element for all organisms, and hence has major benefits as well as negative effects. Here we assume that the benefits accrue to the farmers applying nitrogen in their fields. Against these benefits stands the cost of the chemical or organic fertiliser, which is also paid by the farmer. For the social cost-benefit analysis we only need to take into account the negative environmental effect of an excess of nitrogen caused by the application of fertiliser. The benefit of legumes consists in the mitigation of this negative effect.

The estimates here are primarily based on the European Nitrogen Assessment of 2011.[43] We can divide the negative effects into two main categories, namely those on the functioning of ecosystems (and the services these provide) and the effects on human health. The value of ecosystem services is sometimes calculated on the basis of restoration costs, and sometimes through contingent valuation (see section 2.2 of this report). Restoration costs for Europe have been estimated at an average of €3.0.kg^{-1} for eutrophication and €2.7 for air pollution through ammonia and NO_x (converted into prices of 2013).[44] Contingency valuation tends to arrive at higher values, but the methodological problems of this method (see section 2.3) lead us to prefer restoration cost as a basis.

3.3.3. Non-nitrogen effects of legumes

Starting with the impact on soil erosion (a by-product of a higher content in soil organic matter, as we saw in section 3.2.3): although we refrained from attempting to quantify the extent of soil erosion in Europe, a very rough estimate has been made of the cost of soil erosion in 2005: just over €5,000 million for the EU-25, including both on-site and off-site effects but excluding the greenhouse effect.[45] If we assume (even more roughly) that widespread adoption of legumes in crop rotations could reduce this figure by 1%, then we have an aggregate benefit of €50m from this effect alone.

---

[43] Brink, C., Grinsven, H. van, 2011. Costs and benefits of nitrogen in the environment, in: Sutton, M.A., Howard, C.M., Erisman, J.W., Billen, G., Bleeker, A., Grennfelt, P., Grinsven, H. van, Grizzetti, B. (Eds.), The European Nitrogen Assessment, Cambridge University Press, Ch. 22, pp. 513-540.

[44] Brink et al., op. cit., p. 520.

[45] Kuhlman, T., Reinhard, S., Gaaff, A., 2010. Estimating the costs and benefits of soil conservation in Europe, Land Use Policy, 27, 22-32.

The phosphorus mobilisation effect can be valued at the price of P fertiliser, which in early 2014 costs about €376 per tonne of P_2O_5.[46]

We refrain from pricing the biodiversity effects and the effect on pesticide use (these two effects overlap, of course), since we cannot even quantify these.

3.3.4. Economic effects at farm level

In the study on protein crops for the European Parliament, it was estimated that, based on figures from France and the Netherlands, gross margins for grain legumes were on average €344.ha^{-1} lower than for wheat. In our standard rotation, this would translate to €86.ha^{-1}.yr^{-1}. However, that figure does not include the pre-crop effect (the higher yield of the succeeding wheat crop thanks to the legume grown before). In a survey of regions in six countries, rotations with legumes were found to be on average €24.ha^{-1} lower than cropping-plans without them, with a range from -€181 to a benefit of +€7.[47] This includes pre-crop effects. Since then, results obtained by modelling have become available for the case-study regions in Legume Futures (in Sweden, Germany, Italy, Scotland and Romania).[48] It is not easy to derive an average from these results, but the figure of -€24 appears to be slightly optimistic. We shall assume a round figure of -€50.ha^{-1}.yr^{-1}, but it has to be kept in mind that the range is very large.

For the grass-clover mixture, gross margins are estimated to be €400 per hectare lower on average.[49]

3.3.5. A note on the social discount rate

As we have seen, the discount rate to be used in SCBA has a critical effect on the outcome, particularly when we consider the long term. It is therefore important to decide what the rate should be. This a hotly debated issue in welfare economics. As already alluded to in Chapter 2, in long-term analysis it is not only the difference in welfare between consumption today and future consumption that counts: the discount rate expresses also the degree to which we care for future generations. It has even been argued that the rate should be zero, because we do not have the right to deprive future generations of the natural resources we have today. Against that, however, it should be considered that future generations also inherit the accumulated investments and welfare

---

[46] Information downloaded from http://www.gbminerals.com/phosphate/phosphate_prices/ and converted into euros and into P_2O_5.
[47] Bues et al., op. cit., pp. 87-89.
[48] Schläfke, N., Zander, P., Reckling, M., Hecker, J.-M., Bachinger, J., 2014. Legume Futures Report 4.3; Agronomic analysis of cropping strategies.
[49] Helming, J., Kuhlman, T., Linderhof, V., Oudendag, D., 2014. Legume Futures Report 4: Impacts of legume scenarios (Legume Futures Deliverable 4.5), p. 66.

growth that have been achieved in the past. Furthermore, there is the possibility that these future generations will not exist, which will also lead to a positive discount rate; and more generally, there is the uncertainty about the effects of whatever action we take for the future, which should increase the discount rate – although some argue that risk should be kept separate from the discount rate.[50]

The Stern Review on the economics of climate change[51] uses a very low discount rate, which is composed of several elements. One part is the pure time preference descrribed in Chapter 2, and this is set at a very low value of 0.1%. The other component reflects the rate of income growth combined with the elasticity of the marginal utility of consumption. This reflects the likelihood that future generations will be richer and that the richer we are, the lower will be the additional happiness provided by an extra unit of consumption; of course, economic growth could also be negative, in which case future consumption will be valued higher than consumption today. Although the Stern Review does not specify a particular discount rate, it implies an effective social discount rate of 1.4%.[52] We shall use this rate as the lower end of our analysis.

We also use an alternative rate, which is based purely on time preference as is commonly expressed by individuals. A basis for this could be the rate at which people are apparently willing to sacrifice present consumption for the sake of higher future consumption, i.e. the interest paid on safe investment. Interest rates on bank deposits are not reliable gauges for this, because of the many policy factors that influence them. We propose to take the return on U.S. treasury bonds as a starting point. That rate is 5%. However, it is not quite risk-free, because the U.S. government might print more money (as it has been doing since the economic crisis of 2008), leading to inflation and therefore a decrease in the value of the dollars paid to investors. We shall therefore apply a reduced rate of 3% to express the expected return in real terms rather than in nominal dollars – assuming an inflation rate of 2%, which is roughly what inflation in the U.S. has been over the last five years.[53]

[50] Van Liedekerke, 2004, op. cit.
[51] For the reference, see note 3.
[52] Dietz, S., 2008. A long-run target for climate policy: the Stern Review and its critics. Report to the Committee on Climate Change Secretariat, London School of Economics and Political Science.

[53] This is also the rate used by the economist William Nordhaus, a critic of the Stern Review (Taylor, J., 2006. Nordhaus vs. Stern, Cato at Liberty, 28-11-2006, Cato Institute, Washington, D.C.).

3.4. Tentative calculation of costs and benefits

In this section we bring together the various threads spun in the previous sections: we assess those elements of section 3.1 that can be quantified, multiply the quantities found in section 3.2 by the values estimated in section 3.3 and then add them up to arrive at a tentative value per hectare for the two standards set: in arable agriculture, a value for a rotation consisting of one year faba bean followed by three years wheat as compared to four years wheat alone; and in pasture-based farming, modestly fertilised grassland with 25% clover as compared to conventional grassland. The result is shown in Table 2.

Table 2. Overview of costs and benefits of two legume-supported agricultural systems

		faba bean/wheat			***grass/clover***		
environmental impact (benefit +, cost -)	*unit per ha*	*quantity*	*price*	*value*	*quantity*	*price*	*value*
reduction of greenhouse gas emissions	t CO_{2e}	1.975	€18-72	€36-142	1.347	€18/72	€24-97
reduction in eutrophication	kg N_r	-30 to +7	€3	-€90 to +€21	39	€3	€117
reduction in ammonia emissions	kg NH_3	13.5	€3.3	€44	15-30	€3.3	€49-98
reduction in NO_x emissions	kg N_r	0.19	€2.7	€0.51	0.003	€2.7	€0.08
phosphorus mobilisation	kg P_2O_5	7.6	€0.38	€2.86	4.5	€0.38	€1.69
reduction in soil erosion & pesticide use, increase in biodiversity				p.m.			p.m.
total environmental effects				-€7 to +€210			€192-314
cost to farmer							
gross margin				-€50			-€400

A few preliminary conclusions can be drawn from these figures, rough as they may be.

- The environmental benefits of clover on grassland are larger than those of grain legumes on arable land. However, the cost to the farmer is also higher.
- If we take the most favourable scenario, i.e. where we use the carbon price calculated in the Stern Report and we assume that excess leaching of nitrate from legume fields can be avoided by appropriate crop management, the environmental benefits are much higher than the average loss to the farmer. However, bearing in mind that the range in gross margins from grain legumes is very large, this will vary highly by region and by crop.
- If, on the other hand, we use the much lower carbon price proposed by the IMF and if we accept that nitrate leaching will be problematic, the calculated

environmental effects from rotations with grain legumes may be too low to justify special incentives for growing legumes on arable land. It must be borne in mind that we have not quantified all environmental effects, so the net figure of -€57 per hectare is not an indication of the overall social benefit of rotations with legumes, but rather the cost of promoting biodiversity and a healthy soil. Whether these benefits are worth that price is a question that cannot be answered with the figures at our disposal.

- For forage legumes, the price of providing said benefits appears to be higher: of the order of €100-200 per hectare.

- For grain legumes, the largest environmental benefit seems to be the climate mitigation effect – at least as far as quantifiable benefits go. This is the case even if we use the lower of the two carbon prices. It is different for forage legumes, however, or at least for clover on grassland: the climate mitigation effect is lower here. In part this is because we assume that even with a significant proportion of clover the grassland will still be fairly heavily fertilised – at least with organic manure, leading to N_2O emissions.

- On the other hand, eutrophication will be significantly lower in grass-clover swards compared to conventional grassland: not only is fertiliser applied in somewhat smaller quantities, but there is no crop residue ploughed into the soil as on arable land. Also, ammonia emissions are reduced, leading to less acidification.

- As was perhaps to be expected, the effect of phosphorus mobilisation is modest. However, it may be questioned whether the market price of phosphate adequately represents its value, partly because of the expected shortage of phosphate rock in the foreseeable future and partly because of the long-term effect of P fertilisation and P presence in the soil.

- Both environmental and farm-economy effects have long-term as well as immediate aspects. For instance, the buildup of carbon in the soil is cumulative, meaning that as the organic matter content rises it will only generate major effects after a number of years. On the other hand, the increase in soil carbon is likely to level off after some time. Similarly, some of the improvements achieved by growing legumes (higher biodiversity, less soil erosion) will also lead to higher yields, but only in the longer term. Whether this is sufficiently attractive to the farmer depends on the latter's perspective on time, hence on the discount ratio. That ratio is incorporated into the price of carbon used here (particularly in the higher price), but not in the prices of the other environmental effects.

4. CONCLUSIONS AND RECOMMENDATIONS

The variation in local conditions is very large, which makes it difficult to judge the validity of an average figure. Moreover, from among the great variety of cropping systems with and without legumes we chose just two. Still, for an overall view the attempt must at least be made.

The figures quoted in this report can and should be combined with the outcomes of the scenarios run in CAPRI, reported in Legume Futures Report 4.5. Not all of the effects described in this report can be modelled in CAPRI (for instance, the effect of a legume crop on the yield of the next crop in the rotation). On the other hand, the outcomes of CAPRI are more sophisticated than the figures quoted here, in that they take secondary effects into consideration: effects on production, on market balances, and on prices.

It cannot be clearly concluded that the benefits of legumes are worth the cost. At best we can say that legumes deliver significant benefits and therefore deserve attention from policy-makers. Neither the costs nor the benefits quoted here are cast in stone – particularly as not all benefits can be quantified. Concerning the costs, i.e. the often lower margins from growing legumes, these can be lessened by conscious policy efforts: research on increasing legume yields, and spreading knowledge on legume cultivation will help to improve the economics of legumes. There are also trends that may lead to a reversal of the decline in legumes: increasing popularity of organic farming, higher prices of fertilisers and of imported soya will all contribute.

Yet, direct incentives such as those modelled in Legume Futures Report 4.5 will also be needed if the trend of decline is to be reversed. Autonomous developments such as cited above will make legumes more attractive, but probably not attractive enough. Whether the social benefits gained by such incentives depends on the value orientation of the policy-maker: whether he or she takes a long-term or a short-term view, and whether the unquantified benefits (increased biodiversity and more sustainable soil management, to name the most important ones) are sufficiently valuable to justify the social cost.

Furthermore, any programme to promote legumes will have to consider how to encourage crop management in such a way that nitrate leaching is minimized. As the figures quoted in this report show, the environmental cost of eutrophication may nullify the climate benefits of legumes, at least on arable land.