Fostering sustainable legume-based farming systems and agri-feed and food chains in the EU

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Macro-developments that can influence European legume value chains

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Summary

This reports describes developments that can influence to the development of legume value chains in the European Union. In Chapter 4, a general picture of the ‘protein challenge’ is described: challenges in the field of supplying a future world population with sufficient feed and food protein. Chapter 5 describes the topic of environmental/ecological services concerning increasing the amount of legumes grown in the EU, making a subdivision into developments influencing legume value chain development on a farm level, and on a societal level. Developments regarding legume value chains specifically for feed are discussed in chapter 6, focussing on soya bean production and imports, plant breeding, feed alternatives, and integration of legumes in farming systems. Chapter 7 describes food related developments that influence legume value chain development, focussing on current protein intake of EU citizens, promotion of legume consumption, and meat replacement products.

1 Introduction

Currently, 70 % - 75 % of all EU animal feed compounds (mainly soya bean) are imported from North and South America. A higher (animal) protein demand due to world population growth and increased income per capita would result in more land being used in North and South America being converted to soya production, with associated negative environmental and ecological consequences (deforestation, etcetera), while also resulting in higher risks/uncertainty for the EU livestock production (including eggs and dairy) because of its dependency on soya imports. If the EU is to decrease this dependency, more protein crops are to be grown within the EU. This report focusses mainly on legume value chains, and where applicable other protein sources are also considered.

Developments in several areas that are of influence on European legume value chains are discussed in this report. Following DESTEP analysis methodology, originating in the 1960's [1] as a company strategy tool and later expanded upon, these developments can be of different origins: Demographic, Environmental/ecological, Social, Technological, Economic, and Political. This report uses the distinction between the feed and food markets for legumes. Although the feed market is ultimately driven by the market for the animal products resulting from feed, the direct food market for legumes is quite distinct from that for feed. The feed market is by far the larger of the two but maybe more importantly for this report, both markets have their own developments and influences, although there also are links and overlaps. The examples mentioned in this report are not meant to be an exhaustive overview.

This report starts with describing a general picture of the 'protein challenge' in Chapter 2: challenges that are faced in the area of feed and food protein. In Chapter 3, the topic of environmental/ ecological services concerning increasing the amount of legumes grown in the EU is described. Developments regarding legume value chains for Feed are discussed in Chapter 4, followed by Chapter 5 on Food which deals with developments that could influence the direct food market: the consumption of legumes in the EU.

2 The protein challenge

The protein challenge can be described as the challenge to meet the rising demand for protein of the world's population by 2050. According to FAO, people in developed countries are consuming a lot more protein than the daily requirement, and a large part of this is animal protein. As the developing world increases its income per capita, the global demand for protein will increase, even more so when combined with the expected population growth and increased meat consumption that is associated with increased income of several billion people. This would increase the pressure on the world's agriculture to provide both plant and animal protein to an unprecedented level. Part of the solution to the protein challenge is to transition to less protein consumption in the developed world with a smaller contribution of animal protein to the total protein intake, while managing/limiting the increase in animal protein consumption that may be expected in the developing world.

2.1 Global population growth, income per capita, urbanisation

The world's population is expected to grow to 9-10 billion by 2050, and generally speaking the income per capita is expected to increase, with an associated increase in the global demand for animal protein (meat and dairy) [2]. While the expected population growth is expected to mostly occur in developing countries (~1.3 % per annum), and less so in developed countries (~0.4 % per annum), associated demand increases will affect the EU. Other important developments are income increase per capita and urbanisation, both resulting in increased demand for animal products. However, the growth of meat consumption in recent decades has slowed down to equal to or less than the population growth in developed countries, and to 2 to 2.5 times the population growth in developing countries [2].

The global demand for agricultural products in general is expected to grow by 1.1 % per annum, meaning that global production by 2050 should be 60 % higher than it was in 2007 (or 40 % higher compared to 2017). Agricultural yields are still growing but at a slower pace in the developed world and while productivity increase will be important, it is clear that more -and more efficient use of- land, water, nutrients, and energy will be needed for meeting the 2050 protein demand [2-4].

2.2 Brief EU history: population growth, production, consumption and import of legumes

EU-28 population grew from 407 million in 1960 to 512 million in 2017. Population growth is slowing down and Eurostat forecasts an increase from 508 million in 2015 to 528 million by 2040, after which population numbers are expected to decline to 519 million in 2080 (data: Eurostat).

EU meat production has increased from 17 Mt to 43 Mt, for beef, pig and poultry meat combined, between 1960 and 2011. The ensuing increased demand for feed proteins has been met by an increase in grain legume production from 3.3 Mt to 4.3 Mt per year, of which also a larger part was used for feed, but the largest share by far of the increased demand was met by increased import of soya bean from 2.7 Mt to 37 Mt in 2011. This amount of imported soya bean represents about 15 Mha of agricultural land. The EU consumption of grain legumes has decreased: in 1960, 67 % of the grain legume area (nearly 6 Mha) was used for production of grain legumes used for human consumption: largely common bean (50 %), and also chickpea, cowpea, groundnut, and lentil. In 2010, this combination accounted for 22 % [5]. In the EU, consumption of pulses such as beans and peas per capita has decreased by approximately 25 % between the early 1960's and 2013 (FAOstat) and of the food grain legumes consumed in the EU in 2013, 57 % are EU produced [5].

2.3 The strength of soya bean

When developing EU legume value chains that are to reduce the EU dependence on imported soya bean, mainly as an animal feed component, it is important to consider the strengths of soya bean. Taking into account the two available options of either growing soya beans on EU land or replacing soya in animal feed with other protein crops, these strengths are as follows:

Firstly and on an international level, EU grown soya would have to compete with imported soya beans. Secondly and on a much more local level, farmers would have to choose to grow soya over another crop, such as wheat, sunflowers, or rapeseed. Thirdly, soya is readily used in animal feed production, and is not so easily replaced in this aspect.

The first two reasons for soya bean's strength are clearly economic, and can be considered similar in nature. The 'strength' of (imported) soya beans means that it is difficult for EU farmers to profitably produce soya beans. This can be described as a 'yield gap': on a crop level, growing soya beans is less profitable for EU farmers per hectare of land than growing wheat, maize, rapeseed, sunflower seeds, or sugar beets, for example, as shown in Table 1 (not taking into account costs for irrigation, weed & pest control, etcetera). Unless growing soya beans brings advantages to farmers on a farm level, getting EU farmers to produce soya beans on a large scale instead of the other crops mentioned in Table 1 will be very difficult. Examples of these advantages are: a positive influence in crop rotation, on soil quality, or on decreasing nitrogen fertilizer use: see paragraph 3.1. Of course, higher production yields would help: see paragraph 4.3 on breeding.

Table 1. Yields and export prices of soya bean compared to other crops.

Crop	Average yield (tonne/ha)	2013 yield (tonne/ha)	Average exp price (US$/tonne)	2013 exp price (US$/tonne)	Average value (US$/ha)	2013 value (US$/ha)
Soya bean	2.7	2.6	375	333	1026	870
Wheat	5.4	5.6	276	305	1494	1704
Maize	7.2	6.8	321	367	2298	2515
Rapeseed	3.1	3.1	566	602	1765	1881
Sunflower seeds	1.9	2.0	637	693	1232	1383

Average yield: 2010 to 2014; Average export price: 2009-2013 (FAOstat)

This indication of competitiveness is supported by publications of de Visser *et al.* [6], mentioned in paragraph 4.3, and by Bues *et al.* [5], albeit described somewhat differently.

The third reason has to do with the feed-related properties of soya beans. Soya bean meal contains a large fraction of easily digestible protein, and its amino acid composition is very well suited for many feeding purposes. It is low in fibre and ash, and also contains few Anti-Nutritional Factors (ANF), so it can be incorporated at high levels, at the wish of the feed manufacturer. When composing an animal feed, manufacturers use composition software in order to get the desired properties of a compound feed, at the lowest cost. The difficulties of replacing soya bean meal quickly become apparent: inclusion of replacements is usually limited to a low percentage, as one or more of the properties - regarding costs and nutritional value- of the replacements are restrictive for higher inclusion. In short, the above indicates that reducing European dependency on imported soya beans for animal feed will be challenging.

2.4 Present day policies

2.4.1 CAP (Common Agricultural Policy): brief history and influence on legume production

The EU Common Agricultural Policy dates back to 1962, when it was introduced to strengthen food security and stabilise the agricultural markets using product and price support. It has since then been reformed several times, putting more emphasis on environmental and rural development and on halting over-production, most importantly by no longer coupling subsidies to amount of output. In 1974, price support for soya beans was introduced, followed by peas, faba bean, and lupins in 1978 for feed and in 1982 for food. Support for chickpea and lentils (both for food) and vetches (for feed) was added in 1989. A reform in 1992 (the MacSharry reform) resulted in more direct support for farmers, shifting from price support. Soya bean received less support per tonne than other protein rich crops, resulting in a steep decline in area used to grow soya bean. The Blair House Agreement in 1992 restricted the growth area for oilseeds including soya bean to receive support to 5.5 Mha. Further decoupling in 2003 lead to Single Payment Schemes (SPS), making farm payments conditional to compliance to environmental and animal welfare demands. Reductions in support resulted in further reduction of the production of soya bean and pea. Currently, there are no restrictions on growing oilseeds (soya bean is considered an oilseed in this regard), but there are also no import tariffs on oilseeds, so soya bean and soya bean meal can be imported tax free. In effect, the Blair House Agreement is now redundant, although still in place. Regarding protein crops (not referring to soya bean), some support remains in Finland, France, Lithuania, Poland, Slovenia, and Spain. All in all, grain legume production (excluding soya bean) decreased to about 1.3 % of arable EU land in 2009, and a EU average of 1.8 % including soya bean in 2010, albeit with fairly large regional differences [5].

The 2013 CAP reform introduced ‘Greening’, meant to promote environmentally friendly farming by connecting it to the direct payments system. Farmers that receive these specific payments have to diversify crops, maintain permanent grass land, and in case the arable land of a farm is larger than 15 ha, dedicate 5 % of it to Ecological Focus Areas (EFA’s). One of the ways to do this is to reduce inputs or improve soil protection by growing catch crops (see Chapter 3) or crops than fix nitrogen (legumes) [7]. This policy promotes of legume production in the EU.
In 2017, the European Commission introduced a regulation banning the use of pesticides on EFA’s, claiming to hereby strengthen the environmentally friendly intention of EVA’s [8]. However, if farmers are no longer allowed to use pesticides on their legume crops in EVA’s, this would negatively affect legume production in the EVA’s and potentially, by extension, negatively affect growth of legume production in the EU [9, 10].

2.4.2 EU policy on GMO

Currently, 59 genetically modified (GM) products are approved for import into the EU. These consist of 12 types of cotton, 27 types of maize, 4 types of rapeseed, 15 types of soya bean, and 1 type of sugar beet. 26 applications are pending. Most of the modifications increase the crop’s tolerance to herbicides or pesticides. All of the approvals are for applications in feed as well as in food [11].

Concerning approval for growing GM crops in the EU, no GM protein crops are approved for cultivation. GM maize MON810 has been approved in general, but with the caveat that EU states could issue a national prohibition, which most EU states did. Another approved crop is the Amflora potato, but its developer BASF has ceased its activities on GM crop cultivation.

Regarding the import of genetically modified feed products into the EU, approval is needed. If the authorisation is given, it will inevitably be at a later time than production authorisation is given in the country of origin, which leads to the issue of asynchronous GM authorization. This means that while authorisation is not (yet) given, the producer and traders may only export non-GM product to the EU and also have to be careful to segregate un-authorised GM products from the ones authorised by the EU. This increases costs and financial risks, and could therefore hamper trading. Possibly more so in the future, as new GM traits may be introduced more often and more rapidly [12]. It could be suggested that if China, with nearly 3 times larger import of soya beans, has less strict regulations, North- and South American producers may focus more on trading with China than with the EU, which would also make fulfilling EU's demand more difficult. Also, if EU were to grow more of its own non-GM soy, international competitiveness of this soya would be reduced, as cheaper GM soya would still be widely available. This would increase costs for EU livestock farmers and in turn reduce their international competitiveness.
Currently, China approves import of GM soya beans to be used in animal feed. It processes all soya beans in China and permits the use of the resulting GM soya bean oil for human consumption, but does not permit cultivation of GM food crops [13, 14].

Regarding GMO in food, EU legislation states that if a food product contains more than 0.9 % of an ingredient from a GMO source, this should be clearly mentioned on the label [15].

2.4.3 National policies

The biofuel blending mandate has resulted in more land being used for production of rapeseed, of which the oil is to be used for biodiesel. The cake that results from seed pressing is rich in protein and can be used for animal feed. In this manner, the biofuel blending mandate negatively affects the development of legume production.

The Green Deal approach is an initiative of the Dutch government to facilitate sustainability developments. A Green Deal is an agreement between the national government and other parties, such as companies, other organisations or regional/local governments. Sustainable developments can be supported by adjusting regulations, supporting negotiations, and/or helping companies enter foreign markets. The scope is very wide: resources, biodiversity, water, mobility, energy, climate, food, construction, and biobased economy. Governmental support initiatives like this likely exist in other EU countries as well, and may positively affect development of legume production.

The German Renewable Energy Act promotes the production of maize to be used for biogas production by digestion. This results in more land being used to produce silage maize and increases competition for arable land. In this way, the Renewable Energy Act can be considered to negatively affect the development of legume value chains in Germany (mentioned in [5]).

3 Environmental Services

Two types of environmental/ecological services regarding developing EU value chains for legumes can be distinguished: advantages for the farmer on a crop and farm level, and those for society.

3.1 Advantages for the farmer

As legumes are able to bind nitrogen from the air, their growth requires very little nitrogen fertiliser. Of course, it should be noted that the nitrogen binding capacity is performed at a cost: nitrogen fixation uses glucose and therefore limits the maximum achievable yield somewhat. But generally speaking, the advantage of needing less nitrogen fertiliser is seen as offsetting a consequential pressure on yield.
Cereal crops typically require 100-200 kg N per ha, and growing legumes would therefore reduce nitrogen fertiliser use. It is claimed that, at a farm level, legume nitrogen fixation can also save on nitrogen fertiliser costs for the crop(s) following the legume in crop rotation, as these crops take up nitrogen from the legume crop residues [5].
While true in principle, it should be taken into account that this is not a trait exclusive to legumes. For example, when sugar beet leaves are left as a residue in the soil, their nitrogen –originally from fertiliser– can also be carried over to next year's crop. Residues of different crops contain different amounts of nitrogen to be carried over to the following year. If the following crop is to benefit from the nitrogen containing residue in the soil, care has to be taken that the nitrogen is not washed from the soil or partly converted into nitrous oxide during the time between crops. See paragraph 3.2, on catch crops.

Regarding the use of pesticides, a reduction can be expected when changing from a monoculture to a crop rotation containing legumes. However, legume cultivation does require pesticides as well, so the cost effect on a farm level will be limited [5].

Regarding the organic carbon content of soil, this may be positively affected by inclusion of forage legumes into the rotation. The extent depends on the crops involved, as well as on the farm, climate conditions, etc. As forage legumes are grown year-round, their carbon sequestration effect is greater than for grain legumes. Similarly, as forage legumes grow more biomass and grow for a longer period, they fixate more nitrogen than grain legumes [5].

3.2 Advantages for society

The fact that legumes require little nitrogen fertiliser to grow due to nitrogen fixation from the air, means that less nitrogen fertiliser needs to be manufactured. As nitrogen fertiliser production by the Haber process uses natural gas to supply both the needed hydrogen as well as the process energy, producing less nitrogen fertiliser reduces CO_2 emissions.

Considering the effect of changing from North and South American soya bean to EU grown soya bean for animal feed, the reduction in carbon footprint for meat resulting from less transport are small. When taking into account land use change in South America such as deforestation, EU grown soya bean compares more favourably [16].

Nitrogen fixation by growing legumes can result in less soil nitrate leaching to ground and surface water, and reduced release of nitrous oxide (N_2O, a strong GHG), compared to a crop that does not fixate nitrogen and needs more nitrogen fertilizer. That said, after the legume is harvested, the residue decays and the nitrogen releases into the soil as nitrate. To limit both nitrate leaching and nitrous oxide release, short season catch crops can be planted to capture the nitrate [5]. In other words, crop and crop residue management are important in order to take advantage of the nitrogen related potential.

Generally speaking, changing from a monoculture to a crop rotation system increases biodiversity. In literature, several positive effects on biodiversity are mentioned as resulting from introducing more legumes to crop rotation, ranging from microbial life and underground species to small aboveground animals and birds. The clearest example however is that most legumes, as flowering plants, provide nectar and pollen to bees while crops like wheat and maize do not [5, 17].

4 Feed

4.1 Large importers and producers of soya bean

According to the USDA, China is the largest importer of soya beans by far, with 93 Mt in 2017. Second is the EU, with 15 Mt in 2017 (Figure 1). The EU also imports close to 20 Mt of soya bean meal, while China imports none (Figure 2). China produces an estimated 13.8 Mt of soya beans in 2017, compared to 2.5 Mt in the EU (Figure 3). Interestingly, India, with its 1.3 billion inhabitants, produces an estimated 11.5 Mt of soya beans in 2017, but imports of this crop, including that of soya bean meal, seem negligible [18]. For comparison, the main producers of soya bean in the world are Argentina (53 Mt), Brazil (87 Mt), and the USA (107 Mt) (Figure 4), and together these countries produce over 80 % of the world's 307 Mt soya beans in 2014 (FAOstat).

According to FAOstat, India hardly imports any soya beans, with 121, 837, and 750 tonnes in 2011, 2012, and 2013, respectively. USDA numbers show a similar picture, albeit with soya bean import at a somewhat higher level of 4 kt in 2013 and 80 kt in 2017 [18]. Vaidya (2001) reported that, at the time of publication, India was self-sufficient in feed ingredients, including the protein fraction [19]. Assuming this has not yet changed, as soya bean imports do not seem to have risen since 2001, it remains interesting to ask if India's self-sufficiency is going to last. Since 2001, India's population has increased from 1.0 billion to 1.2 billion in 2014, and to an estimated 1.3 billion in 2017 [20]. Its GDP has also risen from US$494 billion (US$471 per capita) in 2001 to an estimated US$2454 (US$1850 per capita) in 2017 [20].

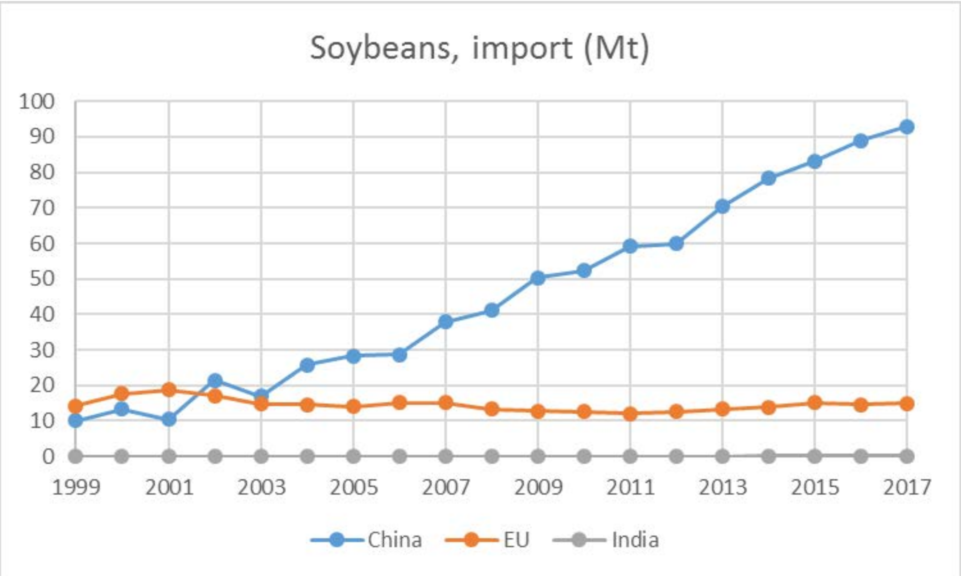

Figure 1. Soya bean import (whole bean) of China, EU, and India from 1999 to 2017 (Mt per year)

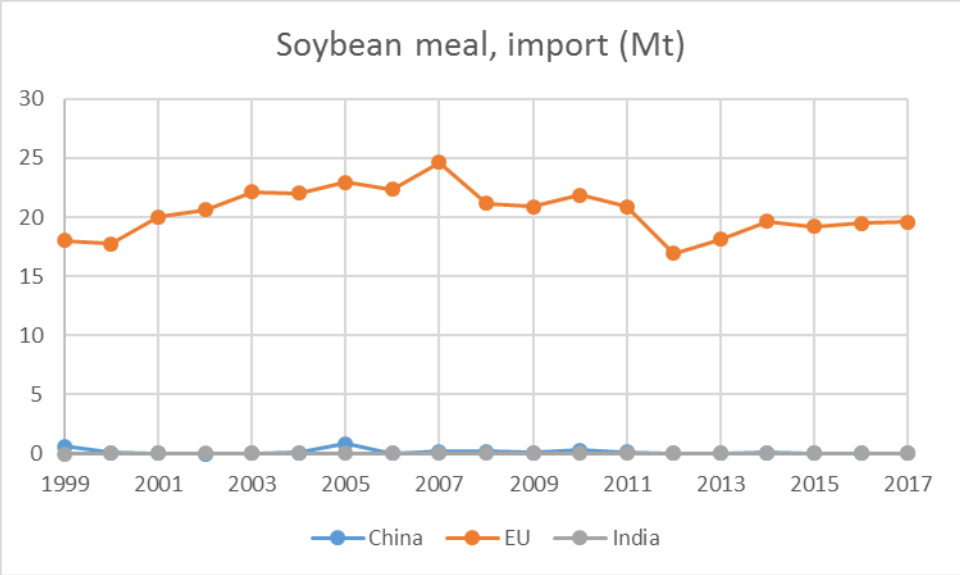

Figure 2. Soya bean meal import of China, EU, and India (Mt per year)

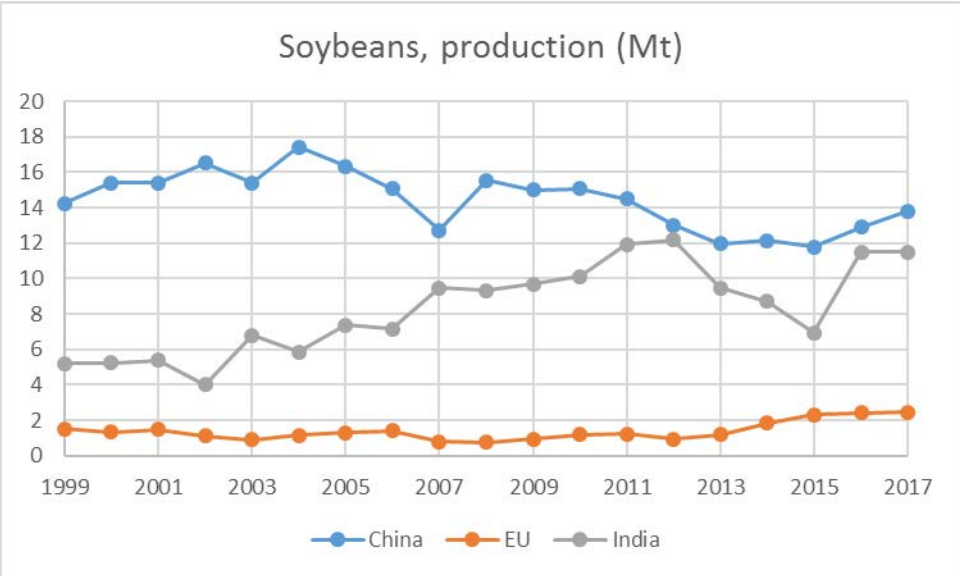

Figure 3. Soya bean production of China, EU, and India (Mt per year)

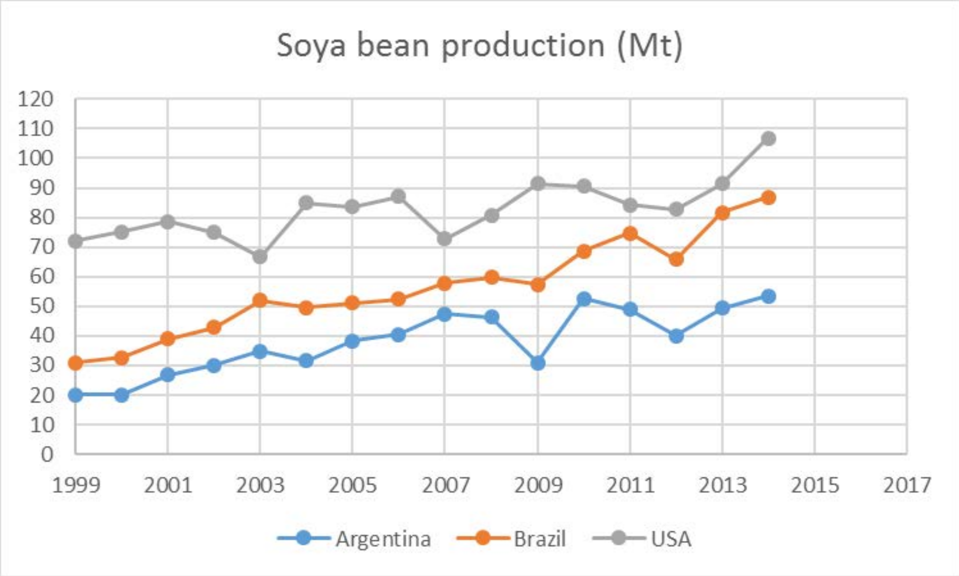

Figure 4. Soya bean production of Argentina, Brazil, and USA, from 1999 to 2014 (Mt per year)

4.2 Price developments of nitrogen fertiliser and soya bean

Recent price increases of nitrogen fertiliser are increasing the potential economic benefits that the production of legumes provides for following crops in crop rotation. Bues *et al.* (2013) report that compared to 2000, nitrogen fertiliser prices have more than doubled, resulting in an increase of fertiliser costs related to farm prices for wheat and milk of 78 % and 63 %, respectively [5].

The prices of soya imports are also increasing and may be expected to continue to increase due to increasing international demand (Figure 1). The large price increase for soya imports around 2007 to 2013, from a previous 200 US$/t to around 600 US$/t (Figure 5), resulted in a ~30 % decreased EU import of soya bean and soya bean meal (Figure 1 and Figure 3). Since 2013, prices have decreased to the 325-350 US$ level, and EU imports have increased accordingly. The current price level of soya is still about 50 % to 75 % higher than in 1999/2000.

Regarding GM free soya, Aramyan *et al.* (2009) reported (in [5]) that the price of GM-free soya may rise by 55 €/t if the EU would import GM-free soya to the extent of 25 % of its total soya imports.

Of course, increasing prices of imported soya also mean that the value of EU-grown protein crops increases. This increase in value of protein crops (including legumes) positively affects their competitive position and decreases the yield gap that is mentioned in paragraphs 2.3 and 4.3 between legumes and other crops.

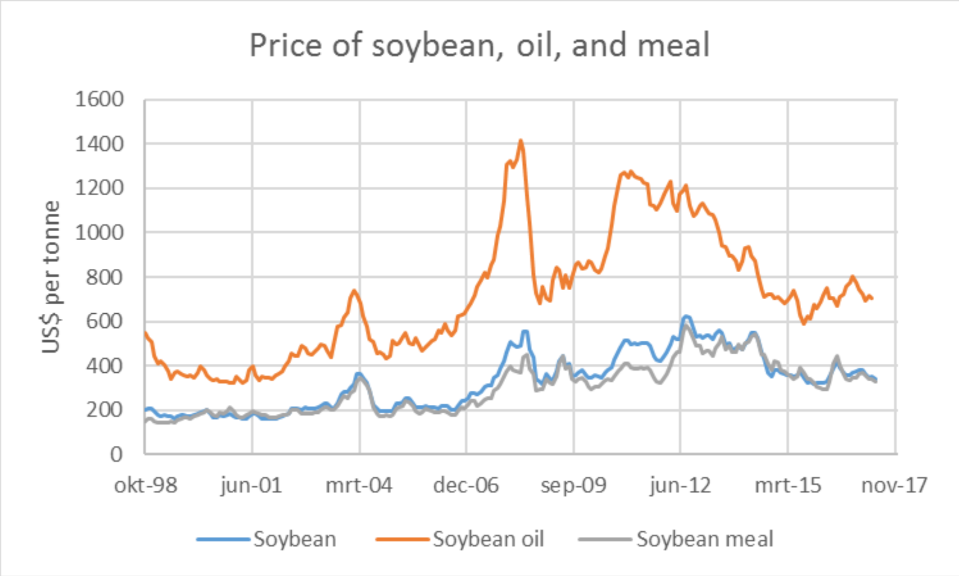

Figure 5. Price development of soya beans, soya bean meal, and soya oil (US$/t) [21].

4.3 Competitiveness of EU legumes and breeding

4.3.1 Breeding and investment

In order to reduce the 70 % - 75 % of soya being imported in to the EU, plant protein production is needed to replace the imports, which requires suitable crop varieties. Regarding legumes for feed, the main crop currently used is soya bean. Including other protein crops cultivated in EU countries, the list is as follows:

- soya bean
- grain legumes (faba bean, field pea, lupins, and other minor crops)
- forage legumes (mainly alfalfa)
- sunflower and rapeseed (not legumes, but still protein crops).

The above list is mentioned by the Focus group on Protein Crops of the European Innovation Partnership as the most promising in facing the protein challenge while covering all agricultural/climatic zones that characterise European agriculture [22].

Breeding is very important in order to provide more competitive varieties of the abovementioned crops, but as current EU market opportunities for these crops are poor (see paragraph 2.4.1), they draw less attention than desired from breeding companies for investment. In order to increase opportunities, breeding investment level needs to be increased. This amounts to somewhat of a catch-22 situation, where breeding investment levels and market opportunities for these replacement crops depend on each other ‘to be in place first’. Breeding is needed to raise competitiveness and raised competitiveness is needed to interest breeders to produce improved varieties. This could also be a Policy/political issue, as EU policy may be used to break the mentioned inter-dependency.

A related development may be that producers focus on local-to-local production (regional business model). This can be focussed on feed as well as on food, and on both. This means that food/feed producers compete less on cost price, and instead use a transparent and short supply chain as a selling point. If this is successful on a smaller scale, it could create some production volume, and in turn would increase interest from plant breeders for improvement of crop varieties, after which a step up to larger scale may be more feasible.

EU Parliament motion 2010/2111(INI) called for support of research in breeding and supply of protein crop seeds, including health benefits (or disease control), also in rural development: crop rotation, mixed cropping, on-farm feed production [22, 23].

4.3.2 Yield increases in USA and EU for wheat and soya

Wheat production yields have increased more over the years in the EU than in the USA (Figure 6). Yields in France and Germany are more than 2.5 that of US wheat, indicating a high intensity level of EU agriculture and an interest of breeding companies to produce improved wheat varieties for the EU wheat production. Concerning USA wheat production, the production is certainly large enough to interest breeding companies in producing new varieties, but as land prices in the USA are generally lower and farmed areas are larger than in most parts of the EU, farming intensity is (assumed to be) lower, leading to lower yields (and also lower associated costs). For soya beans, the case is different, with yields being similar in the EU and the USA. USA production is much larger than in the EU, which is so small that it greatly reduces the potential for breeding companies to develop new varieties for EU conditions (see above). Together, this suggests that, if soya bean production were to be taken up large in intensive EU farming, production yields could be greatly increased.

Another way to look at this: EU wheat yields have gone up by a factor 3 since the 1960's, and so has average EU soya bean yield compared to the USA, albeit at a low scale of production. Wheat production yield in the USA has more or less doubled in the same period, as has soya bean yield. It could be concluded, although not very securely, that the potential for EU soya bean yield development is present.
Similar points as above are mentioned in Bues *et al.*, 2013 [5].

Figure 6. Yield, area, and production of wheat and soya bean in EU, France, Germany and USA.

4.3.3 Competitiveness of pea and soya bean versus wheat and maize

Compared to soya bean, pea contains a large starch fraction. When pea is used to replace soya bean (meal) in compound feed, the starch fraction of pea limits its inclusion, as cheaper starch sources than pea are available (mostly from cereals). If the starch fraction is separated from the protein rich fraction, for example by wind sifting, both fractions can be sold/applied separately. Theoretically, this could improve the application possibilities of pea in feed, but the separated starch may not add much to the total value as, similarly to what is mentioned above, it competes with cereal starch sources.

On a production level, yields of pea and soya bean are more or less equal, but when comparing the potential value of pea with soya bean using their average composition, it is clear that soya bean is more valuable because of its higher content in valuable oil and protein contents, and absence of less valuable starch. Both soya bean and pea however would have to be produced at higher yields in order to equal wheat production value, and even more so to be equal to that of maize [6]. Using this calculation method, rapeseed would not require a yield increase to be equally valuable as wheat, with soya bean and sunflower needing approximately 30 % yield increase, and pea needing a yield increase of 76%. When comparing to the more valuable maize, these numbers grow to 25 % for rapeseed, 63-64 % for soya bean and sunflower, and to 120 % for pea. These numbers are all averages with high variance due to differences in production area and climatic conditions, but they do show that the legumes soya bean and especially pea have to be greatly improved to compete with cereals like wheat and maize from a production value perspective [6]. It should be noted that the above focusses on competitiveness on a production level only. Additional advantages may result from integration in farming systems, focussing more on a rotation perspective (see chapter 3 and paragraph 4.5).

4.4 French pea and faba bean cultivation for use in feed

Peas and faba bean are already produced in the EU as animal feed. Taking France as an example: in the 2015/16 season, of the +/- 600 kt peas produced, about 20 % was used for human nutrition in France, 25 % was used as feed for French livestock, 20 % exported to other EU countries mainly to be used as animal feed, and ~30% was exported outside the EU, mainly to India. The cultivation of peas started growing intensively in the early 1980s, from ~300 kt to over 3500 kt at the end of that decade. Since the late 1990s, production declined towards ~600 kt in 2007, and production has stayed more or less at this level since. Around 2000, France's cultivation of faba beans started growing, after having been at a low level for most of the 1990's. At the peak in 2010, 500 kt of faba bean was grown, after which cultivation of this crop has declined towards 250 kt – 280 kt of recent years. About 65% of the currently grown faba bean in France is used for animal feed, most of which in France itself. Of the 500 kt cultivated in 2010/11, about half was exported to Egypt, for human consumption. Between then and now, export to Egypt has declined to 10 kt, less than 5 % of the total, partially replaced by export to Norway of 60 kt, or 25 % of the current production [24]. Comparing prices, French peas cost about 215 €/t, faba bean for human consumption ~205-215 €/t, faba bean for animal feed 180-200 €/t. Imported soya bean meal is priced at 340 – 375 €/t in the last year [25].

4.5 Integration in farming systems

4.5.1 Arable farming

Assuming competitive legume crops are available, then the introduction, expansion, and assimilation into EU agricultural systems remains an important issue. Cereals are prominently represented in EU agriculture, with 38 % of all arable land being used for the production of wheat or maize in 2013, although large differences exist between EU nations (Table 2). In 2013, the ten EU countries that together represent 80 % of all EU arable land, accounted for 85 % of all wheat and maize produced in the EU, and six of these countries had more than 45 % of their arable land in use for cultivation of wheat or maize.

Although the high prevalence of cereals in EU agriculture in Table 2 implies that crop rotation is at least not applied 'across the board', crop rotation is still very important, as it supplies the farmer with necessary mechanisms for quality & disease control of land and crops. For example, wheat can be considered an important crop to include in a rotation, as farmers can control dicotyledonous weeds easily while growing wheat, as wheat itself is monocotyledonous. The weed control positively affects crops in following years in the rotation. Of high importance is the effect that introduction of legumes to a rotation will have on the population and growth of nematodes in the soil. Nematodes can be very detrimental to crops and different crops have different effects on the size and composition of the nematode population. A certain crop may promote a certain balance in nematode population, which in turn may negatively affect crops that follow in the rotation. Therefore, it is of great importance for crop yields, soil health, and pest and disease control where and with what recurrence a legume crop is placed in an existing rotation schedule, as well as what crop is replaced.

Table 2. Arable land and land used for wheat and maize cultivation in EU and EU nations (1000 ha) (FAOstat and EUROstat, 2013)

	Arable land	Wheat	Kernel maize	Green maize	Wheat (%)	Kernel maize (%)	Green maize (%)	Wheat + maize (%)
EU	108085	25780	9775	6023	24	9	6	38
France	18306	5319	1840	1487	29	10	8	47
Spain	12181	2125	442	107	17	4	1	22
Germany	11876	3128	497	2003	26	4	17	47
Poland	10792	2138	614	462	20	6	4	30
Romania	8746	2104	2519	56	24	29	1	54
Italy	6827	1902	908	327	28	13	5	46
Unit. Kingd.	6265	1615	11	183	26	0	3	29
Hungary	4403	1090	1243	102	25	28	2	55
Bulgaria	3479	1314	428	21	38	12	1	51
Czech Rep.	3149	829	97	234	26	3	7	37
Greece	2621	545	183	13	21	7	0	28
Sweden	2596	323	1	15	12	0	1	13
Denmark	2408	568	13	181	24	1	8	32
Lithuania	2291	667	17	23	29	1	1	31
Finland	2224	228	0	0	10	0	0	10
Slovakia	1394	368	222	93	26	16	7	49
Austria	1354	297	202	111	22	15	8	45
Latvia	1208	369	0	20	31	0	2	32
Portugal	1154	52	112	84	5	10	7	22
Ireland	1113	61	0	15	5	0	1	7
Netherlands	1038	153	21	230	15	2	22	39
Croatia	876	205	288	29	23	33	3	60
Belgium	816	202	74	177	25	9	22	56
Estonia	632	124	0	5	20	0	1	20
Slovenia	185	32	42	30	17	23	16	56
Cyprus	79	7	0	0	9	0	0	9
Luxembourg	62	14	0	14	23	0	22	46
Malta	9	0	0	0	0	0	0	0

Wheat: including spelt.

4.5.2 Forage legume: alfalfa

Alfalfa is a legume crop that can be used for forage by grazing the fresh product or using it as hay or silage for ruminant feed. As alfalfa is a legume and can fix nitrogen from the air, an interesting question is why it is not grown more often on grasslands in EU.

Alfalfa can be refined to produce protein rich fractions to be used to feed pigs and poultry. The French company Désialis produces concentrated Alfalfa extract for poultry and ruminants (pet food also mentioned, but no mention of product for pigs). The French organisation Leaf For Life (Leafforlife.org) promotes the consumption of leafy crops, among which Alfalfa. It describes the production of an Industrial Leaf Concentrate Process using alfalfa oriented towards animal feed as well as human consumption.

4.5.3 Mixed crops: grass and clover

Growing mixtures of grass and clover on lands used for grazing cows results in less (if any) nitrogen fertilizer needed. For example, a mixed grass/white clover dairy system needed 69 kg inorganic N per hectare per year while producing 85 % of the milk yield per hectare resulting from a grass system receiving 275 kg inorganic N per hectare per year. Nitrogen utilisation was the same (25 %) in both systems, and there was no difference in nitrate concentration in drain water. 15 % less total energy was used in the white clover/grass system [26]. More milk production by cow grazing on grass/clover mixtures compared to grass only has also been reported [27]

With rising costs for N-fertiliser and animal feed, mixing clover with grass on pastures is getting more interest from dairy farmers. The company Pure Graze is selling seed mixtures containing grass, clover and herbs for use on pastures. Different mixtures are sold: clover content ranges from 10 to 23 mass %. The herbs are added claiming to improve animal health [28].

4.6 Alternatives to legumes in feed

As it is the goal of this report to describe developments that could influence legume value chains in the EU, it is important to consider what the alternatives for legumes are in animal feed. The main protein sources other than soya in compound animal feed currently are:

1) Sunflower meal and rapeseed meal, the by-products from the oil extraction of the respective crops. Sunflower oil is mostly used for human consumption, with Ukraine and the Russian Federation as the main producers of sunflower seeds before the EU, with 14 Mt, 11 Mt, and 8.6 Mt estimated production for 2017, respectively. The largest rapeseed producers are Canada and the EU, with 21 Mt each of estimated production in 2017 [18]. A large part of the rapeseed grown in the EU is used for the production of biodiesel.
2) DDGS (Dried Distillers Grains with Solubles), a by-product mainly originating from the production of fuel ethanol in North America.

Other developments in alternative protein sources for animal feed are: 1) protein concentrates or isolates from crops such as duckweed and grass, 2) insects, 3) algae, or 4) bacterial single cell protein (SCP). Most of these alternatives, although possibly promising, are still in early stages of their development, with process energy requirement as an important developmental focal point. An example that seems advanced in its larger scale development is SCP production from methane. The company Calysta (US) is reported to produce at 100 t per year scale, for fish feed. Unibio (UK) has a similar process, and both companies plan to scale up production [29].

A 2014 study comparing replacements of non-EU soya bean with EU protein sources in starter pig compound feed with the main focus on equal or reduced carbon footprint, concluded that the best alternative at the time was European soya bean, compared to sunflower meal, poultry meat and bone meal, insects (meal worms), DDGS, defatted algae, and bacterial Single Cell Protein [16].

On a production level, taking into account production yields and general composition (starch, oil, protein, other) value, rapeseed seems a viable competitor for wheat, while rapeseed would need a yield improvement of 25 % on average to compete with maize [6].

It should be remembered that in order to replace soya bean in compound feed, inclusion levels of alternatives are likely limited, necessitating a mixture of alternatives to replace soya bean meal (see paragraph 2.3, the strength of soya bean).

Worth mentioning are examples of other legumes than soya beans being used in non-compound feeds: whole cropping beans in the UK, to be used as roughage and protein [30], faba beans for cattle and sheep [31], and peas as forage feed (www.lgseeds.co.uk). Also, locally grown soya beans can be used as roughage [32].

4.7 Growth of fish farming

The growing fish farming market requires plant proteins for feed. Both for herbivorous fish as well as for carnivorous species, as plant protein sources are also used in feed for the latter. The growth of fish farming may have ecological advantages, but it would increase the need for plant protein [33]. Worldwide, the share of aquaculture in the total production of aquatic animal production has been growing from 10 % in 1985 to close to 45 % in 2014, or close to 74 Mt of aquaculture product in 2014, of which close to 50 Mt of finfish. For Europe (source does not specify EU), aquaculture production increased from approximately 1 to 2.9 Mt in the same period, of which 2.3 Mt of finfish. Worldwide, about 50 Mt of aquaculture product was from fed animal species [34].

4.8 Growth of animal production in EU

The production of animal products in the EU has been generally growing in the last decades (Figure 7). Pig's meat has been the biggest grower in absolute terms, as well as the most produced meat type, with over 22 Mt in 2014. Relative growth numbers are largest for chicken meat, almost quadrupling production since 1970 to 11 Mt in 2014. Turkey meat production has also been rising, from close to zero in 1970 to almost 2 Mt in 2014. Egg production has been more or less stable since 1980, at close to 7 Mt per year. Also milk production has been relatively stable since the early 1990s, at 150 Mt per year (secondary y-axis in Figure 7), with an increase since the early 2010s to 160 Mt in 2014. The only meat type of which the production in in decline is that from cattle. Cattle beef production has dropped over 25 % since the early 1990s, going from 10 Mt to 7.4 Mt in 2014.

The number of animals held at a specific moment (or 'animal places') in the EU for the production of the animal products depicted in Figure 7 can be found in Figure 8. Not surprisingly, the number for chickens is the largest of by far. The number of chicken places present in the EU countries has been steadily increasing, from 1 billion in 1970 to 1.3 billion in 2014. The number for cattle has been decreasing since 1985, from 120 million to around 90 million in 2014. While pig meat production numbers have been increasing, the number of pig places in the EU has been decreasing since the second halve of the 1980s, from 170 million to 149 million in 2014. Apparently, pig places are being more efficiently used, for example by using faster growing animals.

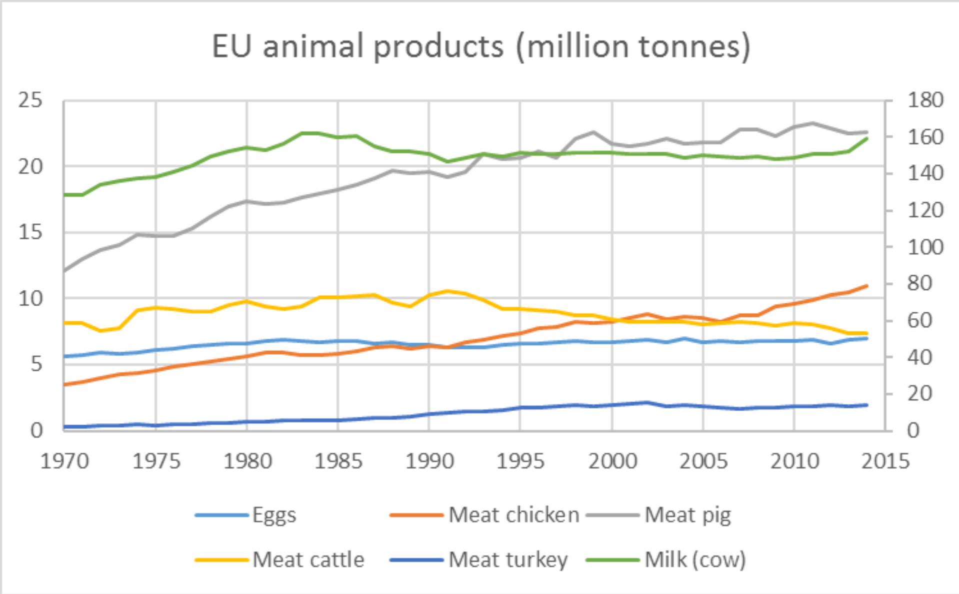

Figure 7. EU animal products from 1970 to 2014 in million tonnes. Cow's milk is depicted using the secondary y-axis (FAOstat).

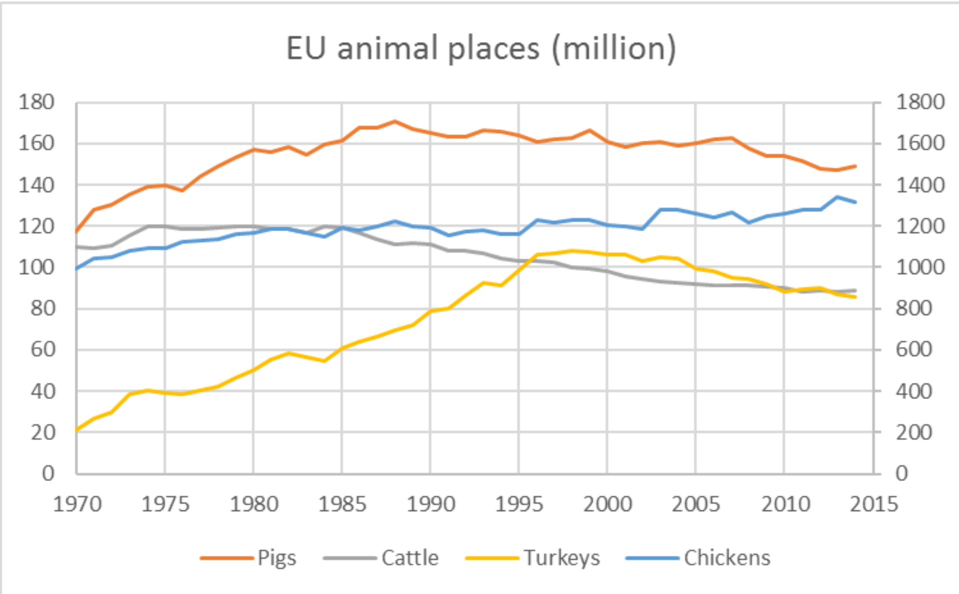

Figure 8. EU husbandry animal places 1970 to 2014 (million). Chicken places are depicted using the secondary y-axis (FAOstat).

5 Food

The food market for legumes is of a much smaller volume than the feed market. However, consumers' dietary habits and future dietary changes do not only influence the development of legume chains in a direct manner. In addition to legumes being consumed directly, future consumption of meat, fish, eggs, and dairy drive the feed market and the legumes used in it.

5.1 Consumption of protein

On average, the daily diet of EU citizens contains 104 g protein per person, according to FAOstat data of 2013. 58 % of this comes from animal sources, 28 % from cereals, 6 % from potatoes/vegetables, and 1.6% from pulses (Table 2). Similar tables for each of the EU countries and of the United States can be found in the Appendix. When comparing protein intake from pulses (mainly beans and peas), soya bean, and ground nuts between EU countries, interesting differences can be noted (Figure 7). In Italy, Spain and Greece, the average consumption of protein from pulses is relatively high. It is even higher in Estonia, but due to its relatively small number of inhabitants, Estonia's consumption does not affect the average EU consumption much. Inhabitants of Austria, Czech Republic, Germany, and Slovenia seem to be consuming relatively a lot of protein from soya bean, compared to the other EU countries. Of course, taking into account population numbers, Germany has the most influence on the average EU soya bean protein consumption. The relative protein intake from groundnut (peanut) in the EU varies less between countries than that of pulses and soya bean. Compared to the United States, the average relative intake of protein from pulses and groundnut in the EU is noticeably lower.

The average EU citizen consumes more protein than the recommended daily intake of 0.83 g per kg body weight, mentioned in an expert consultation by the World Health Organization [35]. This amounts to 58 g per day for a 70 kg person. From a sustainability perspective, especially the consumption of animal protein is too high, as the production of 1 kg of animal protein takes on average 4 kg of plant protein for milk, and 2.7 for chicken, 5.4 for pork and 10.3 to 11.8 for beef. When taking into account that not all of the animal is consumed, the numbers for consumed protein of the latter three categories grow to 4.3 for chicken, 11.9 for pork, and 22.7 to 25.9 for beef [36].

Regarding animal protein consumption and increasing income per capita, it is interesting to note that the growth of meat consumption has slowed down to equal or less than the population growth in recent decades, at least in developed countries [2]. In other words, with increasing income, people - on average- are no longer consuming more animal protein than before, and sometimes less than before. See paragraph 5.3.

Table 3. Composition of EU average daily protein intake (%) in 2013, with main contributing product groups (FAOSTAT, 2013).

	gram	% of total	% of animal / vegetal
Total	104		
Animal protein	60	58	
Vegetal protein	43	42	
Animal products			
Meat		27	46
Milk, excl. butter		20	34
Fish, seafood		6.4	11
Eggs		3.6	6.2
Offal		1.4	2.3
Cream		0.3	0.5
Butter, ghee		0.1	0.1
Other		0.2	0.4
Total		58	100
Vegetal products			
Cereals, excl. beer		28	67
Vegetables		3.4	8.2
Starchy roots		2.8	6.6
Pulses		1.6	3.8
Soya beans		0.2	0.5
Groundnuts		0.6	1.5
Beer		0.9	2.1
Treenuts		0.8	1.9
Coffee and products		0.7	1.7
Cocoa beans and products		0.4	1.0
Tea, incl. mate		0.1	0.3
Other		2.2	5.2
Total		43	100

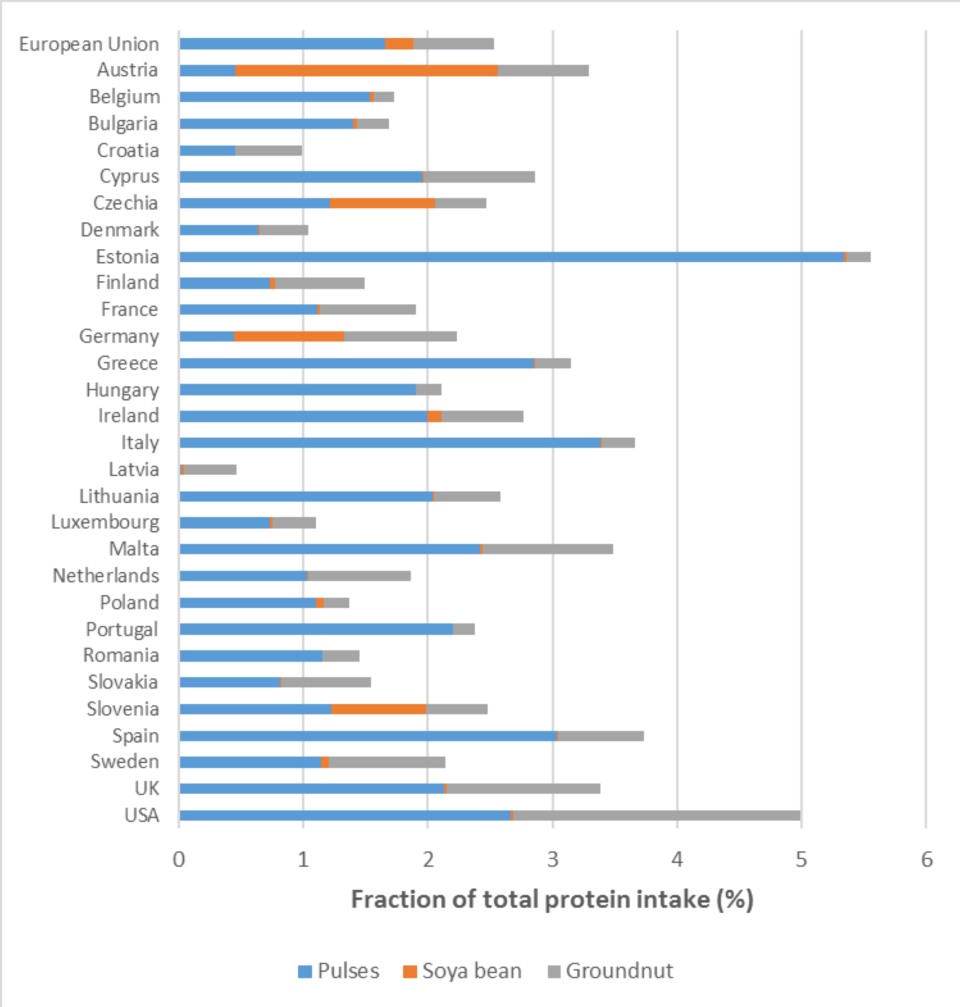

Figure 9. Protein intake from pulses, soya bean, and groundnut (% of total protein intake) in EU countries and USA.

5.2 Nutritional value of plant proteins compared to animal proteins

Considering the amino acid composition is a way of determining the nutritional value or quality of food proteins. In general, animal protein contains amino acids in a ratio that is well suited for human consumption. Plant protein commonly contains these amino acids in less than optimal ratios. For example, the essential amino acid lysine is usually present in a lower concentration in plant protein compared to animal protein. The same goes for methionine and cysteine, although the latter is considered semi-essential. This means that a balanced mixture of plant protein is needed to reach a balanced amino acid intake, when replacing animal protein. Furthermore, the digestibility and availability of plant proteins is generally lower than those of animal protein. This suggests that more plant protein is needed to reach an equal uptake when comparing to animal protein. Nonetheless, if the protein intake is equal or above the recommended level, the supply of all essential (and semi-essential) amino acids can be considered sufficient or exceeding sufficiency for adults. For growing children, this may not be the case [37].

5.3 Consumer perception

In recent years, consumers seem to be becoming more aware of their food, in the sense that consumers to a greater extent than before are preferring to consume less animal protein (or meat) , while replacing it with plant protein. Some examples of reasons for doing this are:

<u>Health</u>: A high intake of animal protein may coincide with a higher animal fat intake. As animal fats contain a relatively large fraction of saturated fatty acids, cardiovascular disease is associated. Government policies can be applied to reduce animal consumption, and increase fish and vegetable consumption, for example in the Netherlands [33]. Regarding high protein intake on its own, a correlation has been shown between high intake of both total protein as well as animal protein and type 2 diabetes, while not for vegetal protein. The exact mechanism and further details are not yet known [38].
Possibly, a related subject is that of recent or relatively recent food chain related diseases or other negatives connotations (e.g. fipronil, avian flu, swine fever, mad cow disease).

<u>Overfishing:</u> Consumers are growing more aware of the environmental/ecological and social issues that arise from overfishing. Fish farming is seen as a solution to meet the demand for fish, and the industry is growing. Notwithstanding ecological advantages of fish farming compared to overfishing the open sea, plant protein is needed for the fish feed [33].

<u>Sustainability:</u> Greenhouse gas (GHG) emissions, deforestation, animal welfare, and water scarcity are also reasons used to promote vegetarianism and veganism, for example by the European Vegetarian Union (a cooperation of EU national vegetarian/vegan organisations).

Of the issues mentioned above that relate to meat consumption and the consumers' tendencies and receptiveness to dietary change from animal to plant protein sources, it may be important to note that British consumers mention health and animal welfare as more important motivations in avoiding to eat red and processed meats than environmental sustainability, as is claimed by a British study [39].

<u>Regionalism:</u> Consumption of food that is locally or regionally grown seems to become more popular. The selling point usually is in the area of transparency in the production chain, sustainability, and non-GM. An example is the organisation Donau Soja, which promotes sustainable non-GM soya production in the Danube region (www.donausoja.org).

5.4 Initiatives to promote plant protein consumption

Several initiatives promoting the consumption of plant protein exist in the EU, and they originate on a national level. These initiatives may differ greatly in their origin, field, focus, etcetera. They broadly can be divided into three categories: governmental/research, consumer based, and producer based. The examples below are not an exhaustive list, as many more examples likely exist.

Next to LEGVALUE, the EU project TRUE (TRansition paths to sUstainable legume-based systems in Europe) recently started. The project is comprised of 22 partners from 10 EU countries and runs from 2017 to 2021 [40].

In France, IMPROVE (Institut Mutualisé pour les Protéines Végétales) is a private enterprise created with funding from French companies (Avril, Tereos, Vivescia, Invivo, etc), and with INRA as one of the shareholders (source: Chardigny, Person. Comm.). Generally speaking, IMPROVE does contract research in the field of valorisation of plant proteins for food, feed, biobased materials and cosmetics.
ANSES -the French agency for food, environmental and occupational health & safety-, promotes an increase of consumption of pulses by a factor 2 in its most recent revision of the dietary guidelines, while advising to reduce red meat consumption. Emphasising their importance, the group of pulses has been added as a separate food group, while they used to be categorised under the "starches" group [41].

In the Netherlands, the Green Protein Alliance is a retail-producer based initiative for the promotion of plant protein. Their goal is ambitious: to bring the Dutch protein consumption distribution from the current 37:63 % animal vs plant protein intake (data '07-'10, Dutch ratio of animal to plant protein intake is different to EU average) back to the 50:50 % it was in 1960, by 2025. This is to be done mostly by promoting large increases in consumption of pulses, nuts and seeds, mushrooms, and seaweed/algae, at the expense of meat consumption [42]. The Dutch Centre for Nutrition also recommends paying attention to the level of protein intake, also stating a preference for plant protein over animal protein, this being partly for health reasons and partly for sustainability reasons (www.voedingscentrum.nl). In 2017, the Dutch ministries of Economic Affairs and of Foreign Affairs, together with producers, a worker's union, and environmental organisations and knowledge institutes, have signed a covenant aimed at promoting international sustainable production of and consumer preference for plant proteins, by pilot scale projects [43].

In Germany, the German Nutrition Society (DGE) published a report on vegan nutrition, in which it recommends pulses for meat replacement and soya products to replace dairy. The combination of pulses, cereals and potatoes is mentioned to be able to meet the protein requirements of adults, with uncertainty on the same subject for children [44]. DECHEMA (Society for Chemical Engineering and Biotechnology) supports the development of different types of Single Cell Protein (see paragraph 5.5.1) [45, 46].

5.5 Approaches to promote plant protein consumption

Different approaches to promote the consumption of plant protein can be taken depending on their focus. A general approach is to promote consumption of plant protein sources such as pulses, hereby indirectly replacing animal protein intake. Some focus on directly replacing meat products with plant protein based processed products: meat replacements. Another approach focusses on the production of plant protein based products (soya milk, etc) to replace dairy.

5.5.1 Development of meat replacement products

Apart from products such as pulses that may replace meat in a dietary sense, there is a development of processed products made from legumes and other novel protein sources to mention when considering legume value chains. When directed specifically towards replacing meat, these products are usually referred to as meat replacements or meat analogues.

The growth of meat replacement products in recent years is impressive: more sources need to be checked, but estimates place the global meat replacement market (including tofu and below-mentioned products) at US$5.96 billion in 2020 [47]. Most of the growth is expected in Asia, USA, and Europe.

A quick and indicative survey by the authors of this report of the online shopping website of the largest supermarket chain in the Netherlands (Albert Heijn), showed that the currently available meat replacements -soy based, dairy based, and Quorn- tend to be priced similarly to 'organic' or high end meat products (for example focussing on hamburger-like patties and sausages). Or, about 50 % to 100 % more expensive than the cheapest meat equivalents.

Several types of meat replacement products exist, or are in development:

Soya protein based

Soya bean (protein) can be used more or less 'as is' or simply as a ground paste. Several techniques exist for producing soya protein based products, focussing more on imitating the 'mouthfeel'. For example:

- Extrusion is an established technology in which a material is pushed through a die in order to shape the resulting product. Inside the extruder, the ingredients are mixed under high shear and heated. The combination of shear forces and heat can be used to create a fibrous structure from a soy protein containing mixture of ingredients.
  Examples are:
  - Beeter (in NL) or Plenti (outside NL). Produced by Ojah. Marketed specifically as replacement of meat or fish (http://plenti.eu)
  - Beyond meat (USA); Marketed as meat replacement. (http://beyondmeat.com)
- Shear cell technology also uses shear forces to create fibrous structures from soy protein containing mixtures. Compared to extrusion, the shear cell technology for creating meat analogues is still in development. It is claimed that it can create superior products and/or at milder processing conditions. Some samples of meat analogues have been produced [48].

Both of the above technologies are applied to structure soya protein in such a way that the resulting product is somewhat fibrous, hereby resembling meat.

Pea protein based

In meat replacement products made using extrusion (mentioned above), sometimes pea protein is also applied. The German company IGV produces extruded pea protein flakes, crispies and nuggets, to be used in sausages, 'meat'balls, bolognaise sauce, and burger patties, but also applicable in muesli (www.igv-gmbh.de/en).

Dairy based

Although still animal protein, dairy based meat replacement products are available and thus compete with legume based products. The environmental impact of these products is usually similar to that of meat. The most known example is Valess, produced by Campina (NL), marketed as an alternative for meat and fish. The traditional South-Asian dish paneer, a fresh cheese, can be considered a meat replacement.

Seaweed based

Traditionally, seaweed (or macroalgae) is part of many Asian culinary cultures. Specifically as a meat replacement, it is used in burger patties, developed by the company Dutch Weed Burger (NL) (http://dutchweedburger.com), and by the Damhert Nutrition (Be). The patties are partly seaweed, partly other ingredients, such as soy.

Microalgae based

Although regarded a promising protein source since decades, specific meat replacement products made from micro-algal protein do not yet seem developed. What is done is that microalgae such as *Chlorella* or cyanobacteria such as *Spirulina* are mixed in with other ingredients in patties (Damhert, Be), bread, or other snack products (Dutch Weed Burger, NL). The inclusion level of micro-algae in these applications seems to be relatively low, hereby making a limited addition to the total protein content of the product.

Single Cell Protein (SCP) based

The intracellular protein of bacteria, yeasts, fungi, and micro-algae (all single cell microorganisms) can be used to replace meat protein in food products. Sometimes the whole cells are used. Whether or not the micro-algae used as stated above can be considered Single Cell Protein, can depend on the level and reason of inclusion. The development of SCP protein products can be oriented towards both feed and food applications.

- A well-known example of a single cell protein food product is Quorn (UK), which typically uses protein from the fungus *Fusarium venenatum* mixed with egg albumen as binder. Using egg white does mean that the product still contains some animal based protein. Recently, a potato extract is used instead of egg white in the vegan line of Quorn products (www.quorn.co.uk).
- Worth mentioning is this aspect is the development of single cell protein 'from CO_2 and electricity'. These technologies are comparable to growing SCP using sugar, in that they also grow micro-organisms for the intracellular protein. The largest difference is that these new technologies use microorganisms that use carbon dioxide (CO_2) as the carbon source and hydrogen as the energy source by the organisms, instead of using organisms that take both carbon and energy from sugar. The mentioned electricity is used to electrolyse water to the needed hydrogen (and oxygen), and the CO_2 could be captured from the air or a more concentrated stream.
- 'Single cell protein from methane' is also mentioned, and is similar in principle to a sugar-fed fermentation. Here, instead of sugar, methane is used to feed a specific microorganism, hereby creating intracellular protein. Compared to animal protein, plant protein and 'classic' single cell protein, these CO_2 and methane based technologies would hardly need any land to produce protein. The single cell protein from methane is in production for animal feed at a 100 tonnes per year scale [29]. The Finnish company VTT works on a similar method, using methane from biogas production [49].

Insect based

Recently, insect based foods are gaining some popularity. Although several insect species are used, the main focus seems to lie with crickets and mealworms, both whole as well as a ground meal. The meals can be applied in many products, ranging from energy/fruit bars and pasta to the more direct meat replacement products such as patties. The website bugburger.se has a list with many product types, producers, and insect growers [50]. Examples of EU companies that produce specific meat replacements based on insect protein are: Bug Foundation (Germany) and Damhert Nutrition (Belgium).

In vitro meat

Strictly speaking not a meat replacement, but artificially grown real muscle fibres. This technology has successfully produced some samples, but still requires a lot of development.

5.5.2 Existing processed legume products

Soya milk is a well-known product that can be seen as a replacement for milk, hereby replacing animal protein. More literal meat replacements are products such as tofu, made from soya milk, and tempeh, made from fermented soya beans. They originated centuries ago in China and Indonesia, respectively. Pea protein can be used to produce noodles, although not a meat replacement in this application.

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7 Partners involved in the work

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8 Annex: Composition of average daily protein intake (%) in 2013 of EU, EU countries, and USA, with main contributing product groups (FAOstat, 2016).

	EU average			USA average			Austria			Belgium		
	gram	% of total	% of animal or vegetal	gram	% of total	% of animal or vegetal	gram	% of total	% of animal or vegetal	gram	% of total	% of animal or vegetal
Total	104	100%		110	100%		106	100%		100	100%	
Animal protein	60	58%		70	64%		63	59%		58	58%	
Vegetal protein	43	42%		40	36%		43	41%		41	42%	
Animal products												
Meat	28	27%	46%	38	35%	55%	31	29%	49%	21	22%	37%
Milk, excl butter	20	20%	34%	22	20%	31%	22	21%	35%	24	24%	41%
Fish, seafood	6.6	6.4%	11%	5.1	4.6%	7%	4.1	3.9%	7%	6.5	6.5%	11%
Eggs	3.7	3.6%	6.2%	4.3	3.9%	6%	4.6	4.3%	7%	3.8	3.8%	6%
Offal	1.4	1.4%	2.3%	0.2	0.2%	0%	0.6	0.6%	1%	1.7	1.7%	3%
Cream	0.3	0.3%	0.5%	0.0	0.0%	0%	0.6	0.6%	1%	0.7	0.7%	1%
Butter, ghee	0.1	0.1%	0.1%	0.1	0.0%	0%	0.1	0.1%	0%	0.2	0.2%	0%
Other	0.0	0.2%	0.4%	0.0	0.0%	0%	0.0	0.0%	0%	0.0	0.0%	0%
Total			100%			100%			100%			100%
Vegetal products												
Cereals, excl. beer	29	28%	67%	24	22%	60%	27	25%	62%	26	26%	62%
Vegetables	3.6	3.4%	8.2%	3.2	2.9%	8%	3.3	3.1%	8%	4.6	4.6%	11%
Starchy roots	2.9	2.8%	6.6%	2.4	2.2%	6%	2.3	2.2%	5%	4.1	4.1%	10%
Pulses	1.7	1.6%	3.8%	2.7	2.4%	7%	0.5	0.4%	1%	1.5	1.5%	4%
Soya beans	0.2	0.2%	0.5%	0.0	0.0%	0%	2.1	2.0%	5%	0.0	0.0%	0%
Groundnuts	0.7	0.6%	1.5%	2.3	2.1%	6%	0.7	0.7%	2%	0.2	0.2%	0%
Beer	0.9	0.9%	2.1%	0.7	0.6%	2%	1.5	1.4%	3%	1.0	1.0%	2%
Treenuts	0.8	0.8%	1.9%	1.0	0.9%	3%	1.1	1.0%	2%	1.3	1.3%	3%

	Bulgaria			Croatia			Cyprus			Czechia		
	gram	% of total	% of animal or vegetal	gram	% of total	% of animal or vegetal	gram	% of total	% of animal or vegetal	gram	% of total	% of animal or vegetal
Total	84	100%		84	100%		78	100%		87	100%	
Animal protein	41	49%		48	57%		45	58%		50	58%	
Vegetal protein	42	51%		36	43%		33	42%		37	42%	
Animal products												
Meat	18	22%	44%	19	23%	40%	24	30%	52%	22	25%	44%
Milk, excl butter	16	19%	38%	19	23%	40%	12	15%	26%	20	23%	40%
Fish, seafood	2.1	2.5%	5%	5.9	6.9%	12%	6.0	7.8%	13%	2.6	2.9%	5%
Eggs	2.6	3.1%	6%	2.5	3.0%	5%	2.6	3.4%	6%	3.4	3.9%	7%
Offal	2.4	2.8%	6%	1.0	1.2%	2%	1.2	1.6%	3%	1.5	1.7%	3%
Cream	0.0	0.0%	0%	0.0	0.0%	0%	0.0	0.0%	0%	0.3	0.3%	1%
Butter, ghee	0.0	0.0%	0%	0.0	0.0%	0%	0.0	0.0%	0%	0.1	0.1%	0%
Other	0.3	0.4%	1%	0.0	0.0%	0%	0.0	0.1%	0%	0.1	0.1%	0%
Total			100%			100%			100%			100%
Vegetal products												
Cereals, excl. beer	33	39%	78%	26	30%	70%	20	26%	63%	24	28%	66%
Vegetables	1.7	2.0%	4%	2.6	3.1%	7%	3.1	4.0%	10%	2.2	2.5%	6%
Starchy roots	1.1	1.3%	3%	1.7	2.1%	5%	0.9	1.1%	3%	3.2	3.6%	9%
Pulses	1.4	1.7%	3%	0.5	0.5%	1%	2.0	2.5%	6%	1.2	1.4%	3%
Soya beans	0.0	0.0%	0%	0.0	0.0%	0%	0.0	0.0%	0%	0.9	1.0%	2%
Groundnuts	0.3	0.3%	1%	0.5	0.6%	1%	0.9	1.1%	3%	0.4	0.5%	1%
Beer	1.0	1.2%	2%	1.1	1.3%	3%	0.4	0.5%	1%	1.9	2.2%	5%
Treenuts	0.3	0.4%	1%	0.5	0.6%	1%	0.8	1.0%	2%	0.4	0.4%	1%
Coffee and products	0.6	0.7%	1%	0.9	1.1%	3%	0.5	0.6%	1%	0.3	0.4%	1%
Cocoa beans and products	0.4	0.5%	1%	0.8	0.9%	2%	0.6	0.7%	2%	0.6	0.6%	1%
Tea, incl. mate	0.0	0.0%	0%	0.0	0.0%	0%	0.1	0.1%	0%	0.1	0.1%	0%
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

	Denmark			Estonia			Finland			France		
	gram	% of total	% of animal or vegetal	gram	% of total	% of animal or vegetal	gram	% of total	% of animal or vegetal	gram	% of total	% of animal or vegetal
Total	109	100%		104	100%		118	100%		111	100%	
Animal protein	70	64%		53	51%		73	62%		69	63%	
Vegetal protein	39	36%		51	49%		45	38%		41	37%	
Animal products												
Meat	29	27%	42%	18	17%	33%	27	23%	36%	30	27%	43%
Milk, excl butter	23	21%	33%	26	25%	49%	32	27%	44%	23	21%	33%
Fish, seafood	8.6	7.9%	12%	4.0	3.8%	7%	10	8.8%	14%	9.0	8.2%	13%
Eggs	5.1	4.7%	7%	3.7	3.5%	7%	3.0	2.5%	4%	4.1	3.7%	6%
Offal	3.4	3.2%	5%	1.9	1.8%	4%	0.7	0.6%	1%	2.9	2.7%	4%
Cream	0.7	0.6%	1%	0.1	0.1%	0%	0.4	0.4%	1%	0.3	0.3%	0%
Butter, ghee	0.0	0.0%	0%	0.0	0.0%	0%	0.1	0.1%	0%	0.2	0.2%	0%
Other	0.0	0.0%	0%	0.0	0.0%	0%	0.0	0.0%	0%	0.0	0.0%	0%
Total			100%			100%			100%			100%
Vegetal products												
Cereals, excl. beer	26	24%	66%	33	31%	65%	31	26%	69%	29	27%	71%
Vegetables	3.4	3.1%	9%	3.3	3.2%	6%	2.6	2.2%	6%	3.4	3.1%	8%
Starchy roots	2.2	2.0%	6%	3.2	3.1%	6%	2.8	2.3%	6%	2.2	2.0%	5%
Pulses	0.6	0.6%	2%	5.3	5.1%	11%	0.7	0.6%	2%	1.1	1.0%	3%
Soya beans	0.0	0.0%	0%	0.0	0.0%	0%	0.0	0.0%	0%	0.0	0.0%	0%
Groundnuts	0.4	0.4%	1%	0.2	0.2%	0%	0.7	0.6%	2%	0.8	0.7%	2%
Beer	0.8	0.8%	2%	1.5	1.4%	3%	1.1	0.9%	2%	0.3	0.3%	1%
Treenuts	1.2	1.1%	3%	0.7	0.6%	1%	0.4	0.3%	1%	0.7	0.6%	2%
Coffee and products	1.5	1.3%	4%	0.9	0.9%	2%	2.1	1.7%	5%	0.8	0.7%	2%
Cocoa beans and products	0.9	0.8%	2%	1.1	1.0%	2%	0.5	0.4%	1%	0.8	0.7%	2%
Tea, incl. mate	0.1	0.1%	0%	0.1	0.1%	0%	0.1	0.1%	0%	0.1	0.1%	0%
Other	2.2	2.1%	6%	1.8	1.7%	4%	2.7	2.3%	6%	1.6	1.5%	4%
Total			100%			100%			100%			100%

	Germany			Greece			Hungary			Ireland		
	gram	% of total	% of animal or vegetal	gram	% of total	% of animal or vegetal	gram	% of total	% of animal or vegetal	gram	% of total	% of animal or vegetal
Total	102	100%		109	100%		79	100%		110	100%	
Animal protein	61	61%		59	54%		42	53%		65	59%	
Vegetal protein	40	39%		50	46%		37	47%		45	41%	
Animal products												
Meat	28	27%	45%	25	23%	42%	21	27%	50%	31	28%	47%
Milk, excl butter	25	24%	40%	24	22%	41%	14	18%	34%	25	22%	38%
Fish, seafood	4.2	4.2%	7%	5.2	4.8%	9%	1.5	1.9%	4%	5.2	4.7%	8%
Eggs	3.8	3.8%	6%	3.2	2.9%	5%	3.9	4.9%	9%	2.8	2.5%	4%
Offal	0.4	0.4%	1%	1.4	1.3%	2%	0.8	1.0%	2%	1.4	1.2%	2%
Cream	0.5	0.5%	1%	0.2	0.2%	0%	0.5	0.6%	1%	0.4	0.4%	1%
Butter, ghee	0.1	0.1%	0%	0.0	0.0%	0%	0.0	0.0%	0%	0.1	0.1%	0%
Other	0.0	0.0%	0%	0.0	0.0%	0%	0.1	0.1%	0%	0.0	0.0%	0%
Total			100%			100%			100%			100%
Vegetal products												
Cereals, excl. beer	26	26%	66%	30	27%	60%	27	34%	73%	30	27%	65%
Vegetables	3.1	3.1%	8%	6.4	5.9%	13%	2.9	3.6%	8%	3.7	3.4%	8%
Starchy roots	2.5	2.5%	6%	3.1	2.8%	6%	2.0	2.5%	5%	3.4	3.1%	8%
Pulses	0.4	0.4%	1%	2.9	2.6%	6%	1.9	2.4%	5%	2.0	1.8%	4%
Soya beans	0.9	0.9%	2%	0.0	0.0%	0%	0.0	0.0%	0%	0.1	0.1%	0%
Groundnuts	0.9	0.9%	2%	0.3	0.3%	1%	0.2	0.3%	1%	0.7	0.6%	1%
Beer	1.3	1.3%	3%	0.5	0.4%	1%	0.9	1.1%	2%	2.1	1.9%	5%
Treenuts	1.3	1.3%	3%	1.4	1.3%	3%	0.0	0.1%	0%	0.6	0.6%	1%
Coffee and products	1.0	1.0%	3%	0.7	0.6%	1%	0.0	0.0%	0%	0.3	0.3%	1%
Cocoa beans and products	0.2	0.2%	0%	0.5	0.5%	1%	0.5	0.6%	1%	0.3	0.2%	1%
Tea, incl. mate	0.1	0.1%	0%	0.1	0.0%	0%	0.0	0.0%	0%	0.4	0.4%	1%
Other	1.9	1.9%	5%	4.0	3.7%	8%	1.5	1.9%	4%	2.1	1.9%	5%
Total			100%			100%			100%			100%

	Italy			Latvia			Lithuania			Luxembourg		
	gram	% of total	% of animal or vegetal	gram	% of total	% of animal or vegetal	gram	% of total	% of animal or vegetal	gram	% of total	% of animal or vegetal
Total	109	100%		91	100%		124	100%		114	100%	
Animal protein	58	54%		51	56%		76	61%		72	63%	
Vegetal protein	50	46%		40	44%		48	39%		42	37%	
Animal products												
Meat	29	26%	49%	19	20%	36%	27	21%	35%	33	29%	46%
Milk, excl butter	17	16%	29%	16	18%	32%	27	22%	35%	24	21%	33%
Fish, seafood	6.9	6.3%	12%	7.3	8.0%	14%	17	13%	22%	8.4	7.4%	12%
Eggs	4.2	3.8%	7%	4.1	4.5%	8%	3.9	3.1%	5%	4.3	3.7%	6%
Offal	1.2	1.1%	2%	3.2	3.5%	6%	1.9	1.5%	2%	2.0	1.7%	3%
Cream	0.2	0.2%	0%	1.4	1.5%	3%	0.4	0.3%	0%	0.2	0.2%	0%
Butter, ghee	0.1	0.1%	0%	0.0	0.0%	0%	0.1	0.0%	0%	0.1	0.0%	0%
Other	0.1	0.0%	0%	0.0	0.1%	0%	0.1	0.1%	0%	0.1	0.0%	0%
Total			100%			100%			100%			100%
Vegetal products												
Cereals, excl. beer	35	32%	70%	28	30%	68%	34	28%	71%	25	22%	59%
Vegetables	4.5	4.1%	9%	3.2	3.5%	8%	3.0	2.4%	6%	4.0	3.5%	10%
Starchy roots	1.5	1.4%	3%	5.1	5.5%	13%	4.1	3.3%	9%	2.1	1.8%	5%
Pulses	3.4	3.1%	7%	0.0	0.0%	0%	2.0	1.6%	4%	0.7	0.6%	2%
Soya beans	0.0	0.0%	0%	0.0	0.0%	0%	0.0	0.0%	0%	0.0	0.0%	0%
Groundnuts	0.3	0.2%	1%	0.4	0.5%	1%	0.5	0.4%	1%	0.4	0.3%	1%
Beer	0.4	0.4%	1%	1.0	1.1%	3%	1.4	1.1%	3%	1.2	1.0%	3%
Treenuts	1.1	1.0%	2%	0.6	0.6%	1%	0.4	0.3%	1%	0.1	0.0%	0%
Coffee and products	0.9	0.9%	2%	0.5	0.5%	1%	0.7	0.6%	2%	4.0	3.5%	9%
Cocoa beans and products	0.3	0.3%	1%	0.6	0.6%	1%	0.0	0.0%	0%	1.3	1.1%	3%
Tea, incl. mate	0.0	0.0%	0%	0.1	0.1%	0%	0.1	0.1%	0%	0.1	0.1%	0%
Other	2.8	2.6%	6%	1.5	1.6%	4%	1.4	1.1%	3%	3.3	2.9%	8%
Total			100%			100%			100%			100%

	Malta			Netherlands			Poland			Portugal		
	gram	% of total	% of animal or vegetal	gram	% of total	% of animal or vegetal	gram	% of total	% of animal or vegetal	gram	% of total	% of animal or vegetal
Total	110	100%		112	100%		101	100%		111	100%	
Animal protein	62	56%		76	68%		53	52%		67	61%	
Vegetal protein	49	44%		36	32%		48	48%		44	39%	
Animal products												
Meat	30	27%	48%	35	31%	46%	28	28%	53%	31	28%	46%
Milk, excl butter	18	17%	30%	29	26%	38%	15	15%	29%	17	16%	26%
Fish, seafood	8.6	7.8%	14%	6.9	6.2%	9%	5.5	5.4%	10%	14	12.2%	20%
Eggs	3.6	3.3%	6%	4.4	3.9%	6%	2.4	2.3%	4%	2.8	2.5%	4%
Offal	1.0	0.9%	2%	0.4	0.3%	0%	1.3	1.3%	2%	2.3	2.1%	3%
Cream	0.0	0.0%	0%	0.0	0.0%	0%	0.5	0.5%	1%	0.1	0.1%	0%
Butter, ghee	0.0	0.0%	0%	0.0	0.0%	0%	0.1	0.1%	0%	0.1	0.0%	0%
Other	0.1	0.1%	0%	0.0	0.0%	0%	0.0	0.0%	0%	0.0	0.0%	0%
Total			100%			100%			100%			100%
Vegetal products												
Cereals, excl. beer	32	29%	65%	22	19%	60%	36	35%	74%	29	26%	66%
Vegetables	7.2	6.6%	15%	3.0	2.7%	8%	3.0	2.9%	6%	4.9	4.4%	11%
Starchy roots	1.6	1.4%	3%	4.0	3.6%	11%	4.5	4.5%	9%	2.9	2.6%	7%
Pulses	2.4	2.2%	5%	1.0	0.9%	3%	1.1	1.1%	2%	2.2	2.0%	5%
Soya beans	0.0	0.0%	0%	0.0	0.0%	0%	0.1	0.1%	0%	0.0	0.0%	0%
Groundnuts	1.1	1.0%	2%	0.8	0.7%	2%	0.2	0.2%	0%	0.2	0.2%	0%
Beer	0.5	0.5%	1%	0.7	0.7%	2%	1.4	1.3%	3%	0.6	0.6%	1%
Treenuts	0.8	0.7%	2%	1.1	1.0%	3%	0.4	0.4%	1%	0.5	0.5%	1%
Coffee and products	0.3	0.3%	1%	0.4	0.4%	1%	0.3	0.3%	1%	0.8	0.7%	2%
Cocoa beans and products	0.8	0.7%	2%	0.0	0.0%	0%	0.1	0.1%	0%	0.6	0.5%	1%
Tea, incl. mate	0.4	0.4%	1%	0.2	0.2%	1%	0.1	0.1%	0%	0.0	0.0%	0%
Other	1.8	1.7%	4%	2.9	2.6%	8%	1.3	1.3%	3%	2.0	1.8%	5%
Total			100%			100%			100%			100%

	Romania			Slovakia			Slovenia			Spain		
	gram	% of total	% of animal or vegetal	gram	% of total	% of animal or vegetal	gram	% of total	% of animal or vegetal	gram	% of total	% of animal or vegetal
Total	103	100%		73	100%		96	100%		105	100%	
Animal protein	47	46%		35	48%		52	54%		65	62%	
Vegetal protein	56	54%		38	52%		44	46%		40	38%	
Animal products												
Meat	16	16%	35%	16	22%	46%	24	25%	46%	31	30%	48%
Milk, excl butter	23	23%	50%	11	15%	32%	20	21%	39%	14	14%	22%
Fish, seafood	1.8	1.7%	4%	2.3	3.2%	7%	2.9	3.0%	6%	12.7	12.1%	19%
Eggs	4.0	3.9%	9%	4.7	6.5%	13%	2.7	2.8%	5%	4.2	4.0%	6%
Offal	1.6	1.5%	3%	0.7	1.0%	2%	1.7	1.7%	3%	2.5	2.3%	4%
Cream	0.0	0.0%	0%	0.1	0.1%	0%	0.6	0.7%	1%	0.1	0.1%	0%
Butter, ghee	0.0	0.0%	0%	0.1	0.1%	0%	0.1	0.1%	0%	0.0	0.0%	0%
Other	0.0	0.0%	0%	0.1	0.1%	0%	0.0	0.0%	0%	0.0	0.0%	0%
Total			100%			100%			100%			100%
Vegetal products												
Cereals, excl. beer	40	39%	72%	28	39%	75%	31	32%	69%	24	23%	62%
Vegetables	5.3	5.1%	9%	1.8	2.4%	5%	2.8	2.9%	6%	3.7	3.5%	9%
Starchy roots	4.3	4.1%	8%	2.2	3.0%	6%	2.3	2.3%	5%	2.4	2.3%	6%
Pulses	1.2	1.1%	2%	0.8	1.1%	2%	1.2	1.3%	3%	3.0	2.9%	8%
Soya beans	0.0	0.0%	0%	0.0	0.0%	0%	0.8	0.8%	2%	0.0	0.0%	0%
Groundnuts	0.3	0.3%	1%	0.7	1.0%	2%	0.5	0.5%	1%	0.7	0.7%	2%
Beer	1.1	1.1%	2%	1.0	1.3%	3%	1.0	1.1%	2%	1.0	1.0%	3%
Treenuts	0.2	0.2%	0%	0.4	0.6%	1%	0.8	0.9%	2%	1.1	1.0%	3%
Coffee and products	0.4	0.4%	1%	0.5	0.7%	1%	0.8	0.8%	2%	0.7	0.6%	2%
Cocoa beans and products	0.3	0.3%	1%	0.3	0.4%	1%	0.9	0.9%	2%	0.7	0.6%	2%
Tea, incl. mate	0.0	0.0%	0%	0.0	0.0%	0%	0.0	0.0%	0%	0.0	0.0%	0%
Other	2.4	2.3%	4%	1.8	2.5%	5%	2.6	2.7%	6%	2.0	1.9%	5%
Total			100%			100%			100%			100%

	Sweden			United Kingdom				
	gram	% of total	% of animal or vegetal	gram	% of total	% of animal or vegetal		
Total	108	100%		103	100%			
Animal protein	71	66%		58	56%			
Vegetal protein	37	34%		45	44%			
Animal products								
Meat	30	28%	43%	29	28%	50%		
Milk, excl butter	27	25%	38%	19	18%	33%		
Fish, seafood	8.3	7.7%	12%	5.5	5.3%	9%		
Eggs	4.2	3.9%	6%	3.4	3.3%	6%		
Offal	0.3	0.3%	0%	0.9	0.9%	2%		
Cream	0.9	0.8%	1%	0.0	0.0%	0%		
Butter, ghee	0.1	0.1%	0%	0.1	0.1%	0%		
Other	0.0	0.0%	0%	0.0	0.0%	0%		
Total			100%			100%		
Vegetal products								
Cereals, excl. beer	23	21%	62%	28	27%	62%		
Vegetables	3.0	2.7%	8%	3.3	3.2%	7%		
Starchy roots	2.4	2.2%	6%	4.2	4.0%	9%		
Pulses	1.1	1.1%	3%	2.1	2.1%	5%		
Soya beans	0.1	0.1%	0%	0.0	0.0%	0%		
Groundnuts	0.9	0.9%	3%	1.2	1.2%	3%		
Beer	0.8	0.7%	2%	1.0	0.9%	2%		
Treenuts	0.9	0.8%	2%	0.4	0.4%	1%		
Coffee and products	1.7	1.6%	5%	0.4	0.3%	1%		
Cocoa beans and products	0.5	0.4%	1%	0.7	0.7%	2%		
Tea, incl. mate	0.1	0.1%	0%	0.5	0.5%	1%		
Other	2.5	2.3%	7%	3.2	3.1%	7%		
Total			100%			100%		