Land use change as a determinant of the European agricultural vulnerability confronted with pollinator decline

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Abstract

Insect pollination is essential for the production of a large array of crops. In the last decade, there has been evidence of a worldwide pollinator decline. A major pressures for this decline seem to be land use change and agricultural intensification. Yet the policy response is not as fast as it should be. One can explain this reluctance by the low visibility of this impact into the agricultural sector in the near future. This paper analyzes the evolution in next years of the European agricultural vulnerability confronted with pollinator decline through the evolution of land use change. The vulnerability of agriculture to insect pollination loss is a combination of three indicators: 1) the economic value of insect pollination, 2) the vulnerability ratio, and 3) the social welfare loss. The evolution of these indicators until 2080 have been estimated in three scenarios: Growth Applied Strategy (GRAS), Business As Might Be Usual (BAMBU) and Sustainable European Development Goal (SEDG). The overall result is that the European agricultural vulnerability will increase in the near future in all scenarios and thus we demonstrate that policy is needed to protect pollinators.

Keywords: DPSIR, Insect pollinator, Pollination, European policy, Case study, Social welfare, Agriculture, Crops, Economic valuation, Ecosystem services

1. Introduction

Insect pollinators contribute significantly to the economic output of the world agricultural production and a potential pollinator loss would be some important impact on the social welfare (Gallai et al. 2009). But the decline of insect pollinators is unlikely be to be complete and instantaneous, and so it is critical to evaluate the relative importance of pollinators in the future. In this paper, we will assess the evolution of the vulnerability of European agriculture towards pollinators over the 2005 – 2080 period in order to provide elements for policy stakes taking into account insect pollinator protection.

The difficulty here was to quantify the evolution of European agriculture. For this purpose, we used the scenarios. The principle of this approach was developed in order to explain future trends of world evolution confronted with greenhouse gas (GHG) emissions. Indeed, future GHG emissions are the product of very complex dynamic systems, determined by driving forces such as demography, socio-economic development, and technological change (IPCC Special Report on Emissions Scenarios, Nakićenović *et al.,* 2000). Their evolution is therefore highly uncertain and also influenced by policies. Scenarios are storylines explaining possible images of the future trends. They become an appropriate tool to analyze how driving forces may influence future emission outcomes and to assess the associated uncertainties. They assist in climate change analysis, including climate modeling and the assessment of impacts, adaptation, and mitigation. Thus scenarios were built assuming different evolutions of European society, including agriculture, following different political trends and these scenarios were used by the Millenium Ecosystem Assessment (MEA, 2005) and the Intergovernmental Program of Climate Change (IPCC, Nakićenović *et al.,* 2000).

In order to switch from scenario storylines, which are qualitative projections of the future trend, to quantitative assessments of the future trends in Europe, we used the MOLUSC model of land use change (Model Of Land Use SCenarios ; Reginster *et al.,* 2009). We also considered that prices would evolve in the future as a function of production and preferences of consumers. Preferences are represented within an interval of the price elasticity.

Our goal was to study how the dependence of European agriculture to insect pollinator would evolve in the future. However, European agriculture is not uniform and it varies first based upon climatic constraints, which will be taken into account by a North-South division of European countries. So we will study the vulnerability of agriculture confronted with pollinator decline in both regions separately in order to adapt political strategies. Since agricultural profiles differ among countries, we will confront our results with a Northern representative country, Germany, and a Southern representative country, Spain. Both countries are important European agricultural producers, but they have quite different production patterns.

The first step was to evaluate the contribution of insect pollination to European agriculture. We then quantified the vulnerability of European agriculture to pollinator decline. For that purpose, we evaluated the economic loss from pollinator disappearance in both countries based on the dependence ratio of individual crops to pollinators from Klein *et al.* (2007). The second step was to estimate the welfare loss at the European level. To do so, we estimated the consumer surplus loss assuming that producers adapt to pollinator decline at no cost. The third step was to conduct a case study comparing Spain and Germany. In the last part, we discuss these indicators and analyze the possible responses to prevent or alleviate the consequences of pollinator decline.

2. Methodology to estimate the potential impact of pollinator loss

2.1. Description

We limited the scope of our study to direct crops and commodity of crops used directly for human food as reported by FAO (FAO, 2008 ; Table 1). The direct crops are listed individually with their production by the FAO. Commodity crops are an aggregation of different crops for which production figures are pooled together. These aggregations are based on a questionnaire that countries fill out to include important crops for the world market that are nevertheless not listed separately by the FAO. We included commodity crops in the study since they represent a significant part of the European agricultural output.

All crops cannot be substituted for one another. Thus we considered the 9 crop categories used by the FAO (Appendix 4): cereals, edible oil crops, fruits, nuts, pulses, roots and tubers, spices, sugar crops and vegetables. We assumed that all crops within the same category could be perfectly substitutable for one another. Crops were further divided into two crop types (annual and permanent) following the FAO definition (Appendix 4). Permanent crops, such as fruit trees, are sown or planted once, and then occupy the land for several years and are not replanted after harvesting. Annual crops are both sown and harvested during the same agricultural year, sometimes more than once. All the data used are related to the FAO 2005 database (FAO, 2008).

The geographical scale of our study encompasses 27 European countries, *i.e.* the 25 countries members of the European Union in 2005 plus Switzerland and Norway. In the last part, the study aims at comparing more precisely two European countries: Germany and Spain. Germany is a western European country. Germany covers about 350 000 km^2 with a population of ca. 83 million in 2005. The climate is continental with a typical large range of temperatures going from very cold in the winter to quite hot in the summer with moderate rainfalls (500 mm per year). Spain, on the other hand, is located in the Iberian Peninsula in southwestern Europe. It covers an area of about 500 000 km^2 with a population of 43 million in 2005. The climate is mainly Mediterranean with mild winters and hot summers tempered by oceanic and altitudinal influences that lead to many different regional characteristics. Thus both countries are among the largest and post populous in Europe, but, beyond these similarities, it is interesting to compare them because their climate does not enable them to produce the same crop categories.

2.2. The ALARM scenarios

We compared the evolution of European countries between 2005 and 2080 using the three main scenarios elaborated within the ALARM project (Spangenberg, 2007): Growth Applied Strategy (GRAS), Business As Might Be Usual (BAMBU) and Sustainable European Development Goal (SEDG). Those scenarios were developed as the result of the combined efforts undertaken in the framework of the ALARM project by an interdisciplinary team of economists, climatologists, land use experts and modelers to identify pressures and drivers, and to derive effective policy strategies. The work of Spangenberg (2007) describes the challenges of such a kind of work, bringing together different views necessarily inherent to the different fields of investigation, it presents preliminary results, indicates necessary policy priorities, and suggests urgent issues for future research. The three scenarios analyzed cover a broad range of social, economic, political and geo-biosphere parameters, emphasizing the internal coherence of each scenario, but also the conflicts of interest between the different aspects of sustainable development (Kaivo-oja, 1999 ; Spangenberg, 2007).

GRAS and SEDG scenarios represent two extremes policy orientations: GRAS is a liberal, free-trade, globalization and deregulation scenario, while SEDG is a scenario dedicated to integrated environmental, social, institutional and economic sustainability.

Regarding climate change, the GRAS scenario focuses on adaptation rather than mitigation, with some measure taken to limit climate change. The scenario policies show no interest in social and institutional sustainability; economic sustainability is interpreted as economic growth. Regarding agricultural policy, the Common Agricultural Policy (CAP) under GRAS does not protect the prices of European agricultural products and free trade rules the agricultural production. The cheapest products, such as cereals, are imported from southern countries. Consequences are the increase of highly fertile areas, where a small number of farmers improve the productivity with high nitrogen input and pesticide use levels, and the homogeneity of crops on ever-larger fields. On the opposite, the SEDG scenario is normative, *i.e.* it is designed to meet specific goals and derive the necessary policy measures to achieve them. This represents a precautionary approach based upon designing measures under uncertainty to avoid future changes not yet fully known. Under SEDG, the CAP enhances the agri-environmental measures, such as the establishment of set aside areas in agricultural landscapes, and increases landscape diversity. BAMBU scenario extrapolates the expected trends in European Union decision-making and assesses their sustainability and biodiversity impacts. This scenario thus tries to reconcile environmental and economic objectives through efficiency improvements. It includes climate mitigation, adaptation measures as well as explicit, but not radical, measures to alleviate impacts on biodiversity. The CAP is fully implemented and further developed. Thus agricultural production is present in the global market, but with trade barriers. The agricultural focus is on high value-added products and upper market segments. This scenario also leads to an increasing demand for products from organic agriculture, considered more trustworthy and healthy by a majority of consumers. The ALARM scenarios are described in more detailed in Spangenberg (2007).

The GRAS, BAMBU and SEDG storylines include characterizations of future changes in regional climate and atmospheric CO_2 concentration. Changes in mean annual temperature and precipitation are based on HadCM3 climate model simulations (Gordon *et al.,* 2000) assuming the A1F1, A2 and B1 scenarios from the IPCC Special Report on Emissions Scenarios (Nakićenović *et al.,* 2000). GRAS is associated with the A1F1 scenario, BAMBU with the A2 scenario, while SEDG is associated with the B1 scenario.

In addition to these three scenarios, three additional hazard-driven scenarios were developed as a deviation from one of these three scenarios. It is described as one disturbance event with long term and large-scale impact. The first shock is an environmental shock, which causes the collapse of the Gulf Stream and has been introduced in 2050 in the GRAS scenario. This parallel scenario is called the GRAS-CUT scenario and is described as an accentuation of the increase in temperature. The second shock is an economic one due to an excess of the oil consumption. This parallel scenario has been introduced in the BAMBU scenario in 2010 and it is called the BAMBU-SEL scenario. The last shock is a societal shock described as a pandemic introduced in 2010. This parallel scenario is called BAMBU-CANE. Land use scenarios were generated annually until 2080 with the MOLUSC model (Reginster *et al.,* 2009) coupled with the global ecosystem model representing natural vegetation and agriculture (LPJML ; Bondeau *et al.,* 2007). LPJML estimates the potential crop yields in each grid cell for different crop types based on the bio-physical characteristics of each location both today (the baseline) and into the future (the scenarios). To assess land use in this work, we derived yields values from the LPJML model and weighted them by a scenario specific productivity parameter (Reginster *et al.,* 2009). The interpretation of the land use scenario and model are explained with more details in Reginster *et al.* (2009).

2.3. Formulas

We used the same formulas than in the Gallai et al (2009) paper, but we adapted them based upon the scenarios. First, we calculated the TV of the agricultural output for crops directly used for human food in 2005 (TV_{2005}) for the 27 European countries as the sum of the economic value for crop i $\in$ [1; I]:

$$TV_{2005}=\sum_{i=1}^{I} P_i \times Q_i \qquad [1]$$

where P is the production price and Q is the production. For Q_i and P_i, we used the FAO production and price data (FAO, 2008). Production data are expressed in metric tons, while price data are reported in dollars on the FAO database and expressed in euro in our study according to the 2005 exchange rates (FAO, 2008). We considered a single European market where all crops were exchanged freely, which implied a single price. We calculated this price using the price mean weighted by the production of each of the 27 European countries.

Second, we calculated the Economic Value of Insect Pollination services in 2005 ($EVIP_{2005}$). The $EVIP_{2005}$ is defined as the value of the pollinator contribution to the total value of crop production for crops directly used for human food. For each crop, we used a dependence ratio in regard to pollinators (D), that is the proportion of the yield that is attributable to insect pollinators. The $EVIP_{2005}$ was calculated as follows:

$$EVIP_{2005} = \sum_{i=1}^{I} TV_i \times D_i \,, \qquad [2]$$

where D_i is the dependence ratio for each crop $i \in [1; I]$. We calculated de dependence ratios D_i based upon the classification in the extensive review by Klein *et al.* (2007). Starting with the complete set of direct and commodity crops used directly for human food, we selected those pollinated by insects and with 2005 production and price data available. For the individual crops among the 9 commodities, neither the production nor the producer price was available. Additionally not all the crops that composed each of these commodities were dependent on insect pollination at a similar level. Consequently, we could not calculate the economic value of pollinators for these commodity crops and they were not considered further. For the remaining direct crops, we focused on those reviewed in Appendix 2 of Klein *et al.* (2007) and calculated their average dependence ratio based on the reported range of dependence to animal pollination.

Third, we used the indicator of vulnerability defined by Gallai *et al.* (2009). The agricultural vulnerability to pollinator decline depends upon crop dependence to pollinators, and the capacity of adaptation of farmers when confronted with pollinator decline. This indicator, which we called the vulnerability ratio (VR), was calculated as follows:

$$VR = \frac{EVIP}{TV} = \frac{\sum_{i=1}^{I} (P_i \times Q_i \times D_i)}{\sum_{i=1}^{I} (P_i \times Q_i)} \; (\%) \qquad [3]$$

To calculate the three values TEV, EVIP and VR in 2080 under the three ALARM scenarios, we estimated the 2080 surface of permanent crops and annual crops in Europe with MOLUSC (Appendix 5). This model considers annual crops and permanent crops separately, but does not differentiate among crops within each type. Thus it was assumed that all permanent crops would evolve at the same rate *x* and all annual crops would evolve at the same rate *y*. As a result, it was further assumed that the area distribution among crops within each crop type (annual and permanent) would remain constant over time at the same level as it was in 2005 and would not vary in response to the scenario used. We multiplied the 2080 surface for each crop with the crop yield. The evolution of the crop yield was assumed to change over time until 2080 following that of wheat yield. This was simulated using also the MOLUSC model to take into account both management effect and technological effect

(Appendix 6; Reginster *et al.,* 2009). Thus, the formula to estimate the production of crop *i* in each country under each of the three scenarios *S* in 2020 was:

$$Q_{i,2020,S} = (1 + dw + dm + dp)Y_{2005} \times H, \quad [4]$$

where *dw* is the evolution of wheat yield, *dm* is the management effect and *dp* is the technological effect. Y_{2005} is the 2005 crop yield per ha and *H* is the 2005 surface of the crop in ha, both of which were extracted from the FAO database (FAO, 2008).

We considered a free market where governments did not act directly upon the price, but influenced the farmer production strategy. Then the evolution of prices under the different scenarios is a function of the 2005 production, the new production, and the price elasticity of the demand. This price elasticity is an adaptation factor of the demand faced with production change. As this factor could be different following consumers, countries and crops, we assumed that it was included in the range [-1,2; -0,8]. We chose a unique value of the elasticity, e, for all crop species. As in Gallai *et al.* (2009), we made this simplification since the values for most crops have not yet been determined with appropriate econometric data. Some crops, like cereals, are generally associated with lower price elasticities, usually estimated to be $|e| < 0.5$ in the literature. Other crops, such as fruits, appear to have higher price elasticities, with $|e| > 1$ and possibly much more in some cases (Southwick and Southwick, 1992). Fruits, vegetables, nuts, edible oil seed crops, stimulant crops, and spices are the most pollinator-dependent and they are also those that would make the largest part of the total loss. They are also the crops that are likely to have the highest price elasticity in absolute value (Southwick and Southwick, 1992). So the overall appropriate value for e for all crops grown in Europe and directly used for human food is likely around -1. Furthermore, a distinction must be made between short-term and long-term elasticities, the latter being traditionally higher ($|e| > 1$). Since we considered a hypothetical situation of total pollinator loss, long-term elasticities may be more appropriate. Consequently, for the same time period, we calculated different TV and EVIP in response to the range of values of e. The evolution of crop prices under the three scenarios S and at the time t was calculated from the inverse demand function:

$$P_{St_i}(Q_{St_{xi}}) = P_{2005_i}\left(\frac{Q_{St_{xi}}}{Q_{2005_{xi}}}\right)^{\frac{1}{e}} \quad [5]$$

Given a constant price elasticity, the mathematical representation of the demand function comes from the definition of the price elasticity e = $\frac{\delta Q/Q}{\delta P/P}$, which leads to $P(Q) - EQP'(Q) = 0$ assuming e ≠ 0.

Finally, we calculated the social welfare loss. We assumed, following Southwick and Southwick (1992), that the long-term supply curve was perfectly elastic, which means that farmers could switch from one crop to another without increasing production cost and without constraint of arable land availability. This means that there is no producer surplus variation so that the consumer surplus variation is actually the social surplus variation. The consumer surplus is the difference between what the consumer pays and what he is willing to pay according to the assumptions made on the price elasticity of demand (see Gallai *et al.*, 2009). We have to assess what would happen to the food production and markets after insect pollinators decline to a complete loss. The first consequence would be a loss in production from Q_0 to $Q_0(1–D)$ for a similar production effort (*i.e.* without change in the total production costs). If a smaller production is obtained for the same total cost, we can assume that the unitary production cost will grow from P_0 to $P_0/(1-D) = P_1$. We will then consider that P_{i1} is the new price of the crop i on the market of our economy without pollinators. At this price, the effective demand will be $Q_i(P_{i1}) = Q_{i1}$. This assumption allowed us to calculate the consequent surplus loss (CSloss: Figure 1 of Gallai *et al.*, 2009) according to the value of e.

$$\text{CSloss}_\text{i} = Q_{i1}\left(P_{i1} - P_{i0}\right) + \int_{Q_{i1}}^{Q_{i0}} \left[P_i(Q_i) - P_{i0}\right] dQ \qquad [6]$$

For the value e = -1, it comes from [6] that $P(Q) = P_0.Q_0/Q$, and $Q_1(P_1-P_0) = P_0(Q_0-Q_1)$. The consumer surplus loss is then:

$$\text{CSloss}_{\text{e=-1}} = \int_{Q_1}^{Q_0} \left[P(Q)\right] dQ = \int_{Q_1}^{Q_0} \frac{P_0 Q_0}{Q} dQ = P_0 Q_0 .Log \frac{Q_1}{Q_0} \qquad [7]$$

where P_1 and Q_1 are the price and quantity produced without insect pollination, and P_0 and Q_0 are the price and quantity produced with insect pollination at the current level. If we apply this expression to the drop in production consecutive to a total pollinator loss for a crop with a dependence ratio of D, then $Q_1 = Q_0(1-D)$, and it comes $\text{CSloss} = P_0.Q_0.Log(1-D)$. For any price elasticity e ≠ –1, it comes:

$$\text{CSloss}_{\text{e≠-1}} = \frac{P_0 Q_0}{1+e}\left(\left(\frac{1}{1-D}\right)^{1+e} - 1\right). \qquad [8]$$

It is noteworthy that a consumer for which preferences for a good are represented by a price elasticity of –0.8 would consume the same quantity of good for a large variation of its price (> 100%) and it can be defined as person with stronger "anchored" preferences. A consumer for which preferences for the same good are represented by a price elasticity of –1.2 would consume less as prices increased even moderately, and it is defined as a person with lower anchored preferences. Consequently the consumer surplus loss of a person with a price elasticity of –0.8 would be higher than that of a person with a price elasticity of –1.2 because, for a similar price increase due to pollinator loss, the first person would still consume more good than the second one.

2.4. Statistical analyses

The correlation tests between the vulnerability and prices for each crop categories were performed using a Spearman test. For 2005, we compared the vulnerability between countries located in the South to those located in the Northern part of Europe using a Mann-Whitney test (Sokal and Rolf, 1995). We compared the evolution of vulnerability between 2005 and 2080 for each scenario considered separately for both price elasticities using a Friedman test (Sokal and Rolf, 1995). The post-hoc comparison was realized using non parametric method (see Siegel & Castellan, 1988).

We assessed the effects of the different scenarios (GRAS, BAMBU, and SEDG), the price elasticity (-1.2 or -0.8), and the location (southern or northern Europe) on the vulnerability using ANOVAs and the conditions of use were satisfied (normality and homoscedasticity; Sokal & Rohlf, 1995). When the factor was significant, the comparison between the modalities was performed with a post-hoc comparison using the Tukey test. We conducted the analyses with R software (Dalgaard, 2002) and the map illustration were done with Qgis (Sherman, 2006)

3. The European agriculture: production, production value and pollinator impact

In 2005, the 27 European countries produced a total of 80 direct crops and 9 commodities used directly for human food (Appendix 4). Among these, 41 direct crops in 6 categories are dependent on insect pollinators for their production and pollinators are essential for 4 of these crops. The contribution of insect pollinators is also reported as “great” for 12 direct crops, “modest” for 13 and “little” for 12 following Klein *et al.* (2007). It is noteworthy that within each crop category, there was considerable variation among the crops as to their level of dependence on pollinators.

Among the 89 direct crops and commodities produced in Europe in 2005, 54 were annual crops and 18 (33%) among these depend on insect pollinators, while 35 were permanent crops and 23 (66%) among these depends on insect pollinator (Appendix 4).

Among the 10 crop categories, we classified nuts and fruits as permanent crop since all the crops in the category are permanent crops. We can classify cereals, vegetables, roots and tubers, pulse and stimulant crops as annual crop. Edible oil crop and spices categories included the two kinds of crop, with respectively 2 permanent crops and 8 annual crops for edible oil crops and 2 permanent crops and 1 annual crop for spices.

3.1. The European crop production context and its dependence on insect pollinators in 2005

3.1.1. Crop production context

The proportion of land dedicated to the production of crops used directly for human food represented about 39 percent of the total land area (Figure 3-1). The area planted in annual crops covered ca. 155 million ha, which is about 94% of the total land used for crop production in the 27 European countries, while permanent crops covered 10 million ha.

Agricultural production in Europe was primarily devoted to cereals (280 million tons), followed by sugar crops (136 million tons), vegetables (67 million tons), fruits (60 million tons), roots and tubers (59 million tons), edible oil crops (32 million tons), pulse (0.8 million tons), spices (0.1 million tons) and stimulant crops (less than 5 hundred tons, Table 3-1).

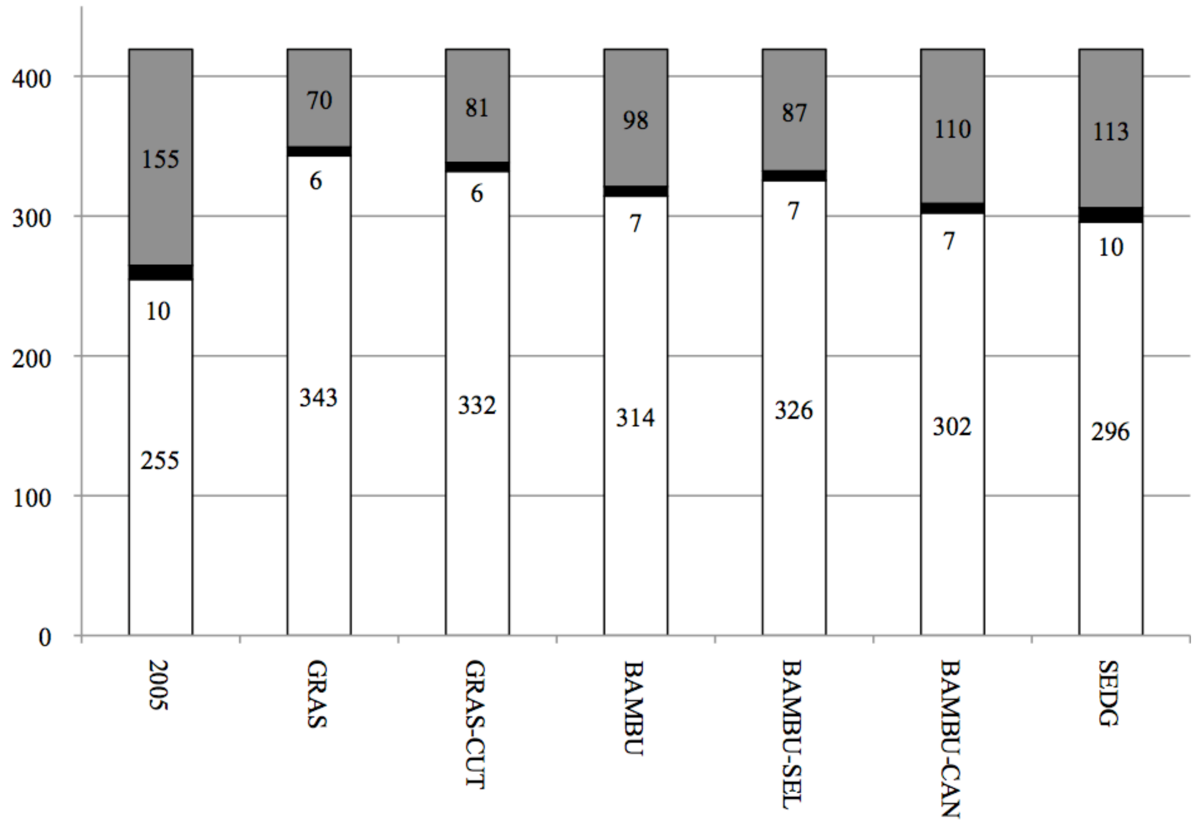


Figure 3-1 – Annual crop area (in grey), permanent crop area (in black) and the rest of land use area (in white) in 10^6 ha for Europe (25-EC members plus Norway and Switzerland) in 2005 and under the ALARM scenarios in 2080.

Table 3-1 – Production, economic value and dependence on insect pollinators for the categories of crop used for direct human consumption in Europe (25-EC members plus Norway and Switzerland) ranked by decreasing vulnerability ratio.

Crop categories *(following FAOStat, 2008)*	Production (Q)	Total Economic Value (TEV)	Average price per production unit	Economic Value of Insect Pollinators (EVIP)	Vulnerability ratio (VR)
	10^3metric tons	10^6€	€ per metric ton	10^6€	%
Nuts	816	1 124	1 376	348	31
Fruits	60 258	36 636	608	7 758	21
Pulse	4 291	1 198	279	131	11
Vegetables	67 127	32 804	489	3 086	9
Edible oil crops	32 232	13 574	421	1 015	7
Spices	67	49	720	2	5
Cereals	279 858	28 572	102	0	0
Roots & tubers	59 383	7 414	125	0	0
Stimulant crops	0.11	0.023	213	0	0
Sugar crops	136 281	6 289	46	0	0
TOTAL	**640 313**	**127 659**		**12 340**	**10**

3.1.2. Importance of insect pollinators in European countries

The 2005 total production value for crops used directly for human food in Europe was almost €128 billion, and the EVIP was €12 billion, that is about 10% of the European TV (Table 3-1). This average figure hides a large range of values among the different crop categories. The three most important crop categories in TV were fruits, vegetables and cereals with €36.6, €32.8 and €28.6 billion, respectively. Fruits and vegetables were also the two categories with the most important EVIP with €7.8 and €3.0 billion, respectively, followed by edible oil crop with €1.0 billion. It is noteworthy that four crop categories did not involve any pollinator-dependent direct crops: cereals, roots & tubers, stimulant crops and sugar crops. These categories represented a total economic value of €42 billion, which amounted to 33% of the total economic value. The most vulnerable crop categories in Europe were nuts with a vulnerability ratio of 31%, followed by fruits (21%), pulses (11%), vegetables (9%), edible oil crops (7%) and spices (5%). The vulnerability ratio was highly and positively correlated with the average price of a production unit (n = 27, Rho = 0.81, P = 0.005), which indicates that the more vulnerable a crop category is to insect pollinators, the higher its average unit price.

3.1.3. A European North-South division of agricultural vulnerability confronted with insect pollinator decline

We determined the vulnerability across countries in Europe (Figure 3-2). We observed an important heterogeneity of the agricultural vulnerability in the face of pollinator loss among countries: the most vulnerable country was Cyprus with a vulnerability ratio of 27% while the least vulnerable country was Ireland with a vulnerability ratio of 1.2%. This variable vulnerability showed a clear geographic pattern that led us to identify two groups in Europe. The first group consisted of all countries under or located north of the 50° North parallel, namely Belgium, Czech Republic, Denmark, Estonia, Finland, France, Germany, Ireland, Latvia, Lithuania, Luxembourg, Netherlands, Norway, Poland, Sweden, United Kingdom. The second group gathered all the countries located south of the 50° North parallel, namely Austria, Cyprus, Greece, Hungary, Italy, Malta, Portugal, Slovakia, Slovenia, Spain, Switzerland. The vulnerability ratio of these two groups was significantly different (n = 27, P = 0.001) as southern countries were more vulnerable than Northern countries (12% compared to 8%, Table 3-2). The TVs of agricultural production for northern and southern countries were approximately the same in 2005 (€62 billion and €65 billion, respectively; Table 3-2), but the TV of northern countries was mainly driven by cereals (34%), vegetables (22%), fruits (19%), roots and tubers (10%), sugar crops (8%) and edible oil crops (5%) while that of southern countries was composed mainly of fruits (38%), vegetables (29%), edible oil crops and cereals (11% each). As a result, the economic value of insect pollinators was much higher in the southern countries than in the northern ones (€7.6 billion and €4.7 billion, respectively).

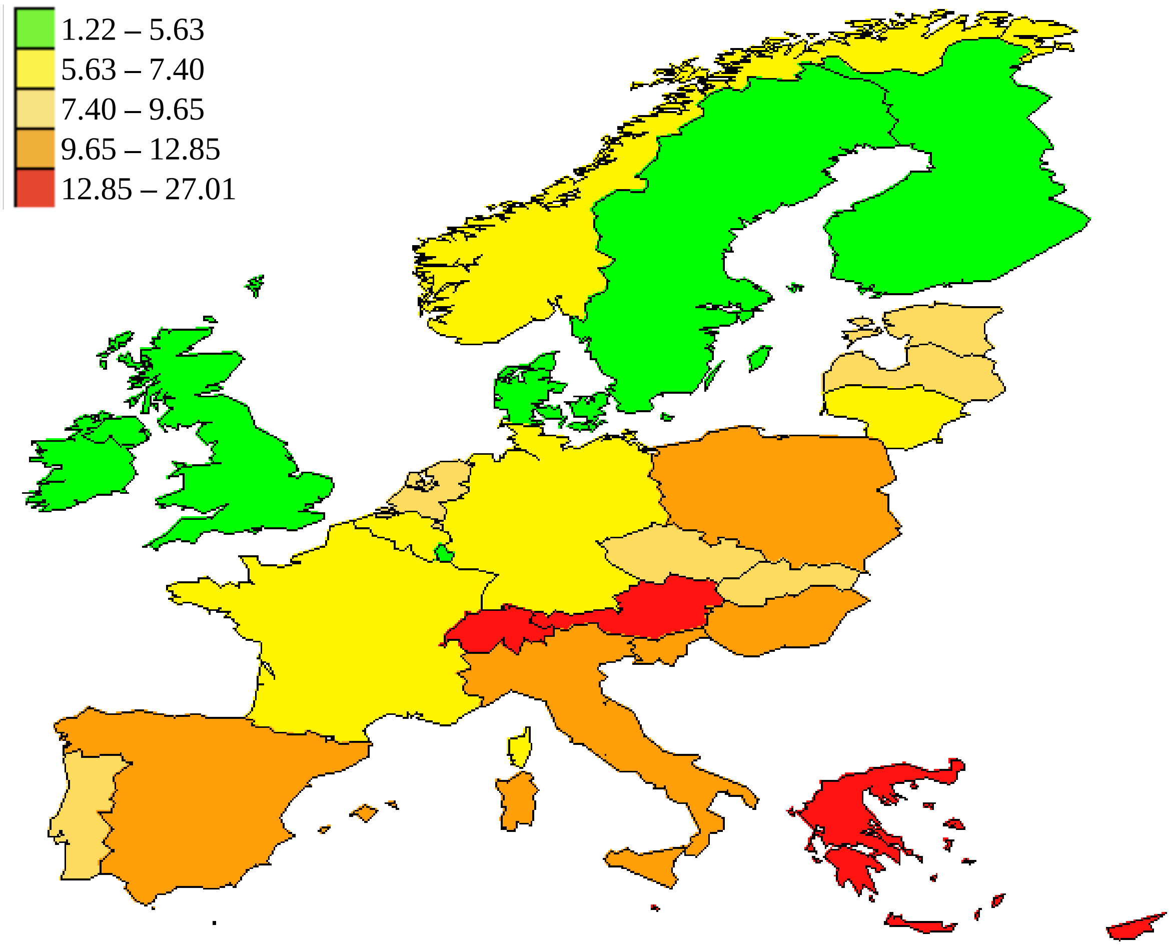


Figure 3-2 – Map of the vulnerability ratio (in percent) of the 27 European countries classified following 5 classes of quantile.

Table 3-2 – Production value and dependence on insect pollinators for each crop category in 2005 for Northern and Southern countries ranked by decreasing total economic value.

Crop categories *(following FAOStat, 2008)*	Total economic Value (TV)	Economic value of insect pollinators (EVIP)	Vulnerability ratio (VR)
	10^6€	10^6€	%
Northern countries (Belgium, Czech Republic, Denmark, Estonia, Finland, France, Germany, Ireland, Latvia, Lithuania, Luxembourg, Netherlands, Norway, Poland, Sweden, United Kingdom)			
Cereals	21 179	0	0
Vegetables	13 987	838	6
Fruits	11 840	2 955	25
Roots & tubers	6 356	0	0
Sugar crops	4 688	0	0
Edible oil crops	3 300	804	24
Pulse	932	102	11
Nuts	138	8	6
Spices	3	0.14	5
Stimulant crops	0	0	0
TOTAL	**62 423**	**4 707**	**8**
Southern countries (Austria, Cyprus, Greece, Hungary, Italy, Malta, Portugal, Slovakia, Slovenia, Spain, Switzerland)			
Fruits	24 796	4 803	19
Vegetables	18 816	2 248	12
Edible oil crops	10 274	211	2
Cereals	7 393	0	0
Sugar crops	1 601	0	0
Roots & tubers	1 058	0	0
Nuts	986	339	34
Pulse	266	28	11
Spices	46	2	5
Stimulant crops	0.023	0	0
TOTAL	**65 235**	**7 633**	**12**

3.1.4. The 2005 European social welfare loss that would result from pollinator loss

The loss of insect pollinators would result in a European consumer surplus loss between €19 billion and €26 billion based upon a range of price elasticities between -1.2 and -0.8 (Figure 3-3). The welfare loss would be more important in southern countries than in northern ones. The consumer surplus loss in northern countries would be between €8.3 and €6.6 billion following a range of elasticities between -0.8 and -1.2 (Figure 3-4.a), while that in southern countries would lie between €17.6 and €12.4 billion with the same range of price elasticities (Figure 3-4.b).

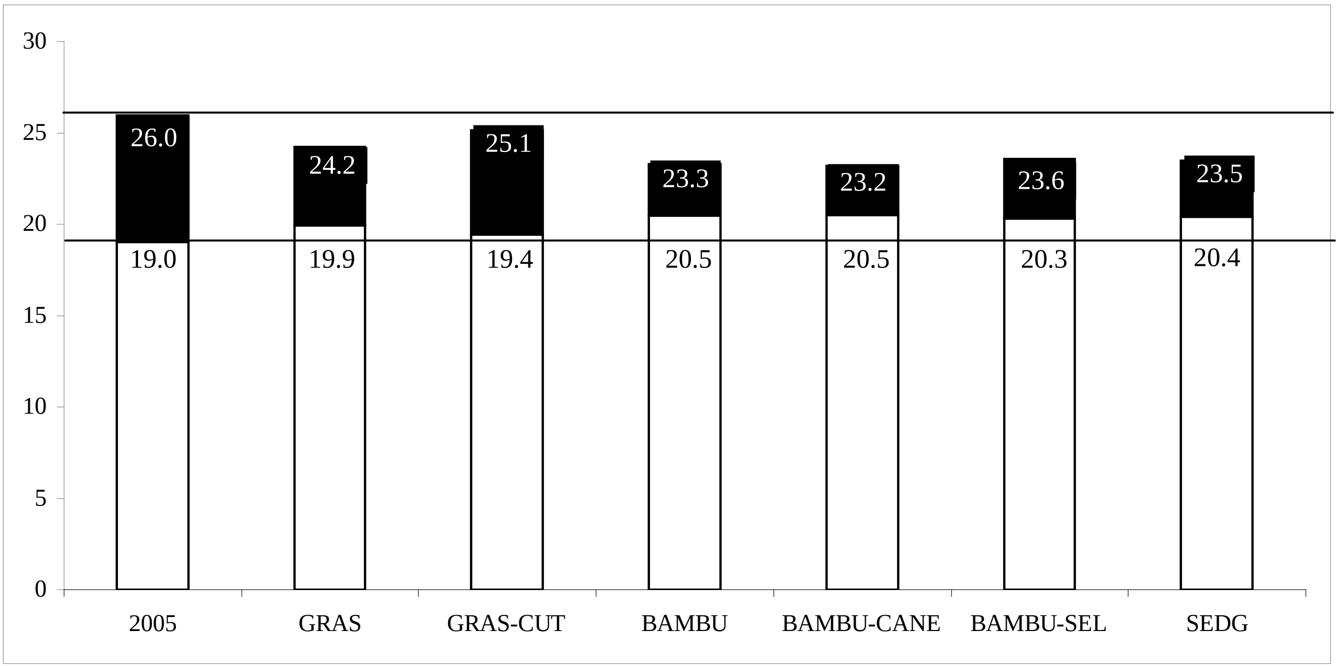


Figure 3-3 – Consumer surplus loss (that corresponds to welfare loss) in 2005 with a price elasticity of -1.2 (white columns) and -0.8 (white and black columns together) in 27 European countries, and it evolution until 2080 under GRAS, GRAS-CUT, BAMBU, BAMBU-CANE, BAMBU-SEL and SEDG scenarios. The black areas indicate the difference in the consumer surplus losses with a price elasticity of -0.8 and -1.2.

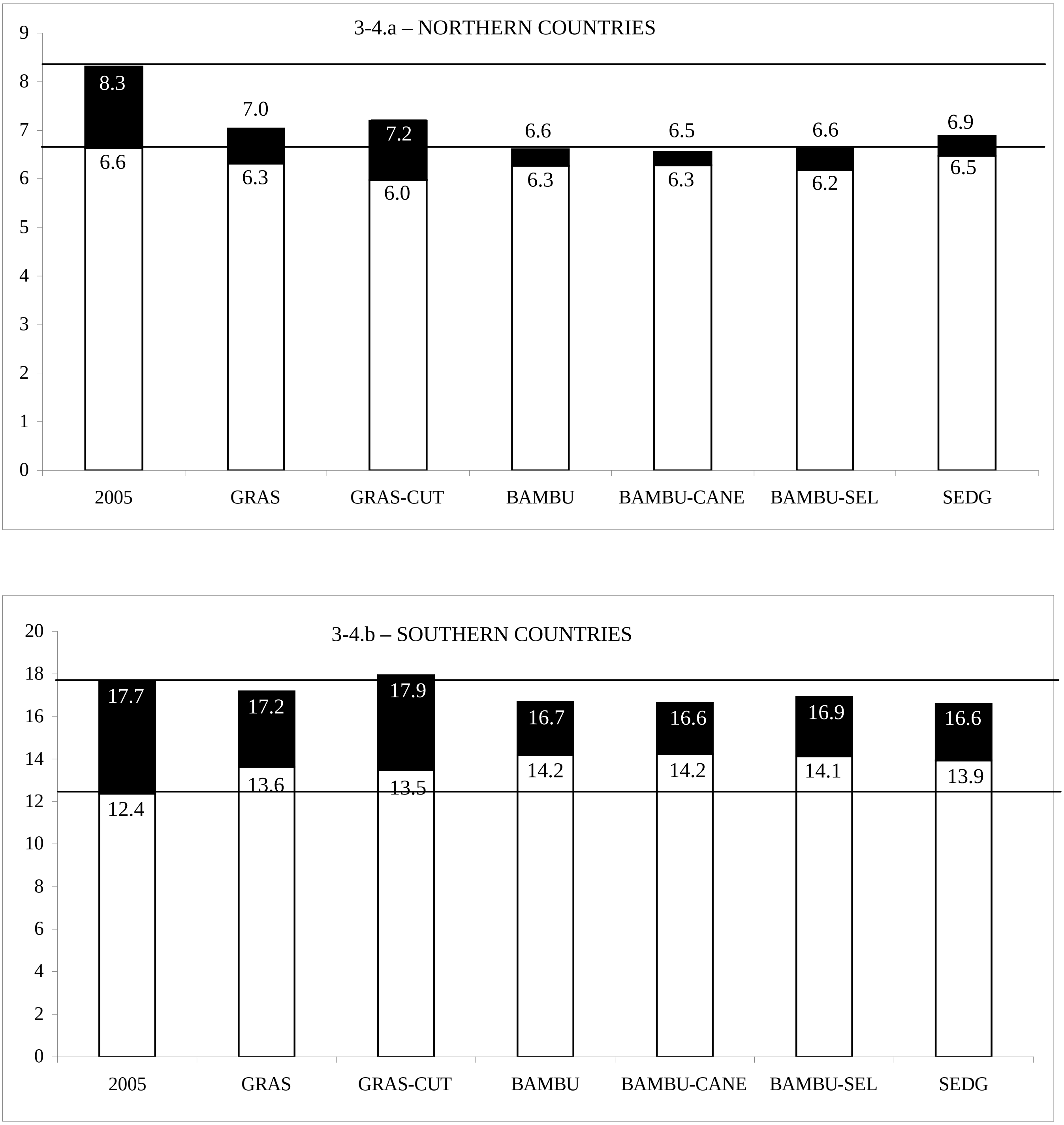


Figure 3-4 – Consumer surplus loss (that corresponds to welfare loss) in 2005 with a price elasticity of -1.2 (white columns) and -0.8 (white and black columns together) in Northern countries (3-4.a) and Southern countries (3-4.b), and it evolution until 2080 under GRAS, GRAS-CUT, BAMBU, BAMBU-CANE, BAMBU-SEL and SEDG scenarios. The black histogram indicates the difference between consumer surplus losses with a price elasticities of -0.8 and -1.2.

Table 3-3 – Production value and dependence on insect pollinators for annual crops in 2005 for Northern and Southern countries.

European regions	Production (Q) 10^3T	Total economic value (TV) 10^6€	Average unit price € per T	Economic Value of Insect Pollinators (EVIP) 10^6€	Vulnerability ratio (VR) %
Northern countries	348 540	42 665	122	1 479	4
Southern countries	219 971	37 816	172	2 752	7
TOTAL	**568 511**	**80 481**	**142**	**4 231**	**5**

Table 3-4 – Production value and dependence on insect pollinators for annual crops in 2005 for Northern and Southern countries.

European regions	Production (Q) 10^3T	Total Value (TV) 10^6€	Average price € per T	Economic Value of Insect Pollinators (EVIP) 10^6€	Vulnerability ratio (VR) %
Northern countries	15 322	10 342	675	2 069	20
Southern countries	56 482	36 835	652	6 039	16
TOTAL	**71 804**	**47 177**	**657**	**8 108**	**17**

3.1.5. Annual crop versus permanent crop

The 2005 total production of annual crops was 568 million tons, 61% of which came from Northern countries, and the total value of their production was €80 billion. The permanent crop produced a total of 72 million tons of produce, of which the Northern countries produced 21%, and the total value of their production was €47 billion. Clearly the production of permanent crops had a much higher unit value (657€/ton) and a greater dependence on insect pollination (17% ; Table 3-4). On the contrary, annual crops were less dependent on insect pollination (5%) and had a lower unit value (142€/ton).

3.2. The crop production context and its dependence on insect pollinators in the European Union under the GRAS, GRAS-CUT, BAMBU, BAMBU-CANE, BAMBU-SEL and SEDG scenarios

In this part, we will examine all changes compared to 2005, in particular those in crop production, crop production value and the contribution of insect pollinators on this crop production in value, vulnerability and consumer surplus loss.

Based on scenarios, policy orientations and strategic choices are translated into quantitative data through land use change for annual and permanent crops. In 2005, annual crops were overall weakly dependent on insect pollinators compared to permanent crops. Assuming that this level of dependence remains constant, since we assumed that the crop composition remained constant within each type, the evolution of the European agriculture dependence on insect pollinators will vary with the ratio between annual crops and permanent crops.

Concerning the vulnerability in 2080, the ANOVA model was significant (DDF = 9, F = 4.861, R^2 = 0.22, P < 0.001). Both the location and the elasticity values significantly affected the vulnerability in 2080 (with P = 0.007 and F = 7.530 and P = 0.05 and F = 3.907, respectively). The vulnerability will be higher when the price elasticity is high (-0.8). And the width of the vulnerability interval will be higher in the Southern part of Europe (between 13.46 and 13.47%) compared to the Northern part (between 7 and 9%). Contrary to expectation, we did not find a significant effect of the scenarios, nor of the interaction between the other factors (with P >0.30).

3.2.1. Crop production context

Under all scenarios, the land used for crop production in Europe will decrease (Figure 3-1). Regarding land used for annual crop production, it will decrease in all scenarios. The most important decrease will be under both GRAS and GRAS-CUT scenarios since the land use for annual crops would decrease by 54% and 47%, respectively, compared to 2005. For the land used for permanent crops, it will not change under the SEDG scenario, but it will decrease from 10 million ha to 6 million ha under the GRAS and GRAS-CUT scenarios and to 7 million ha under the BAMBU, BAMBU-SEL and BAMBU-CAN scenarios.

For the production per crop category, they will all increase in Europe under all scenarios except in some rare cases (Table 3-5). The production of cereal and pulse will decrease between 10 and 50% under GRAS-CUT. The production of roots and tubers will remain the same or decrease by up to 10% under the GRAS scenario and it will decrease under the GRAS-CUT scenario between 10 and 50%. Spice and stimulant crop production will decrease under all scenarios, except SEDG. Both crop categories will decrease more than 50% under GRAS and GRAS-CUT scenarios. Sugar crop and vegetable production will decrease under the GRAS-CUT scenario between 0 and 10%.

Table 3-5 – Table of production in 2080 (in 10^3 metric tons) and its evolution by crop categories for each scenario compared to 2005 values (↑ ≈ >50%, ↗ =]10% ;50%[, → =]0% ;10%[, → =]0% ; -10%], ↘ =]-10%,-50%], ↓ = <-50%).

Crop category (following FAO stat)			**ALARM**	**scenarios**		
	GRAS	**GRAS-CUT**	**BAMBU**	**BAMBU-SEL**	**BAMBU-CANE**	**SEDG**
Cereals	281 415	238 522 ↘	363 295	317 423	394 326	351 414
Edible oil crops	40 857	37 591 ↗	50 457	46 544	52 176	48 965
Fruits	83 032	68 635 ↗	92 800	92 800	92 786	103 783
Nuts	1 193	1 060 ↗	1 395	1 395	1 395	1 551
Pulse	4 559	3 809 ↘	5 532	4 752	5 652	4 911
Roots & tubers	58 268	50 580 ↘	77 056	68 117	83 790	74 373
Spices	24	20	52	52	54	100
Stimulant crops	0.033	0.025	0.119	0.119	0.119	0.272
Sugar crops	147 673	125 713	188 596	163 994	197 905	168 678

Vegetables	71 019 →	62 370 →	90 258 ↗	80 111 ↗	95 570 ↗	79 024 ↗

3.2.2. Impact of pollinator loss under GRAS and GRAS-CUT scenarios

The GRAS scenario is based on the A1F1 scenario (Nakićenović *et al.*, 2000) characterized by rapid world economic and population growth and the disappearance of the CAP, which means that agricultural prices will fluctuate. Regarding the evolution of production, production value and vulnerability ratio, we could assume that European agricultural industry in GRAS scenario will move towards the specialization to produce the most profitable crops and import other ones from the rest of the world. We found that production of cereals, pulses, roots and tubers and sugar crops will not increase compared to 2005 (Table 3-5) while demand for these products will increase. On the contrary, production of profitable crops as fruits, edible oil crops and nuts will increase (Table 3-5). Consequently, the production value of agricultural products will decrease in Northern countries from €62 billion in 2005 to €57–€58 billion depending upon price elasticity (Table 3-6) since these countries were specialized in the production of cereals and roots and tubers. This decrease of agricultural production value in Northern countries will also decrease the possible welfare loss resulting from pollinator loss for both types of consumers: consumers with strong anchored preference on products from insect-pollinated crops and consumers with low anchored preference on these (Figure 3-4.a). On the other hand, the production value will increase in Southern countries from €62 billion in 2005 to €67–73 billion following price elasticity (Table 3-6) since these countries were specialized in the production of the pollinator-dependent fruits and edible oil crops. This increase in production value in Southern countries combined with the large price fluctuation will have different effects on the consumer welfare loss: The welfare loss would decrease for consumers with strong anchored preference for insect-pollinator dependent goods while it would increase for other consumers (Figure 3-4.b).

The stability of crop production in Northern countries implies that their agricultural vulnerability to pollinator loss will not change, while the production increase of fruits, edible oil crops and nuts in Southern countries would lead to a decrease of vulnerability (Table 3-8). This last result may seem surprising, indeed, since we would expect that a reduction in the production of crops that do not depend on insect pollinators (cereals, pulses, roots and tubers, and sugar crops) and an increase in the production of crops that depend on insect pollinators (fruits, edible oil crops and nuts) would lead to an increase in the vulnerability in Southern countries. This suggests that the production price of crops that do not depend on insect pollinators and for which world demand will be high, *e.g.* olive, will greatly increase.

These results would change under the GRAS-CUT scenario, which implies a high temperature rise. The overall European production would decrease (Table 3-5) and European consumers would depend more on imports from the rest of the world. Consequently, the vulnerability of agricultural production value confronted with pollinator decline would not change (Table 3-6). Furthermore, the impact on the welfare loss of Northern consumers, compared to GRAS scenario, would be positive for people with low anchored preferences on crops that are dependent on insect pollinators, but negative for others since their welfare loss would be higher (Figure 3-4.a). The impact of the rise in temperature will be negative compared to the results under the GRAS scenario as well as the 2005 situation for all Southern consumers since their welfare loss will increase (Figure 3-4.b).

Table 3-6 – Compared evolution of the total value (TV) of agriculture in the northern, southern and all 27 European countries under the GRAS, GRAS-CUT, BAMBU, BAMBU-SEL, BAMBU-CANE and SEDG scenarios between 2005 and 2080.

Crop category			**ALARM**	**scenarios**		
	GRAS	**GRAS-CUT**	**BAMBU**	**BAMBU-SEL**	**BAMBU-CANE**	**SEDG**
Northern countries	57 – 58 ↘	59 – 56 ↘	55 – 61 ↘	56 – 59 ↘	53 – 61 ↘	57 – 63 →
Southern countries	67 – 73 ↗	70 – 72 ↗	69 – 74 ↗	64 – 74 →	63 – 75 →	61 – 72 →
27 European countries	124 – 131 →	129 – 128 ↗	124 – 135 →	120 – 133 →	116 – 136 →	118 – 135 →

Table 3-7 – Compared evolution of the economic value of insect pollinators (EVIP) of agriculture in northern, southern and all 27 European countries under the GRAS, GRAS-CUT, BAMBU, BAMBU-SEL, BAMBU-CANE and SEDG scenarios between 2005 and 2080.

Crop category			**ALARM**	**scenarios**		
	GRAS	**GRAS-CUT**	**BAMBU**	**BAMBU-SEL**	**BAMBU-CANE**	**SEDG**
Northern countries	4.1 – 4.5 ↘	4.2 – 4.3 ↘	3.9 – 4.5 ↘	3.9 – 4.5 ↘	3.8 – 4.5 ↘	4.0 – 4.6 →
Southern countries	7.4 – 8.4 →	7.7 – 8.3 ↗	7.2 – 8.7 →	7.3 – 8.7 →	7.2 – 8.8 →	7.2 – 8.6 →
27 European countries	11.5 – 12.9 →	11.9 – 12.6 →	11.1 – 13.2 →	11.2 – 13.2 →	11.0 – 13.3 →	11.2 – 13.2 →

Table 3-8 – Compared evolution of vulnerability to insect pollinators of agricultural value in northern, southern and all 27 European countries under the GRAS, GRAS-CUT, BAMBU, BAMBU-SEL, BAMBU-CANE and SEDG scenarios between 2005 and 2080.

Crop category			**ALARM**	**scenarios**		
	GRAS	**GRAS-CUT**	**BAMBU**	**BAMBU-SEL**	**BAMBU-CANE**	**SEDG**
Northern countries	7 – 8 →	7 – 8 →	7 – 7 ↘	7 – 8 →	7 – 7 ↘	7 – 7 ↘
Southern countries	11 – 11 ↘	11 – 12 →	11 – 12 →	11 – 12 →	11 – 12 →	12 – 12 →
27 European countries	9 – 10 →	9 – 10 →	9 – 10 →	9 – 10 →	10 – 10 →	9 – 10 →

3.2.1. Impact of pollinator loss under the SEDG scenario

Opposite to GRAS, the SEDG sceanrio under which the CAP will be tough is derived from the B1 scenario of IPCC (Nakićenović *et al.*, 2000) with approximately the same characteristics as the A1F1 scenario except that it takes into account reductions in agricultural equipment intensity and the introduction of clean and resource efficient technologies. SEDG also puts emphasis on global solutions to environmental stability. Contrary to the results under the GRAS scenario, the land use for annual crop production will slowly decrease under SEDG while the land use for permanent crops will not change. This will be a consequence of the low production yield (lower than under GRAS and BAMBU scenarios) due to constraints of agri-environmental measures to use clean technologies. Furthermore, the overall production will increase since the European agricultural policy will financially help farmers and consumers to keep constant prices. As a consequence, Northern countries will produce more crops that do not depend on insect pollinators (Table 3-5) and their overall vulnerability to insect pollinator loss will decrease (Table 3-8). On the contrary, the vulnerability will not change in Southern countries (Table 3-8).

The increase of crop production will translate into a decrease of price so that the total value of crop production in 2080 will remain the same as in 2005. So the price increase due to a total pollinator loss would be lower than in 2005. Consequently, the social welfare loss would be reduced compared to 2005 for Northern and Southern consumers alike that have strong anchored preferences on crops that depend on insect pollinators. But the high level of crop production will imply that welfare loss of consumers with weak preferences on crops that depend on insect pollinators will increase.

3.2.2. Impact of pollinator loss under BAMBU, BAMBU-SEL and BAMBU-CANE scenarios

The BAMBU scenario describes the evolution of Europe as ongoing on the same basis as it is now, and it is based on the A2 scenario from the SRES reports (Nakićenović *et al.*, 2000). This scenario describes a divided world, where nations will be self-reliant, the economic development will be regionally oriented and will allow an increase of income per capita and technological change will grow slowly. Consequently, the crop yields will be lower than under the GRAS scenario, but higher than under the SEDG scenario. It explains why overall crop production will increase compared to SEDG scenario. Land use for annual crop production would be higher than under the GRAS scenario, but lower than under the SEDG scenario. This explains why the production of cereals and other annual crops would increase under the BAMBU scenario while it would decrease under GRAS. The consequence is that the vulnerability of Northern countries will decrease while that of Southern countries will not change. It also implies that Northern consumers will consume more crops that do not dependent on insect pollinators than in 2005 and the consumer surplus loss will decrease in Northern countries.

The introduction of an economic shock due to an oil crisis (BAMBUS-SEL) will slow down the annual crop production compared to BAMBU scenario. As a consequence, the agriculture of Northern countries will be more vulnerable to pollinator decline than in the BAMBU scenario.

The introduction of a pandemic shock (BAMBU-CANE scenario), will result in a slower population growth. Consequently the land use for urban will decrease and will be used for annual crop production (Table 3-5). This will result in an increase of annual crop production (Table 3-5), and a decrease of vulnerability of Northern countries (Table 3-8). The consumer surplus loss will be the same as in the BAMBU scenario, except for Northern countries since it will decrease. Indeed, the upper value obtained with an elasticity of -0.8 will be €6.5 billion lower than BAMBU scenario and than the lowest value obtained with an elasticity of -1.2 in 2005 (€6.6 billion ; Figure 3-4.a).

As under the SEDG scenario, the increase of crop production and the decrease of prices will reduce the consumer surplus loss except for Southern consumers that do not prefer insect-pollinated crops. For them, the surplus loss will increase even higher than under the SEDG scenario.

3.3. Conclusion

In 2005, the contribution of insect pollinators to European agriculture was €12 billion. The vulnerability ratio of the agriculture confronted with pollinator loss was about 10 percent. The loss of social welfare in Europe could reach €26 billion considering that European consumers have a strong anchored preference for insect-pollinated goods, *i.e.* with a price elasticity of -0.8. It could reach €19.9 billion if European consumers have low preference for insect-pollinated goods, *i.e.* with a price elasticity of -1.2. We also found a North-South division where Southern countries were more vulnerable to insect pollinator decline than Northern ones. This distinction could be explained by the specialization of some countries in the production of pollinator-dependent crops. It is particularly the case for fruits whose production is mostly located in southern Europe, while northern Europe is more specialized in the production of cereals and other non-entomophilous crops (FAO, http://www.fao.org). Furthermore consumers of Northern countries would be less impacted than consumers of Southern ones.

The contribution of insect pollinators to European agriculture and their impact in terms of social welfare was important in 2005. The question then is to try to forecast how their contribution will evolve over the next eighty years following different policy orientations. Based upon such forecast, we can conclude that insect pollinators will continue to have an important role in the European agriculture whatever the political strategies for economic, social and environmental growth.

However we could predict that using proactive policies, characterized by SEDG scenario, will decrease the need for insect pollinator in Northern countries. On the contrary, using reactive policies, characterized by GRAS scenario, will decrease the need for insect pollination in Southern countries.

Actions for the protection for abundance and diversity of insect pollinators are needed in Europe in order to prevent the future decline. The question is to know if these measures should be undertaken homogeneously across Europe or if they should be undertaken at lower scale. A first element of response is given by the fact that the Southern countries are more vulnerable than Northern one. This implies that the protection of insect pollinator should be accentuated in South of Europe.

So this large-scale study needs to be detailed at the national level. To do this, we will examine the impact of insect pollinator loss in two very different countries agriculture-wise in order to evaluate whether a uniform European policy strategy might be appropriate or not.

4. Case study comparing Germany and Spain

Both countries produced a total of 77 direct crops and 8 commodities directly used for human food (Appendix 7). Among these, 41 direct crops in 6 categories are dependent on insect pollinators for their production and pollinators are essential for 4 of these crops. The contribution of insect pollinators is also reported as “great” for 12 of these direct crops, “modest” for 13 and “little” for 12 (following the terminology of Klein *et al.* 2007). Even at this national scale, it is noteworthy that within each category, there was considerable variation among the crops as to their level of dependence on pollinators.

4.1. The crop production context and its dependence on insect pollinators in Germany and Spain in 2005

4.1.1. Crop production context

In 2005, the proportion of the land dedicated to crop production used directly for human food represented about 54 % of the total land area in Spain and 52 % in Germany (Figure 3-5). The area planted in annual crops was more important in Spain than in Germany with 21.9 and 18.2 million ha, respectively. Moreover, a much larger part of the arable land in Spain was used for permanent crops since these represented 5 million ha, *i.e.* 10 percent of the total land use, compared to < 0.5 million ha in Germany.

Germany's agricultural production was primarily dedicated to cereals, which represented 50 percent of the total crop production, followed by sugar beet (25.3 million tons) and roots and tubers, mainly potatoes, (11.6 million tons). The Spanish crop production was primarily dedicated to fruit, which made 27 percent of the total crop production, followed by cereals and vegetables with 14.1 and 13.1 million tons, respectively (Table 3-9).

Figure 3-5 – Land use in percentage (%) for annual crops, permanent crops and remaining of land area confronted to the total land area in Germany and in Spain in 2005 (FAO, 2008) and in 2080 under the GRAS, BAMBU and SEDG scenarios

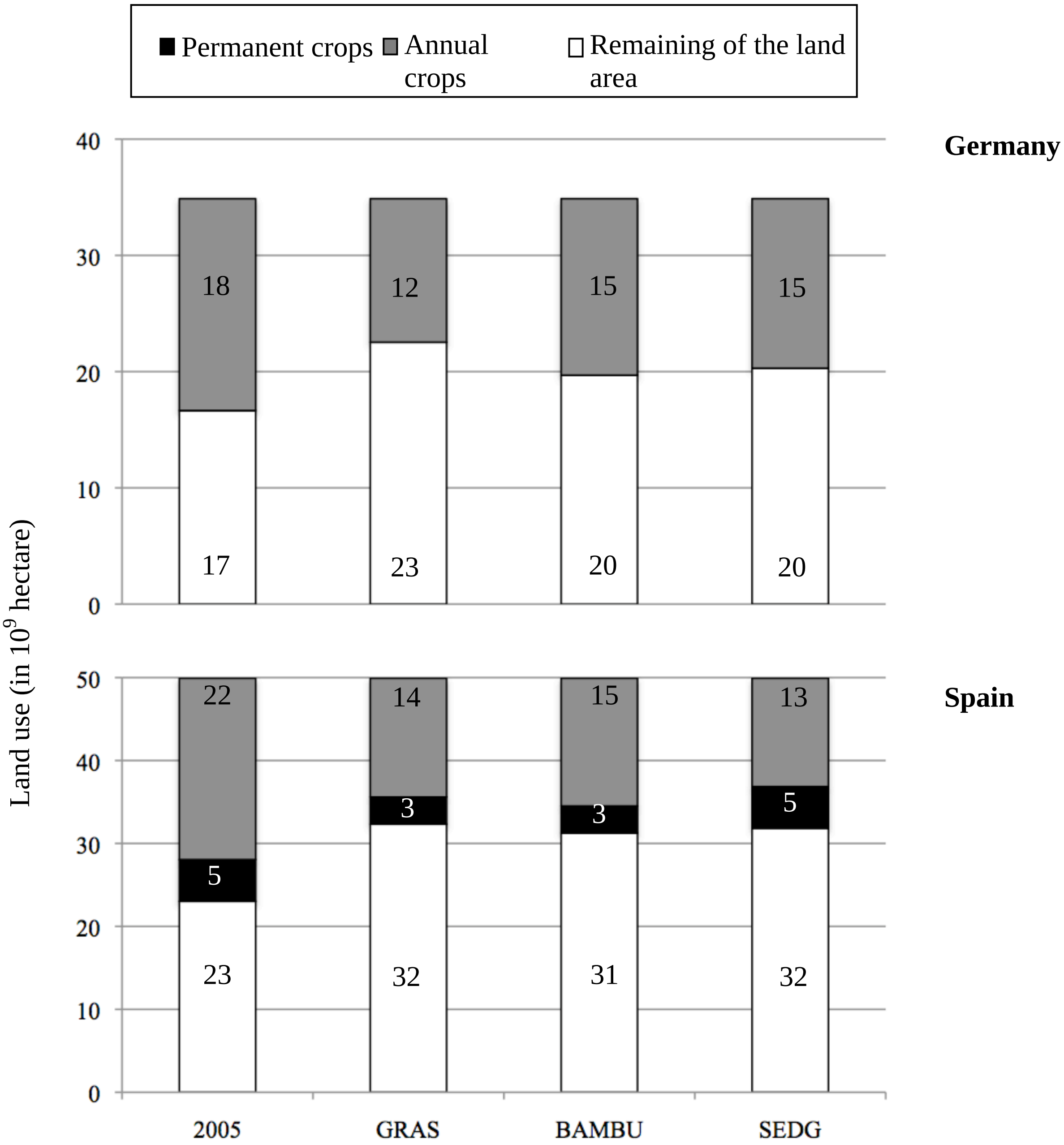


Table 3-9 – Economic value and vulnerability of crop categories in Germany and Spain in 2005.

Countries	Variable	Cereals	Edible oil crops	Fruits	Nuts	Pulse	Roots & tubers	Spices	Sugar crops	Vegetables	**TOTAL**
Germany	Production (Q ; 1000 tons)	48 814	5 153	2 567	18	406	11 624	0	25 285	3 158	**97 025**
	Total Value (TV ; 10^6€)	*4 864*	*983*	*1 851*	*31*	*105*	*1 449*	*0*	*1 167*	*1 517*	***11 968***
	Average value of a production unit (€ per metric ton)	99.6	190.9	721.2	1711.2	259.6	124.7	0	46.2	480.4	
	Economic Value of Insect Pollinators (EVIP ; 10^6€)	*0*	*244*	*389*	*0*	*10*	*0*	*0*	*0*	*78*	***722***
	Vulnerability Ratio (VR ; %)	0	24.9	21.0	0	0	0	0	0	5.2	**6.0**
Spain	Production (Q ; 1000 tons)	14 072	4 442	15 477	268	321	2 616	9	7 344	13 085	**57 634**
	Total Value (TV ; 10^6€)	*1 537*	*3 543*	*8 913*	*339*	*85*	*328*	*7*	*338*	*6 576*	***21 666***
	Average value of a production unit (€ per metric ton)	109.2	797.7	575.9	1264.4	265.5	125.5	719.7	46.1	502.0	
	Economic Value of Insect Pollinators (EVIP ; 10^6€)	*0*	*25*	*1 322*	*169*	*5*	*0*	*0.3*	*0*	*954*	***2 475***
	Vulnerability Ratio (VR ; %)	0	0.7	14.8	49.8	6.2	0	4.7	0	14.5	**11.4**

4.1.2. Importance of insect pollinators in Germany

The 2005 total value for all crops used directly for human food reached almost €12 billion in Germany (Table 3-9). The total value of insect-pollinated crops was €2 billion, which represented 16.7 percent of the overall TV. The main pollinator-dependent crop categories ranked by decreasing economic value were fruits, vegetables, edible oil crops and pulses. Overall, the EVIP was €0.7 billion, and the average production value of a ton of non pollinator-dependant crops was 90 €, while that of the pollinator-dependent crops averaged 769 €. The vulnerability ratio of German agriculture to pollinator loss was 6.0 percent. The edible oil crops with a total value of almost €1 billion had the highest vulnerability ratio (24.9 percent). The fruits had the highest total value (€1.9 billion) and a high vulnerability ratio of 21 percent, followed by vegetables with a vulnerability ratio of 5.2 percent. The 2005 consumer surplus loss in Germany ranged between €1.1 billion and €0.9 billion based upon a price elasticity of -1.2 and -0.8, respectively (Figure 3-6).

4.1.3. Importance of insect pollinators in Spain

The 2005 total value for all crops used directly for human food in Spain was €21.7 billion (Table 3-9). The total of insect-pollinated crops was €8.5 billion, which represented 39 percent of the overall TV. The main pollinator-dependent crop categories ranked by decreasing economic value were fruits, vegetables, edible oil crops, nuts, pulses and spices. Overall, the EVIP was €2.5 billion, and the average production value of a ton of non pollinator-dependant crops was 94 € while that of the pollinator-dependent crops was 688 €. The vulnerability ratio of Spanish agriculture to pollinator loss was 11.4 percent. Nut crops with a total value of only €0.3 billion had the highest vulnerability ratio (50 percent), because of almonds. Fruits had the highest total value in Spain (€8.9 billion) and a high vulnerability ratio (14.8 percent), followed by vegetables with a vulnerability ratio of 14.5 percent. The Spanish 2005 consumer surplus loss ranged between €5.7 billion and €4 billion based upon a price elasticity of -1.2 and -0.8, respectively (Figure 3-6).

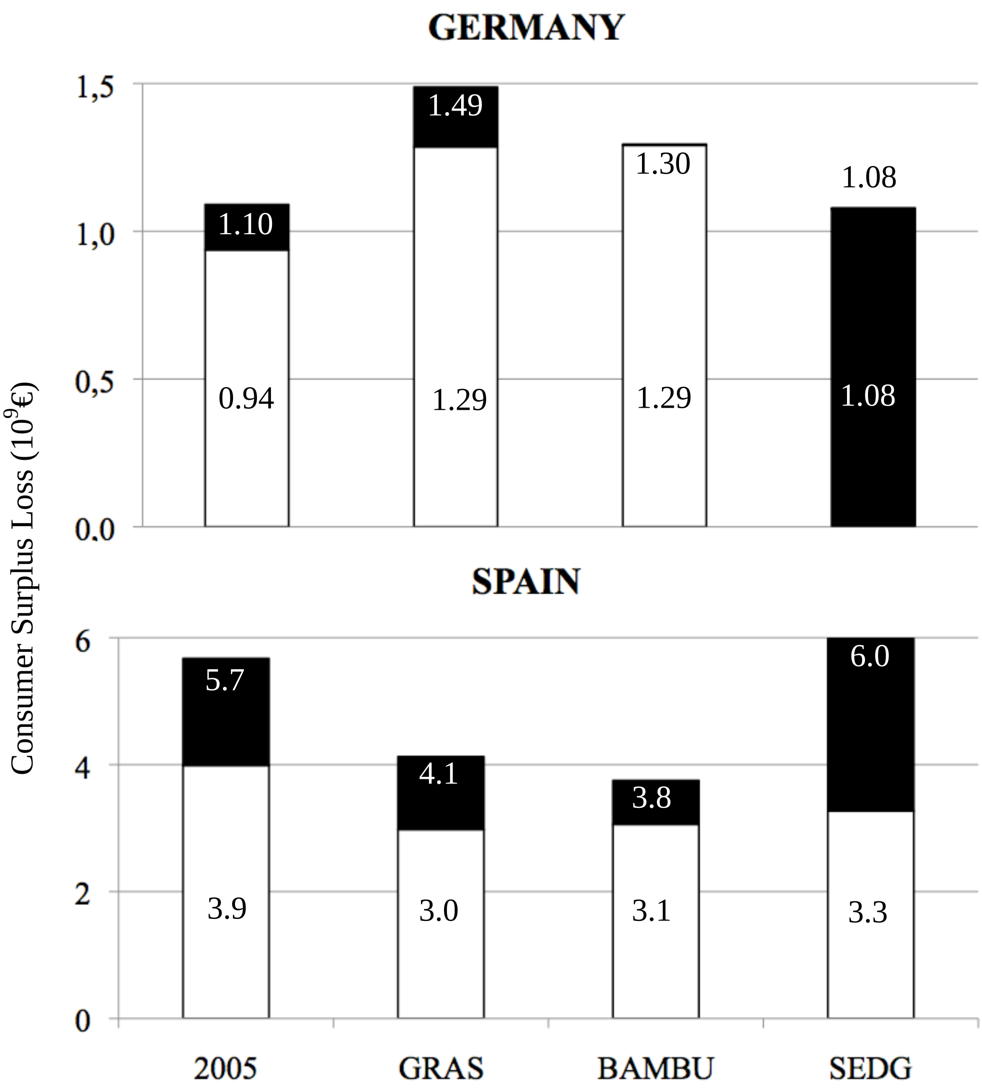
4.2. Crop production context and dependence upon insect pollinator in Spain and Germany in 2080

The crop production context and the impact of insect pollinators were assessed for Germany and Spain under the three ALARM scenarios GRAS, BAMBU and SEDG.

4.2.1. Crop production context

Under all scenarios, the land use for both annual and permanent crops will decrease between 2005 and 2080 in both countries (Figure 3-5). For permanent crops in Spain, the decrease will be more important under the GRAS and BAMBU scenarios (- 2 million ha each compared to - million ha under the SEDG scenarios). For annual crops, the drop in surface will be more important in Spain than in Germany under all scenarios and also greater under the BAMBU and SEDG scenarios than under the GRAS scenario. There will be a general decline of the land used for arable land in both countries and for the three scenarios. However, due to the increase of crop yields, crop production will increase significantly everywhere.

Figure 3-6 – Consumer surplus loss (that corresponds to welfare loss) in 2005 with a price elasticity of -1.2 (white columns) and -0.8 (white and black columns together) in Germany and Spain, and its evolution until 2080 under GRAS, BAMBU and SEDG scenarios. of -0.8 and -1.2.



4.2.2. Impact of pollinator loss under the GRAS scenario

In a future Europe without CAP, *i.e.* with free competition, more than 50% of the land used for annual crop production will be abandoned (Figure 3-1), and the annual crop production will decrease. However, in Germany the land used for crop production, which was essentially used for annual crops in 2005, would not decrease as much (20%, Figure 3-5), so that because of the increase of crop yields, the production will actually increase and the total value of crops will increase. As a result, the vulnerability of German agriculture will not change by 2080 compared to 2005 (Table 3-10). Due to the increase of the total value of crops and more precisely of fruits and nuts in Germany, the consumer welfare loss will increase for two types of consumers *i.e.* consumers with high preferences on crops that depends on insect pollinator and the ones with low preferences (Figure 3-6). On a Europe wide basis, we also observed an increase in the production of fruits, which is the most important crop category in Spain. So we can assume that the increase in crop production in Spain is due to increase of fruit production. But, contrary to Germany and other Southern countries, the Spanish agriculture will face a reduction in the total value of its crops (Table 3-10). This can be explained by the difference between a decrease of prices observed in Europe overall as a consequence of an increase in European production compared that in Spain. We must remember at this stage that in our models the evolution of prices are calculated using the weighted mean of European prices and production changes and that Europe represents a single market. In Spain, the production increase will be less in proportion than the price decrease so that the total value of its production will decrease (Table 3-10). As a result, the vulnerability of Spanish agriculture confronted with pollinator decline would also decrease by 2080 (Table 3-10). Due to the decrease of total value of fruits in Spain, the total value of insect pollinated crop will decrease, which implies that consumer welfare loss will decrease for both types of consumers (Figure 3-6).

4.2.3. Impact of pollinator loss under the SEDG scenario

Considering the SEDG scenario with a stronger CAP, Spain will be representative of the Southern countries since it vulnerability ratio will not change while Germany vulnerability will not follow the evolution of the Northern vulnerability as its vulnerability will not change either (Table 3-10). This is so because of a better yield of crop production that depends on insect pollinator in Germany than in the rest of Europe since prices remain the same. This indicates that the value of insect contribution to crop production will increase. Under this scenario, the Spanish consumer surplus loss will not remain the same as for general Southern consumers (Figure 3-6) because the land used for annual crops in Spain will decrease more than over the rest of Europe (Figures 3-1 and 3-5). This difference could be explained by the interest of Spanish farmers to use land first for permanent crops. Consequently, the contribution of insect pollinators will increase compared to the total value of crops. Another consequence will be that the consumer surplus loss will increase compared to 2005 for consumers with strong anchored preferences on crops that depend on insect pollinators since the consumption loss due to the same variation of price than in 2005 will increase (Figure 3-6). The consumer surplus loss will decrease for consumers that do not have with strong preferences on crops that depend on insect pollinators.

4.2.4. Impact of pollinator decline under the BAMBU scenario

In a future conistent with the current common agricultural policies, the vulnerability of Germany and Spain will evolve in opposite ways of the one observed in Northern and Southern Europe (Table 3-8 and 3-10). We noted in the previous sections that the European evolution of land use for annual crop production under the BAMBU scenario will not decrease as much as under GRAS scenario, but more than under the SEDG scenario. However, this will not hold true in Germany nor in Spain since they will evolve approximately as under the SEDG scenario. But under the BAMBU scenario, the CAP will not be as strong, which means that farmers will use more efficient technologies in terms of production. This implies that the production of annual crops will grow faster than in the rest of Europe (Figure 3-1 and 3-5). Consequently in Germany the total value of crops will increase as will the value of insect pollinator contribution, which implies that vulnerability of German agriculture confronted with pollinator loss will not change and consumer surplus loss will increase (Table 3-10 and Figure 3-6). In Spain, this improvement in production will be coupled with a drop of permanent crops, and, the total value of crops will decrease because the production of permanent crops is more expensive than that of annual crops. The drop of permanent crops will result in a decrease of the value of insect pollinator contribution and a decrease of the vulnerability of Spanish agriculture to pollinator loss as well as a decrease of the consumer surplus loss (Table 3-10).

Table 3-10 – Compared evolution of the total economic value and vulnerability to pollinators of agriculture in Germany and Spain under the GRAS, BAMBU and SEDG scenarios between 2005 and 2080.

Country	Indicator	GRAS	BAMBU	SEDG
Germany	Production (Q ; 1000 metric tons)	110 824 ↗	166 988 ↗	136 648 ↗
	Total Economic Value (TEV ; 10^6€)	15 569 – 15 936 ↗	14 491 – 16 340 ↗	12 366 – 13 775 ↗
	Economic Value of Insect Pollinators (EVIP ; 10^6€)	922 – 1 007 ↗	849 – 987 ↗	715 – 828 →
	Vulnerability Ratio (VR ; %)	5.9 – 6.3 →	5.9 – 6.0 →	5.8 – 6.0 →
Spain	Production (Q ; 1000 tons)	47 633 ↗	63 108 ↗	60 297 ↗
	Total Economic Value (TEV ; 10^6€)	16 726 – 17 977 ↘	14 519 – 16 836 ↘	15 329 – 17 946 ↘
	Economic Value of Insect Pollinators (EVIP ; 10^6€)	1 798 – 1 986 ↘	1 583 – 1 874 ↘	1 733 – 2 054 ↘
	Vulnerability Ratio (VR ; %)	10.8 – 11.0 ↘	10.9 – 11.1 ↘	11.3 – 11.5 →

4.3. Discussion and conclusions

The Germany versus Spain case study enabled us to develop a more detailed interpretation of the results of the comparison between Northern and Southern European countries as these two countries are good representative examples of the two groups.

In Germany, the total value of insect pollination was estimated at €0.7 billion in 2005 or about 6% of the overall value of the crop production used directly for human food. In Spain, the total economic value of insect pollination was more than three times as much, at almost €2.5 billion, and it represented about 11% of the overall value of the crop production used for human food. The Spanish agriculture thus appears nearly twice as much more vulnerable to pollinator loss than the German one. This difference in vulnerability reflects the differences in the categories of crops grown in the two countries as well as in the surface grown. Germany's agriculture in 2005 was concentrated mainly on crops that do not depend on insect pollinators, such as cereals, roots and tubers and sugar beet, which are the principal crop categories for most of the Northern countries, while fruit was the primary production of Spanish agriculture (Table 3-7). The vulnerability to pollinators was greater for each crop category in Spain compared to Germany, except for edible oil crops. While both countries were important producers for this category, Germany specialized in oilseed rape and sunflower, both of which are insect-dependent, whereas Spain was more specialized in olive production, which is not pollinated by insects. The loss of social welfare following pollinator loss would be €1.1 billion in Germany considering that consumers have strongly anchored preferences on crops that depend on insect pollinators and it was €0.9 billion if consumers had a low preference on such crops. In Spain, it would be €5.7 billion if consumers had strongly anchored preferences on crops that depend on insect pollinators and €4 billion otherwise.

Looking at the possible future based upon the different ALARM scenarios, it appears that insect pollinators will be important for Spanish agriculture since the vulnerability ratio will be higher than 10%. It implies that political measures for insect pollinators protection will be recommended. We also observe that the consumer welfare loss in Germany will increase in GRAS and BAMBU scenarios. However the consumer surplus loss is due to price increase. So the question is to know if it would be better to protect insect pollinators or to fixed prices of crops in order to avoid their variation.

The evolution of agriculture in Germany and in Spain will not always follow trends similar to that found for Northern and Southern countries see in preceding section. This justifies the interest of a national analysis of agricultural vulnerability to insect pollinators decline and more particularly the need of localized measures for their protection.

5. Discussion

It is important to remember that a strong vulnerability is not bad for a country, a region or Europe as a whole, it solely means that the area of pollinator protection needs more attention from the government of the given area considered. In other words, the aim of our study is not to try to reduce the economic vulnerability of agriculture confronted with insect pollinator decline and possibly loss, but to try to prevent the consequences of pollinator decline altogether. This is so because a global reduction of vulnerability would imply that the European agriculture aims to eliminate insect-pollinated crops, such as most fruits, vegetables and edible oil crops. Clearly, this would not be not a viable alternative to European consumers. Thus our study provides some information on the future trends of agricultural vulnerability confronted with pollinator decline in order to be able to put in proper perspective the importance of protecting insect pollinators in term of abundance as well as diversity (though for the later we did not address at all the impact of pollinator decline on the wild flora and natural environment).

We will now discuss the different results of the possible scenarios of evolution of European agriculture and its vulnerability, and review possible solutions for insect pollinator protection. We will discuss a way to improve the indicator of the agricultural vulnerability faced to pollinator loss and finally we will discuss the limit of study.

5.1. The future of European agricultural vulnerability confronted with pollinator decline

The 2005 pollinator contribution to the agricultural output of Europe was important since it amounted to 10% of the overall crop production value and the consumer surplus loss following a total loss could reach almost €26 billion. From these figures, we could already conclude that strong protection of insect pollinators would have been necessary by 2005 in Europe. But how will this evolve in the future? To gain some insights to answer this question, we used the three ALARM scenarios: GRAS, BAMBU and SEDG. We found that for European countries considered as a whole, the vulnerability of agriculture will not change in any of the three scenarios. But Europe is a heterogeneous region where agriculture differs among countries. Indeed, we found that European countries could be pooled into two groups based on their agriculture with Southern countries more vulnerable to pollinator decline than Northern ones. So the financial and social means to implement in order to protect insect pollinators would likely not be homogeneous across Europe. The study of the two extremes scenarios (GRAS and SEDG) indicated that the vulnerability of Northern countries would decrease with a stronger CAP, *e.g.* prohibition of the use of polluting tools for crop production such as agrochemicals. On the other hand, the vulnerability of Southern countries would decrease in the absence of a CAP. Considering the most realistic scenario (BAMBU), we found that it would be more likely that the vulnerability of Northern countries would decrease except if we introduced an economic shock that would result in an increase of their vulnerability.

We also observed that the need for pollinator protection could be misinterpreted when comparing figures at the European scale and even at the country scale since we found that the evolution of the agricultural vulnerability in Germany and Spain could differ substantially from their respective group of Northern and Southern countries. And these differences were accentuated when considering the loss in consumer surplus. Indeed, at the overall European level the consumer surplus loss will not increase except in the extreme case of the GRAS-CUT scenario. Yet, at country scale, the consumer surplus loss following complete pollinator decline would increase a lot in Germany under the GRAS and BAMBU scenarios and in Spain under the SEDG scenario regardless of consumer preferences, that is whether consumer preferences are anchored to the insect-pollinated crops or not.

5.2. What responses to insect pollinator decline?

5.2.1. Two indicators of pollinator impact

The main goal of the economic valuation undertaken here is to measure the direct value of this ecological service. We calculated an estimate of this value for the European countries as a whole as well as more country-wise estimate for Germany and for Spain. We calculated the economic value of the contribution of insect pollinators in 2005 and demonstrated that this value would still be significant in the future regardless of the forecast scenario we used. But we also calculated the value of consumer surplus loss following total pollinator decline and this estimate is probably more accurate since it represents the social welfare loss that would result from pollinator loss.

5.2.2. The stakeholder involvement

According to Daily *et al.* (2000) and McCauley (2006), any economic valuation should induce political reaction. In this sense, our valuation is a way of organizing information to help guide decisions. Daily *et al.* state that valuation is *"not a solution or an end in itself"*, deploring that ecosystem functioning is poorly understood, and that *"the importance of ecosystem services is widely appreciated only upon their loss"*. For McCauley (2006), economic valuations are essential to induce stakeholders to recognize the impact of environmental destruction and to conserve the ecosystems. In this context, our economic valuation of the pollinator contribution to agriculture in Germany and Spain shows the potential risks associated with bee decline and could help to stop it through political actions.

5.2.3. Addressing uncertainty

The production optimization over the long term must take into account the preservation of ecological services. An example is given by Roubik (2002) on coffee production in Central America. There, the growers tended to decrease the area of shade trees to increase coffee plant density and the yields over the short term (Muschler, 2001; Lyngbaek *et al.*, 2001). But in doing so, they eliminated nesting sites for bees and led to the erosion of pollinator populations over the long term. The declining yield could be temporarily offset by expanding cultivation or increasing planting density, but such remedies were unstable. On the other hand, protection of insect pollinators can provide economic incentive to preserve natural habitats in intensive agroecosystems as, for rape in Western Canada, yield and profit were maximized when 30% of the land was not cultivated within 750 m of field edges (Morandin and Winston, 2006).

The major way of addressing uncertainty would be to protect pollinator abundance and diversity. A possible response to sustain and possibly enhance bee populations would be to protect their natural habitats. Ricketts *et al.* (2004) demonstrated that coffee plants would benefit from being grown in a context suitable for sustaining valuable pollinators. Also the role of surrounding natural vegetation in providing pollination by native pollinators has been demonstrated for several crops such as cashew nuts (Cunningham *et al.*, 2002; Heard and Exley, 1990) and macadamia nuts (Cunningham *et al.*, 2002; Heard and Exley, 1994). Remnant natural vegetation is also crucial for the survival of feral population of honey bees because it provides nesting sites for colonies, as well as a diverse array of important food plants (Cunningham *et al.,* 2002). Another response to protect bee populations would be to limit the use of agrochemicals, monitor closely the expression and impact of introduced genes in Genetically Modified Plants (Cunningham *et al.,* 2002) and favour the use of organic farming (Gabriel & Tscharntke 2006, Holzschuh et al. 2008).

5.2.4. Policy measures

Few European agricultural policies exist yet that addresses the protection of pollinators (Kuldna *et al.* 2009). But some of these elements were recently taken into account by the European Union agricultural policy through agri-environmental measures that are designed to encourage farmers to protect and enhance the environment on their farmland. These measures may be designed at national, regional and/or local level for reducing environmental risks and preserving semi-natural habitats in cultivated landscapes (European Commission, 2005). An example of such an agri-environmental measure is the 214H measure (*Improving the honeybee pollinator potentials for the preservation of biodiversity* – European Commission, 2005 and 2006) through which the French government provides financial incentives to beekeepers to place their honeybee colonies in Natura 2000 areas to improve pollination of the native flora.

Furthermore, in order to protect the European consumers surplus loss due to insect pollinator decline, the European Commission will have to support financially the producer to avoid the price increase. But this action seems too costly compared to fund necessary for inect pollinator protection.

5.3. The limits of the vulnerability ratio

Yet our results should be interpreted carefully because we studied Europe as a whole and more specifically Germany and Spain considering each of these entities as single market in which only the crop price was influenced by others economies. However, neither Spanish nor German nor even all European farmers produce enough to provide food to all the consumers of their local market (Gallai *et al.* 2009), and the national demand is satisfied by using imports. Consequently a more appropriate assessment of vulnerability should also take into account the capacity of countries in international trade.

Germany appears less vulnerable to pollinator decline based on its crop production structure. However, its imports of insect-dependant products are quite large in economic terms. In 2005, Germany imported more than €0.7 billion worth of tomatoes, €0.8 billion of soybean, €0.4 billion of almond shelled, €0.4 billion of green chile and bell pepper, and €0.3 billion of cucumber and gherkins (FAO, 2008). On the opposite, Spain imported only three insect-dependant crops for less than €0.3 billion worth in total while it imported mainly non-insect dependant produce such as wheat (€1.2 billion) and corn (€0.7 billion) (FAO, 2008). Thus, while it is interesting to examine the vulnerability for agriculture at a national scale, the vulnerability to pollinators decline from a consumer viewpoint should be considered at a larger geographical scale to take into account the flow of goods that results from international trade.

Under the GRAS scenario, and to a lesser extent under the BAMBU scenario, the products are traded freely among all countries in Europe (Spangenberg, 2007). Thus Germany and Spain would be dependent not only on their own agricultural vulnerability, but on the overall vulnerability to pollinators the European agriculture as a whole. On the opposite, under the SEDG scenario, trade is limited to regional scales, which implies that countries will be less affected by what happens in the other states. As a result, both their vulnerability confronted with pollinator decline and the diversity of crops available in their markets would decrease. It is then an ambiguous result since, on one hand, countries will decrease their vulnerability, but on the other hand, they will decrease their welfare.

5.4. Limits of the study

We used a large set of data to support our study at the European scale. We crossed scenario storylines, MOLUSC models and elements from the FAO database. Despite this large set of data, we had to use restrictive assumptions, which are limits to the practical conclusions that can be drawn from our study.

Our calculations were based on the assumption of a total pollinator loss, but our results can to some extent be extrapolated to any level of pollinator decline because there is empirical evidence that the yield of entomophilous crops responds approximately linearly to pollinator density (Dedej and Delaplane, 2003; Steffan-Dewenter, 2003; Clement *et al.*, 2007). We did not take into account the value of beef and dairy products that are produced with the hay from entomophilous forage legumes such as alfalfa. The impact of bee decline could thus be quite a bit higher than we calculated here as suggested by Martin (1975) who considered that 80 percent of the seed production was due to insect pollinators in the USA.

The scenarios describe the evolution of annual or permanent crop surfaces but do not give information concerning the relative changes in the surface of the different crops within each type. Yet there is considerable heterogeneity between pollinator–dependent and non-pollinator dependent crops within each of these types (Table 3-1). This means that the vulnerability of European agriculture confronted with pollinator decline could be different from the one found in this study.

Moreover, we used the same trend of yield evolution for all crops, but this trend is based upon past results that may not hold true. It is unlikely that the yields will evolve in a similar way for all crops. Aizen *et al.* (2008) demonstrated that since 1961 world agriculture gave a greater importance to pollinator-dependent crops. Indeed, they found that the land used for pollinator-dependent crops increased by 70% in developed countries between 1961 and 2006. This increase accelerated in the recent years. If this trend is to continue in the future, the need for pollinators will be accentuated.

Scenarios are storyline describing the future taking into account the interaction between climate change and human activities following different policy strategies. In order to pass from qualitative description to quantitative assessment, some assumptions are done on the evolution of some indicators *e.g.* the firm growth, the population growth, the gross national product evolution and the emission rate of greenhouse gases. Some indicators are well referenced while others are less well so. In the ALARM scenarios, the evolution of crop yield is indexed on the evolution of wheat yield (Appendix 6). However, it is easy to imagine that the evolution of fruit yield could differ from the one of wheat or that evolution of permanent crop yield could differ from that of an annual herbaceous crop such as wheat.

We further assumed that producers would adapt perfectly to the new demand of crop quantity. Thus welfare losses correspond only to the consumer losses. But producers will probably be the first directly affected by pollinator decline. They will need to adapt their production practice, switch from pollinator-dependent crops to less dependent ones, or develop costlier artificial pollination techniques. We can also predict that the intermediaries referred to as the ‘agro food chain’ will be impacted by insect pollinator decline. For a more realistic economic valuation, the resulting adaptation cost should also be taken into account.

We used ANOVAs to assess the significance of the differences between scenarios with the vulnerability as dependent variable, but this variable varied little (Table 3-6). Our models took into account how the prices would adapt to production changes by considering a range of price elasticity and we calculated the vulnerability as the ratio between the value of pollinator contribution and the total economic value of crop production. These two values were estimated based upon how prices change so that the vulnerability will change as a function of the price elasticity. We assume that if we had taken a larger range of elasticities, the ANOVAs might have shown significant differences between scenarios.

6. Conclusion

In 2005, the total economic value of the pollination service was €12 billion in Europe and the corresponding vulnerability ratio was about 10 percent. We estimated the loss of social European welfare between €26 billion and €19.9 billion considering that consumers had more or less flexible preferences on pollinator-dependent crops (*i.e.* for a price elasticity from -0.8 to -1.2). Thus we conclude that insect pollinators were important for European agriculture. More precisely, we found that the Southern European countries were significantly more vulnerable to pollinator decline than Northern ones.

The aim of this paper was to assess the evolution of European vulnerability to pollinator loss in order to determine the need for policy to protect insect pollinators. For this purpose, we studied the evolution of European vulnerability across three ALARM scenarios: GRAS, BAMBU and SEDG. Those scenarios included extreme policy orientations that will affect the vulnerability and social welfare due to pollinator loss. GRAS scenario policies are reactive to climate change while SEDG scenario policies are proactive. BAMBU scenario policies are simply an extrapolation of the 2005 policies. With proactive policies, by 2080 the vulnerability of agriculture from northern countries will decrease while that of Southern countries will not change. But with reactive policies, the vulnerability of Southern countries will decrease while that of Northern countries will not change. The consumer welfare loss for consumers that prefer insect-pollinated crops as well as those that do not will decrease in Northern countries regardless of the scenarios. On the other hand, the consumer welfare loss of Southern countries will increase for consumers that do not prefer insect-pollinated crops, while it will decrease for those that prefer insect-pollinated crops. The consumer welfare loss of people that have high preferences for insect-pollinated crops could even increase in the case of an accelerated increase in temperature.

We also found that when examining the evolution of agricultural vulnerability at the country level, the results can differ from those obtained at a larger regional scale. We studied the evolution of Spanish and German agriculture and Spain clearly belong to the group of Southern countries since it vulnerability ratio in 2005 was 11.4% and Germany belongs to the group of Northern countries as its vulnerability ratio was 6% in 2005. The 2080 vulnerability ratio in Germany will not change under the BAMBU and SEDG scenarios while the vulnerability ratio of Northern countries considered as a whole will decrease. The 2080 vulnerability ratio in Spain will decrease under the BAMBU scenario while the vulnerability ratio of Southern countries considered together will not change. Regarding the impact on the consumer surplus, results were more contrasted at the country level than at the regional level. Indeed, in Germany the consumer surplus loss for both kinds of consumers will increase when considering the absence of a CAP or enforcement of a CAP with little restrictions on use of agrochemicals for example, while under the same scenarios the consumer surplus loss will decrease in Spain.

The insect pollinator protection will be necessary in Spain in the future. But under a reactive policy it will be less important than in a proactive one. The German agriculture will not depends so much than Spain in insect pollinators but the consumer surplus loss due to insect pollinator decline will increase in the future. Consequently a political intervention will be necessary in order to prevent the possible price increase due to pollinator loss.

We found that insect pollinators will have an important impact in the future European agriculture whatever the political strategy undertaken (proactive or reactive). Effective actions for insect pollinator protection or for consumer welfare protection will be necessaries. This paper demonstrated that an effective action has to be realized locally since agriculture of European countries are different and will evolve differently. Furthermore the action will be different depending on the impact of a pollinator decline since it will be measured either on the agricultural industry or on the consumer welfare depending on the countries.

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