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APPLICATION OF THE AHP/ANP TO IDENTIFY THE MOST SUSTAINABLE DIRECTION OF CROP PRODUCTION IN POLAND

Anna Strada

Jagiellonian University, Institute of Economics and Management
Department of Quantitative Methods

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Abstract
The present study aims at determining the most sustainable plant production in Poland, by obtaining priorities for selected alternatives of food crops in Poland ("conventional", "organic" and "transgenic") using the AHP/ANP technique as the multicriteria decision making aid. The study addresses three aspects of sustainability: food health quality, environment and socio-economic issues. The research consisted of three stages: first, review of the existing literature to produce a set of criteria/subcriteria pertinent to sustainable agricultural plant production; second, deriving priorities for the criteria/subcriteria using the AHP (Analytic Hierarchy Process), and third, determining and rank priorities for conventional vs. organic vs. transgenic farming in Poland using the Analytic Network Process (ANP). The ANP were based on four separate models (subnets): Benefits (B), Costs (C), Opportunities (O) and Risks (R). The criteria and subcriteria under these subnets were in line with the main and specific objectives of the AHP model, and followed the same main goal: "Sustainable agricultural development in Poland". The results indicated that "organic crops" are the most preferred option of the Polish agriculture, while "transgenic" and "conventional" agricultural systems are less preferred, but at virtually the same level. The overall preference towards organic farming owes mainly to the high weights assigned for the objectives commonly associated with organic production, such as i.e. "reduced exposure to pesticide residues in food" and "protection of pollinators".

1. INTRODUCTION

There are two leading directions in the current debate on agricultural production in Poland: "Poland free of GMO" (whether or not to allow GM crops in Poland) and "Poland – a niche for ecological (organic) agriculture".

As in many other countries, debate about GMOs in Poland is split between opponents and proponents of transgenic methods, especially in plant production for food and feed purposes, and has serious regulatory consequences. Opponents of transgenic production in Poland (particularly consisting of "green ecologists", but also many scientists) express many concerns about potential risks of GM crops, many of which are unjustified or even amplified, i.e. gaining resistance to antibiotics (Żarski, 2007) despite the fact that antibiotic-resistant markers are not allowed in Europe. On top of that, the argument about the food surplus in Poland is provided in support of the view that "we don't need more food". Conversely, proponents of GMOs warn that food prices are going to rise drastically if Poland continues to resist GM crops. It is due particularly to the raise of costs of animal production due to the ban of GM soy feed (Polish Regulation on Animal Feed 22 July 2006, coming into force 11 August 2008), and higher costs of bio-fuel production resulting from the ban of transgenic oilseed rape.

The second direction articulates that agricultural production in Poland is favorable for organic planting, owing to the specific agrarian conditions rather unique in the European sites. These conditions are portrayed as scattered small-size farms, not mechanized but rather using unreasonably high number of human workforce, traditional cultivation methods and most importantly, relatively low amount of artificial fertilizers, especially nitrogen fertilizers (39.4 kg for one hectare of arable land). Comparative analysis of the EU data demonstrates that the utilization of synthetic fertilizers in the Netherlands is three times higher than in Poland. In addition, such friendly environment for plant cultivation is confirmed by low soil contamination with hazardous metals (Ministry of Agriculture and Rural Development, 2007). In spite of these favorable conditions, and systematically growing number of certified organic farms this path of agricultural production is still not common in Poland. While in Europe the average share of organic farms per total number of farms reached 1.7%, and 3.9% of arable lands (in 2005), this percentage in Poland was only 0.97 and 0.37%, respectively. Due also to the high costs of organic production, a vast majority of consumers cannot afford organic products, albeit the European demand for organic product continues to increase (Ministry of Agriculture and Rural Development, 2007).

The above discourses lead to the following questions: What is the best agricultural development plan for Poland? Should organic production dominate in this country while transgenic methods being avoided, or perhaps these two may coexist in a reasonable proportion? What sort of the criteria should be considered in making such choice? The key to answering these questions is what we want to achieve using one agricultural production method or another. Undoubtedly, the most widely adopted goal in agricultural development is "sustainability".

The concept of "agricultural sustainability" was originally addressed by Food, Agriculture, Conservation, and Trade Act of 1990 (FACTA) as an "…integrated system of plant and animal production having a site-specific application…". Under the law, this system should fulfill several long term objectives, notably: "…satisfy human food and fiber needs; enhance environmental quality and the natural resource base upon which the agricultural economy depends; make the most efficient use of nonrenewable resources and on-farm resources and integrate, where appropriate, natural biological cycles and controls; sustain the economic viability of farm operations; and enhance the quality of life for farmers and society as a whole…" (www.nal.usda.gov). Sustainable agricultural system should be therefore "…resource-conserving, socially supportive, commercially competitive and environmentally sound…" (John Ikerd, quoted by Duesterhaus, 1990, p. 4), producing abundant and wholesome food without polluting the environment or depleting natural resources, and also being in line with socio-economic values (Earles, 2005 in ATTRA).

Numerous studies across different countries attempted to scientifically explore various aspects of agricultural sustainability, notably food and nutrition (i.e. Johns & Eyzaguirre, 2007; Toledo & Burlingame, 2006), food demand of the growing population (i.e. Cohen, 1999), interaction between crops and the environment (i.e. Zhou & Shao, 2008), soil quality and productivity (i.e. Widmer *et al.*, 2006; Cardoso & Kuyper, 2006; Willson, Paul & Harwood, 2001), water-saving management and irrigation (i.e. Zhang *et al.*, 2007; Wichelns & Oster, 2006), weed management and herbicide resistance (i.e. Gerowitt, 2003; Paoletti & Pimentel, 1995), role and protection of pollinators (i.e. Morandin & Winston, 2006; Wilcock & Neiland, 2002; Kevan, 1999) biodiversity of plants, insects, fungi and bacteria (i.e. Dollacker & Rhodes, 2007; Altieri, 1999; Kennedy, 1999; Douds & Millner, 1999). Considerations were also made on how sustainable agriculture can address the human health (Horrigan *et al.*, 2002).

There are four types of farming systems usually reported with respect to sustainability, that is: conventional, organic, integrated, and transgenic. In addition, direct drilling system was also referenced in some studies (Champeil *et al.*, 2004). The term "conventional" refers to an industrialized agricultural production, highly mechanized, promoting monocultures and using synthetic inputs such as chemical fertilizers and pesticides, aiming at maximum productivity and profitability (Eicher, 2003). In other words, conventional model considers farms as factories while plants or animals as production units (Ikerd, 1993). "Organic" (also called "ecological" in some countries) agriculture is described as a method encouraging the use of renewable resources and biodiversity, without artificial fertilizers, herbicides and pesticides, and without the use of genetically modified organisms (GMOs) (Eicher, 2003). "Integrated" system postulates minimization of the use of synthetic fertilizers and pesticides, while supporting crop rotation as a natural method to improve crop productivity (Pacini *et al.*, 2003). The fourth model is "transgenic" or "biotechnology" agriculture, based on the use of genetically modified organisms (GMOs).

Undoubtedly, none of these methods can concurrently assure sustainability in all fields: food security, human health, environment and economy. The initial believe was that only organic farming is sustainable, but this view was later verified (Wagner, 1999). Necessity for the increased food production in pace with the growth in population suppresses environmental sustainability, whereas methods introduced to lessen pollution and reduce other environmental threats from agriculture fail to satisfy the growing demand for food (Sundsbø, 1991). Thus, certain trade-offs are inevitable, and the question is what to sacrifice, at what costs and to what level production goals will be attained.

Thus, another question must be posed: which aspect is of vital importance for the country, and which agricultural system, organic, conventional or transgenic, may accomplish this aspect at the lowest costs? There is no explicit answer to this question, however, multicriteria decision making tools allow to evaluate each option and indicate the optimal one based on the specific criteria. The present study aims at determining the optimal alternative for crop production in Poland (organic, transgenic or conventional?). Through trade-offs it may clarify the advantages and disadvantages of certain policy options under conditions of risk and uncertainty (Saaty, 2001). The research consisted of three stages: first, review of the existing literature to produce a set of criteria/subcriteria pertinent to sustainable agricultural plant production; second, deriving priorities for the criteria/subcriteria using the AHP (Analytic Hierarchy Process), and third, determining and rank priorities for conventional vs. organic vs. transgenic farming in Poland using the Analytic Network Process (ANP).

2. THE APPLICATION OF THE AHP/ANP IN SOLVING COMPLEX PROBLEMS

2.1. THE AHP METHOD

The Analytic Hierarchy Process (AHP) was developed by Thomas Saaty (Saaty, 1992) as a multicriteria decision making tool which decomposes a complex problem into a hierarchy, consisting of specific elements (Alphonce, 1997). It is considered to be the most effective multicriteria decision making method in dealing with multifaceted problems. The AHP has been applied to a wide range of decision problems in almost all domains (Braunschweig & Becker, 2004). It covers both tangible and intangible criteria based on the judgments of knowledgeable experts (Saaty, 2003). This section will only briefly overview the basis of the AHP process, since it has already been evaluated and criticized in numerous publications and also in other chapters of this book.

A hierarchical decision model consists of a goal (always at the top level of hierarchy), criteria that are evaluated for their importance to the goal, and alternatives that are evaluated for how preferred they are with respect to each criterion. Criteria can be further divided into sub-criteria. The goal, the criteria (sub-criteria) and the alternatives are all elements in the decision problem. Often the term "objectives" are used instead of "criteria", dependent on the model: a "criterion" is a principle or a standard based on which elements are evaluated, while an "objective" is something that is sought or aimed for.

Once the hierarchical model has been structured for a decision problem, participating experts make pairwise comparisons for each level of the hierarchy. In fact, the use of pairwise comparisons is one of the major strengths of the AHP to derive accurate ratio scale priorities, as opposed to using traditional approaches of assigning weights. Pairwise comparison is the process of comparing the relative importance, preference, or likelihood[1] of two elements ("children") with respect to an element in the level above ("parent"), in order to obtain priorities for the elements being compared. The

[1] *Importance* is most appropriate when comparing criteria or criteria. *Preference* is appropriate when comparing alternatives with respect to a criterion. *Likelihood* is appropriate when comparing the likelihood of uncertain events or scenarios, such as in risk analysis (Saaty, 2001).

weight factors provide a measure of the relative importance / preference / likelihood of this element for the expert / decision maker (Saaty, 2002).

Test of consistency is another critical step in the AHP process. When a pairwise comparison matrix fails to satisfy the consistency requirement, revisions are required to be made by a participating expert. A consistency test developed by Saaty (1980) allows a certain level of acceptable deviations ($CR < 0.1$). The consistency test involves the use of consistency ratio (CR):

$$CR = \frac{\lambda_{\max} - n}{n - 1} / RI$$

where $\lambda_{\max}$ is the maximum eigenvalue of the pairwise comparison matrix, and RI is a random index dependent on n. If CR is larger than 0.1, the respondent expert is required to revise his judgments until the acceptable level of consistency is obtained.

Since the weights are usually based on highly subjective judgments, the stability of ranking under varying criteria weights must be tested. It is therefore useful to test the sensitivity (responsiveness) of the outcome of a decision to changes in the priorities of the major criteria of that problem. Through increasing or decreasing the weight of individual criteria, the resulting changes of the priorities and the ranking of the alternatives can be examined Saaty, 2002).

The AHP is often used in group settings, where members either discuss to achieve a consensus or stick to their individual judgments. Individual judgments can be aggregated is different ways, of which the most widely applied are two: (1) the aggregation of individual judgments (AIJ) and (2) synthesizing individual priorities (AIP). Forman & Peniwati (1998) suggested that the choice of method depends on whether the group is assumed to act together as a unit or as separate individuals. If the group acts in synergy, AIJ is the most appropriate, while AIP is appropriate for the latter. Thus, the fundamental question is to which category the participant experts belong to. In the two cases, both the geometric mean and the arithmetic mean are appropriate for aggregating the judgments. However, the authors recommend the use of the geometric mean as more consistent with both judgments and priorities of the AHP. In the case of the group members not being of equal importance, a weighted geometric mean can be used with AIJ or weighted geometric or arithmetic mean with AIP.

2.2. THE ANP METHOD

The Analytic Network Process (ANP) is a theory that extends the AHP to cases of dependence and feedback and generalizes on the supermatrix approach introduced in Thomas Saaty’s 1980 book on the AHP. It includes interactions and feedback within clusters (inner dependence) and between clusters (outer dependence). The ANP provides a meticulous framework to include clusters of elements connected in any preferred way to investigate the process of deriving ratio scales priorities from the distribution of influence among elements and among clusters. In this way, the AHP becomes a special type of the ANP (Saaty, 1996).

The Analytic Network Process consists of the following steps (i.e. Saaty, 2001):

Step 1: Define a decision-making problem and present it, as in the case of the AHP, in form of a general goal to be achieved.

Step 2: Decompose the problem into a network with four sub-networks, namely: Benefits (*B*), Opportunities (*O*), Costs (*C*) and Risks (*R*) (BOCR)[2]. They all should jointly contribute to achievement of the main, ultimate goal defined under the *Step 1*.

Step 3: Build individual hierarchical structures for Benefits (*B*), Opportunities (*O*), Costs (*C*) and Risks (*R*). For each structure, define control elements (criteria and sub-criteria).

Step 4: Using the Saaty's fundamental 9-point scale (see other chapters), pairwise compare elements in each level with respect to the same upper level element (compare criteria to the control goal of BOCR, subcriteria to criteria), and the interdependence among the elements. More specifically, For Benefits (*B*) and opportunities (*O*), the question is to ask *what offers the most benefit or presents the greatest opportunity* to influence the criterion (sub-criterion). For costs (*C*) and risks (*R*), the question is to ask *what incurs the highest cost or faces the largest risk*.

Step 5: Calculate priorities in each subnetwork. Calculate global priorities by multiplying priority of the subcriteria by the priority of the respective criterion and divide by 4 (*B*, *O*, *C*, *R*). It is recommended for further analysis to select only those subcriteria that have global priorities above 0.03 (3%) in case of a large number of subcriteria (above 20) or 0.05 (5%) in case of a small number of subcriteria (below 15)[3].

Step 6: Produce a general network consisting of clusters and elements that contribute to all control criteria.

Step 7: For the most significant subcriteria (global priorities above 3% or 5% – see Step 5), produce subnets. Each subnet should consist of the cluster of Alternatives and clusters with other elements such as influencing factors, actors of decision making process, their objectives and points of view, etc. Define their influences and feedbacks. Note that each subnet must include the cluster of Alternatives which are the same in any subnet, while other elements may differ.

Step 8: Using the Saaty's 9-point scale, pairwise compare the elements within and between the clusters (always considering the upper criterion and merits – *B*, *O*, *C* or *R* – within which the comparison takes place). Pairwise compare the clusters in respect to how much they influence particular control criterion

Step 9: Calculate the priorities of alternatives for each merit sub-network (*B*, *O*, *C*, *R*). Using the priorities obtained from Step 5, form an unweighted supermatrix (ideal values), a weighted supermatrix, and a limit supermatrix for each sub-network by ANP, which is suggested by Saaty (1996). The priorities of the alternatives under each merit are calculated by normalizing the alternative-to-goal column of the limit supermatrix of the merit.

Step 10: Calculate overall priorities of alternatives by synthesizing priorities of each alternative under each merit from Step 9 with corresponding normalized weights *b*, *o*, *c* and *r* from Step 5. There are two ways commonly used to combine the scores of each

[2] In some cases, the inclusion of all four subnetworks is not necessary.

[3] In the ANP analysis described here, the importance of subcriteria were indicated by the separate AHP analysis based on the expert judgments.

alternative under B, O, C and R (Saaty, 2003): *additive-negative* ($P_i = bB_i + oO_i = c(1/C_i)_{Normalized} + r(1/R_i)_{Normalized}$) and *multiplicative* (($P_i = B_i O_i / C_i R_i$)). The additive--negative formula requires determining of the importance of each subnetwork: benefits (b), costs (c), opportunities (o) and risks (r), based on so called strategic criteria. *Steps 11–13* explain this procedure.

Step 11: Determine the priorities of the strategic criteria. Build another hierarchy consisting of more general elements allowing to analyze the problem from more general perspective. Likewise in the AHP, Saaty's nine-point scale should be used to obtain pairwise comparison results of the importance of strategic criteria toward achieving the overall objective (Saaty, 1980). Calculate the priorities of the strategic criteria, and examine the consistency property of the matrix.

Step 12: Using a five-step scale (very high, high, medium, low, very low) indicate the importance of Benefits (B), Opportunities (O), Costs (C), and Risks (R) with respect to each strategic criterion (i.e. Saaty, 2004). A ready values can be adopted, calculated as follows: very high – 0.42; high – 0.26, medium – 0.16, low – 0.10 and very low – 0.06 (i.e. Adamus, 2005).

Step 13: Determine the priorities of the merits. Calculate the priority of a merit by multiplying the score of a merit on each strategic criterion from Step 4 with the priority of the respective strategic criterion from Step 3 and summing up the calculated values for the merit. Normalize the calculated values of the four merits, and obtain the priorities of B, O, C, R (Benefits, Opportunities, Costs, and Risks), that is, b, o, c, and r, respectively.

Step 14: Synthesize the whole model by applying the above explained formulas (additive-negative and multiplicative). The alternative which received the greatest value is the optimal one, that contributes most to achievement of the main goal.

Step 15: Conduct sensitivity analysis to test stability of the model.

The above stages are all performed by *Super Decisions* software. One has to remember that consistency check should be performed at each stage of pairwise comparisons.

3. RESEARCH STAGE 1: DERIVING PRIORITIES USING THE AHP

At first, an extensive critical literature review was performed on various aspects of sustainable agriculture, in the perspectives of different agricultural production methods: conventional, organic and transgenic (GM), and it was the key to this research. The review (not reported here due to space limitations) synthesized the extant knowledge of the selected aspects of sustainable agriculture in the perspectives of conventional, organic / integrated and transgenic crops. The review was organized around three group of factors influencing sustainable development of agricultural plant production, namely: food health quality, environmental and socio-economic aspects of sustainable agriculture, in light of the aforesaid agricultural production methods. Specific factors influencing food health quality at the level of health safety involve the presence / absence of food allergens, natural toxins and antibiotic markers in plants, while with regard to food security, provision of abundant and nutritive food. Specific factors influencing the environment have been derived based on definition of sustainability and Environmental Impact Assessment (EIA), and included: pollution by synthetic fertilizers and pesticides, exploitation of soils and natural habitats, gene flow, invasiveness and "superweeds", impact on non-target species, particularly pollinators and impact on biodiversity of crops and wildlife. Socio-economic aspects covered economic efficiency of farm businesses, profits from "GM-free" status of national products, corporate control over national agriculture and the consumer choice.

Table 17.1 summarizes the main literature findings on advantage (+) and disadvantage (–) factors influencing food health quality (security + safety), environmental safety and socio-economic safety, with respect to three cropping systems: conventional,

Table 17.1: Summary of the Literature Review Findings Transformed into the AHP Objectives

Main areas		**Potential source of advantages (+) or disadvantages (–) pertaining to the cropping systems**			**AHP Objectives**
		conventional	**organic**	**transgenic**	
Food health quality	*Food security*	(+): increased efficiency of crop production results in low prices and high availability of food	(–): high costs of organic production result in high prices and low availability of food	(+): increased efficiency of crop production results in low prices and high availability of food	abundant food (accessibility, affordability)
		(–): relying on monocultures which reduce nutritional diversity of crops	(+): better composition of nutrients due to improved diversity of crops	(–): relying on monocultures which reduce nutritional diversity of crops (+): possibility to increase nutritional value of food by genetic modification	nutritive food
	Food safety	(–): extensive use of pesticides increases the level of residues in food	(+): production without the use of pesticides eliminates residues of pesticides in food	(+): reduced use of pesticides decreases the level of residues in food	reduced human exposure to pesticide residues in food
		(–): extensive use of pesticides which increases the allergenicity	(+): production without the use of pesticides eliminates allergenicity	(–): recombinant "new" allergenic proteins (+): reduced use of pesticides; possibility to eliminate known allergens from plants	reduced human exposure to plant allergens
		(+): due to the use of synthetic pesticides, protection from insect damage and consequently, from natural toxins	(–): vulnerability to insect damage and consequently, increased level of mycotoxins	(–): recombinant "new" toxic proteins (+): due to the insect resistance, protection from insect damage and consequently, from natural toxins	reduced human exposure to mycotoxins in plant food raw materials
Environmental safety		–	–	(–): crops with herbicide resistance may lead to increase in fitness of weeds if the transgenes are transferred into wild varieties	protection of weeds from herbicide tolerance

	(–): excessive use of pesticides harms pollinators	(+): production without the use of pesticides eliminates threat to pollinators	Risk: crops with insect resistance Bt may be harmful to non-target insects, such as pollinators (+): reduced use of pesticides decreases threat to non-target species	protection of pollinators – bee populations
	(–): excessive use of pesticides pollutes the environment	(+): production without the use of pesticides eliminates pollution by pesticides	(+): reduced use of pesticides decreases pesticide residues in the environment	minimizing the spread of pesticides in the environment
	(–): excessive use of pesticides and fertilizers, homogeneity of seeds	(+): elimination of synthetic pesticides and fertilizers from breeding practices, maximum protection of non-crop habitats, diversity of seeds	(–): recombinant DNA technology develops seeds by restricting the genetic diversity to obtain uniform and predictable results	protection of genetic biodiversity
	(–): high soil pollution by synthetic pesticides and fertilizers	(–): require high quality soils; some practices i.e. post-emergent harrowing for weed control are destructive to the soil (+): production without the use of pesticides eliminates pollution	(+): plants resistant against abiotic stresses, such as dry, salty or acidic soils (including marginal lands)	conservation of soils and natural habitats
Socio-economic safety	–	(+): allows independency of national farmers on large corporations	(–): since specific GM varieties resist only to a specific herbicide, farmers become increasingly dependent on a small number of multinational firms supplying the package of seeds, fertilizers, and pesticides	maintain autonomy of national farmers
	–	(+): positive consumer attitudes towards organic production	(–): consumers generally against GM technology	using socially acceptable production methods
	(–): high costs of synthetic fertilizers and pesticides (+): high productivity of land and labor	(–): labor intensive, lower yields due to high losses (+): low costs of chemical inputs	(–): high prices of seed material (+): herbicide tolerance, insect resistance, resistance to viruses, fungi, bacteria and stress tolerance decrease the need for pesticides, reduce yield losses and labor input	improved farm efficiency
	(+): "GM-free" presents a marketing potential at international market	(+): "GM-free" presents a marketing potential at international market	(–): national agriculture may lose a competitive advantage of being a 'GM--free' land	"GM-free" status
	–	(–): lower quality organoleptic values of the product	(+): quality features of crops may be improved (better smell and taste)	increase sensory qualities of food

organic and transgenic. The right column (*Objectives*) illustrates the transformation of the respective advantages and disadvantages into the objectives which will next be included in the AHP model. The idea behind this conversion is that decision-makers should promote benefits and reduce risks through support of the agricultural direction that best fulfills the objectives. In attempt to build the analytical model for the multi-criteria decision-making in Poland, several agricultural experts in Poland were asked to assess the schema and its elements in relevance to the Polish specific conditions. Both general and specific objectives can be achieved through formulation of a political strategy that promotes one of the agricultural methods. The role of experts in this process is limited to providing suggestions and recommendations which can be further transformed into decisions by those who hold political power.

In the constructed model, the main goal is "sustainable plant production in Poland", in terms of three general objectives: (1) food health quality, (2) environmental safety, and (3) socio-economic safety. Specific objectives and directions of crop production are in line with the literature findings (**Table 17.1**), as was presented in **Figure 17.1**.

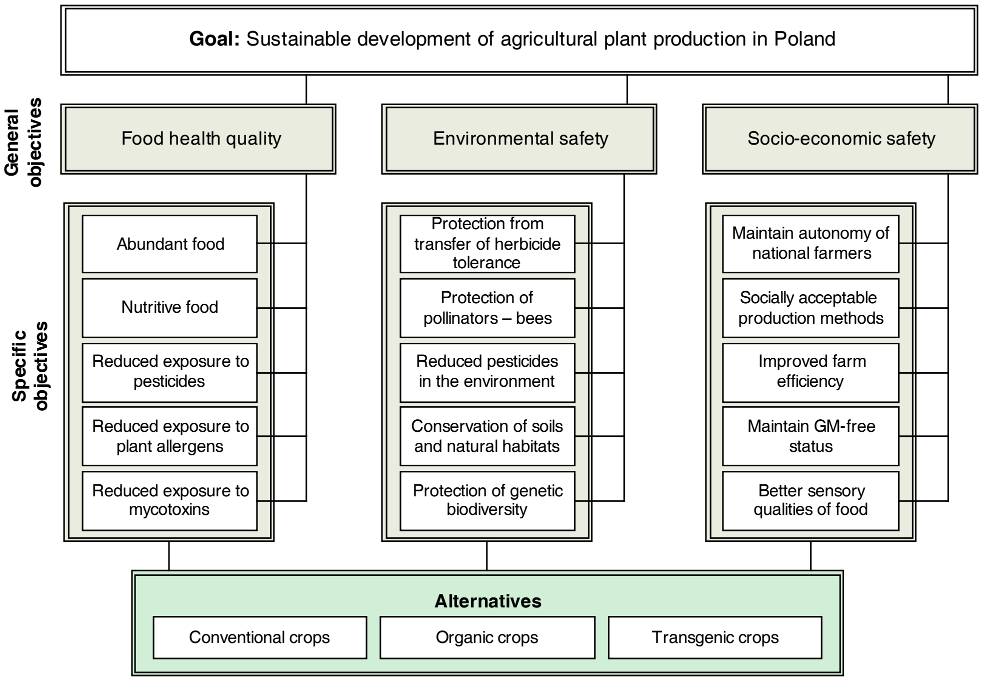

Figure 17.1: The AHP Model for Decision Problem Concerning the Choice of Crop Production Direction in Poland

Respondents to the AHP/ANP interviews consisted of 20 experts (initially – 35) attached to institutions with responsibility in decision support in the areas of food safety, environment and agro-economy in Poland, including Ministry of Agriculture and Rural Development (Department of Plant Breeding and Protection and Department of Analysis and Planning – Division of Environmental Protection in Rural Areas), government research institutes whose activity includes agri-food and biotechnology research as well as academic experts known as agricultural and food safety consultants to the Ministry of Agriculture and Rural Development and to the Ministry of Health. The AHP/ANP analysis was performed using Super Decision v. 1.2.1 software. At each stage, consistency ratio was checked and judgments were either revised, rejected or adjusted (if small). Models were built for each expert separately and integrated by synthesis of individual priorities (AIP), following suggestion by Forman & Peniwati (1998), through normalized geometric means. The aggregated weights for the main objectives (criteria) and specific objectives (sub-criteria) are depicted in **Table 17.2**.

Table 17.2: Local Priorities for Main and Specific Objectives (Geometric Means Normalized)

Criteria/Subcriteria	Altogether
Food health quality	0.487
Nutritive food	0.157
Abundant food	0.181
Reduced exposure to pesticide residues	0.315
Reduced exposure to plant allergens	0.156
Reduced exposure to mycotoxins	0.190
Environmental	0.267
Protection from herbicide tolerance	0.130
Protect of pollinators – bees	0.306
Reduced pollution by pesticides	0.229
Conservation of soils and natural habitats	0.150
Protection of genetic biodiversity	0.185
Socio-economic	0.246
Maintained autonomy of national farmers	0.135
Socially acceptable production methods	0.179
Improved farm efficiency	0.226
Maintained "GM-free" status	0.164
Consumer sensory satisfaction from food	0.295
CR < 0.1	

As presented in **Table 17.2**, "Food health quality" was given the highest weight (0.487), which suggests that the experts put high relevance to this objective. "Environmental safety" and "Socio-economic safety" received virtually similar scores (0.267 and 0.246, respectively). "Reduced exposure to pesticide residues in food" under the objective "Food health quality" was considered the most important specific objective, its value reaching 0.315. It indicates that this specific factor has the highest impact on food health quality and on the main goal, which is sustainable agriculture, a fact that should be considered in agricultural policy strategies. It was followed by "Reduced exposure to mycotoxins in plant raw materials" (0.190), not far from "Abundant food" (0.181). Under the objective "Environmental safety", "Protection of pollinators" was given the highest weight (priority equal to 0.306). "Nutritive food" and "Reduced exposure to plant allergens" were given virtually the same priorities

(0.156). Within the "socio-economic safety" category of objectives, "consumer satisfaction from sensory values of food plants" got the highest weight (0.295). "Maintained autonomy of national farmers" (0.135) received the lowest weights, which indicates its relative irrelevance with respect to the impact on socio-economic sustainability.

4. RESEARCH STAGE 2: DERIVING ALTERNATIVES USING THE ANP

The Analytic Network Process allows more explorative and thorough analysis of factors contributing to sustainable agricultural development, presented in the previous chapter. The outcomes are more accurate and reliable than in Analytic Hierarchy Process. The ANP is considered to be an extension of AHP (Saaty, 2001). This stage takes the objectives analyzed in the preceding one with respect to three crop production alternatives: conventional, organic and transgenic, and transforms them into the models of "benefits" (*B*), "costs" (*C*), "opportunities" (*O*) and "risks" (*R*) (BOCR). These models consist of the networks of mutual influences and feedbacks between the most important factors in decision making process. The BOCR models presented here have been derived based on the research stage 1, and supplemented by additional issues that were not included in the AHP model.

Table 17.3 presents global priorities of the objectives integrated for all 20 experts calculated as local priorities of subcriteria multiplied by the relevant priority of the respective criterion. It is recommended that those sub-criteria that have global priority weights below 0.03 (in case of a number of sub-criteria exceeding 20 in one model) or below 0.05 (if the number of sub-criteria does not exceed 20) should be excluded from the subsequent ANP analysis. Consequently, in the present analysis 9 elements is considered: "Reduced exposure to pesticide residues", "Reduced exposure to mycotoxins", "Abundant food", "Protection of pollinators", "Reduced exposure to plant allergens", "Nutritive food", "Consumer satisfaction from food", "Reduced pollution by pesticides" and "Improved farm efficiency". Only for these objectives the ANP sub-systems will be built, although the remaining elements will be also mentioned in the analysis, mainly for comparative purposes.

The complete ANP model consists of four separate models (subnets): Benefits (*B*), Costs (*C*), Opportunities (*O*) and Risks (*R*), where Opportunities and Risks are considered as "hidden" Benefits and Costs, respectively (Saaty, 2002). In this analysis, Opportunities and Risks are interpreted as uncertain aspect of decision-making problem, for example, a dependency between crop production method and allergenicity of plant. To build the ANP networks, it was essential to first transform the objectives into Benefits, Costs, Opportunities and Risks pertaining to three categories: food health quality, environmental safety and socio-economic safety. The main goal is the same as in case of the AHP analysis, that is "Sustainable development of plant production in Poland", and the objective is to find the alternative that is most beneficial and offers most opportunities while at the same time representing the lowest risk and the lowest costs variant. **Figure 17.2** outlines a general schema of the BOCR model, consisting of the Goal, Merits, Control criteria, Subcriteria and Alternatives.

Table 17.3: Global Priorities for Specific Objectives
(Local Priority of Subcriterion × Priority of the Respective Criterion)

Sub-criteria (Specific objectives)	Altogether
Maintained autonomy of national farmers	0.033
Protection from herbicide tolerance	0.035
Conservation of soils and natural habitats	0.040
Maintained "GM-free" status	0.040
Socially acceptable production methods	0.044
Protection of genetic biodiversity	0.049
Improved farm efficiency	**0.056**
Reduced pollution by pesticides	**0.061**
Consumer sensory satisfaction from food	**0.073**
Nutritive food	**0.076**
Reduced exposure to plant allergens	**0.076**
Protect of pollinators – bees	**0.082**
Abundant food	**0.088**
Reduced exposure to mycotoxins	**0.093**
Reduced exposure to pesticide residues	**0.153**
$CR < 0.1$	

Figures 17.3–6 present the ANP networks for Benefits, Costs, Opportunities and Risks. The model aims at finding the alternative that provides the most benefits and opportunities to agricultural sustainability in Poland, while at the same time representing the lowest costs and risks. Three control criteria: food health, environmental and socio-economic were considered in all models but Opportunities, which only included food health and socio economic criteria. Only the subcriteria that received highest priority weights in the AHP analysis were included in the subnets. For example, in case of Benefits, under the "food health", the following sub-criteria have been identified: "Food without pesticide residues", "Food without mycotoxins" and "Abundant food". In case of "Food without pesticide residues", the subnet consists of three positive health effects that result from this benefit, namely: reduced (or not higher) allergy prevalence and cancer incidence, since it was found that pesticides may be allergenic and carcinogenic, as well as decreased incidence of stomach ailments resulting from ingestion of pesticide residue in food. For "Food without mycotoxins", positive health effects involved reduced cancer incidence due to carcinogenicity of mycotoxins and reduced incidence of mycotoxin poisonings. The "Abundant food" subcriterion involves the benefit of reduced diseases resulting from deficiencies of proteins, vitamins and minerals, that happen commonly if food is not available. Environmental benefits include three elements: "Reduced use of synthetic pesticides", "Preserved genetic biodiversity" and "Better soil conservation", however, the subnet was built and analyzed only for "Reduced use of synthetic pesticides", since the remaining two got the priorities below

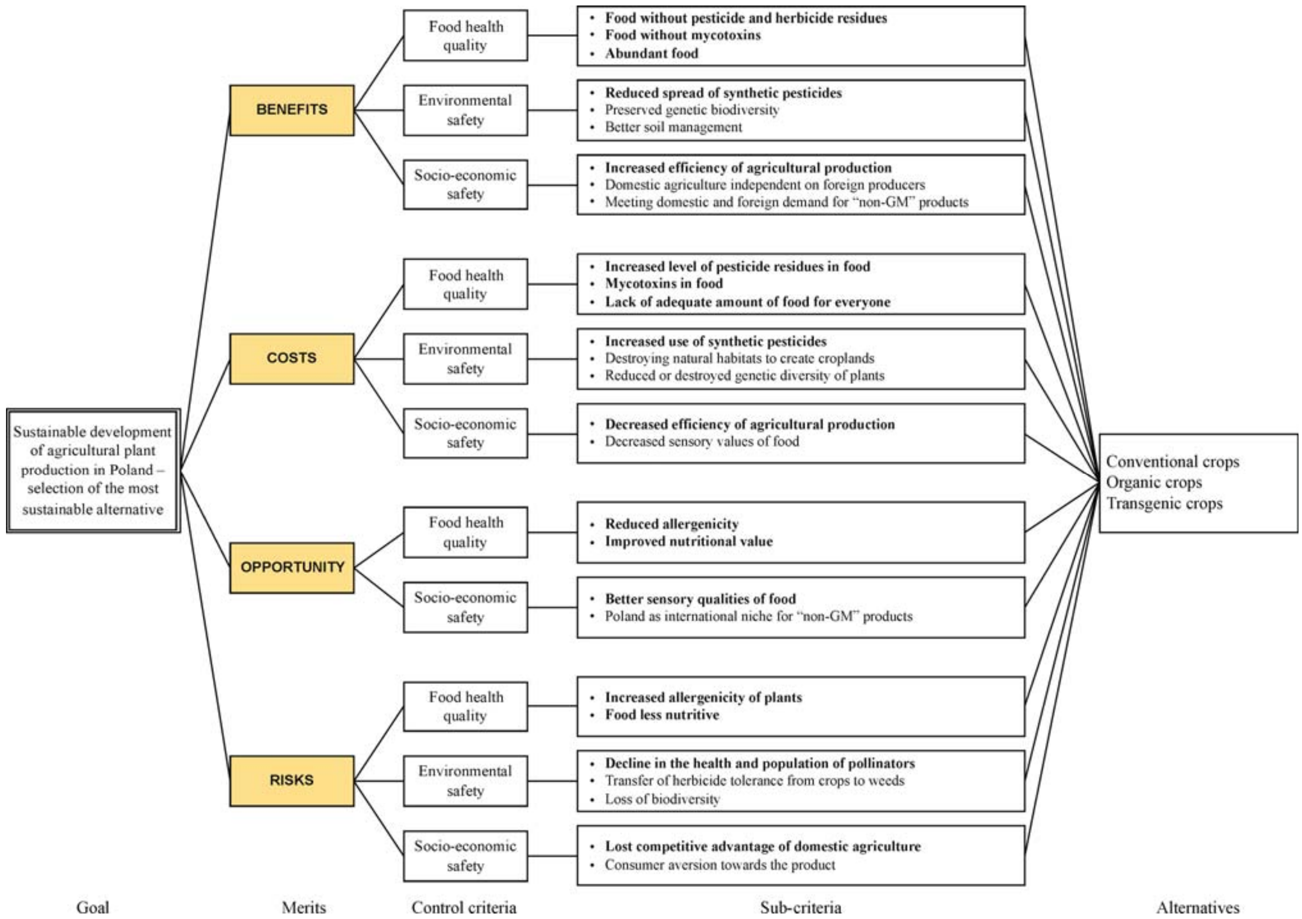

Figure 17.2: The ANP Schema for BOCR Model

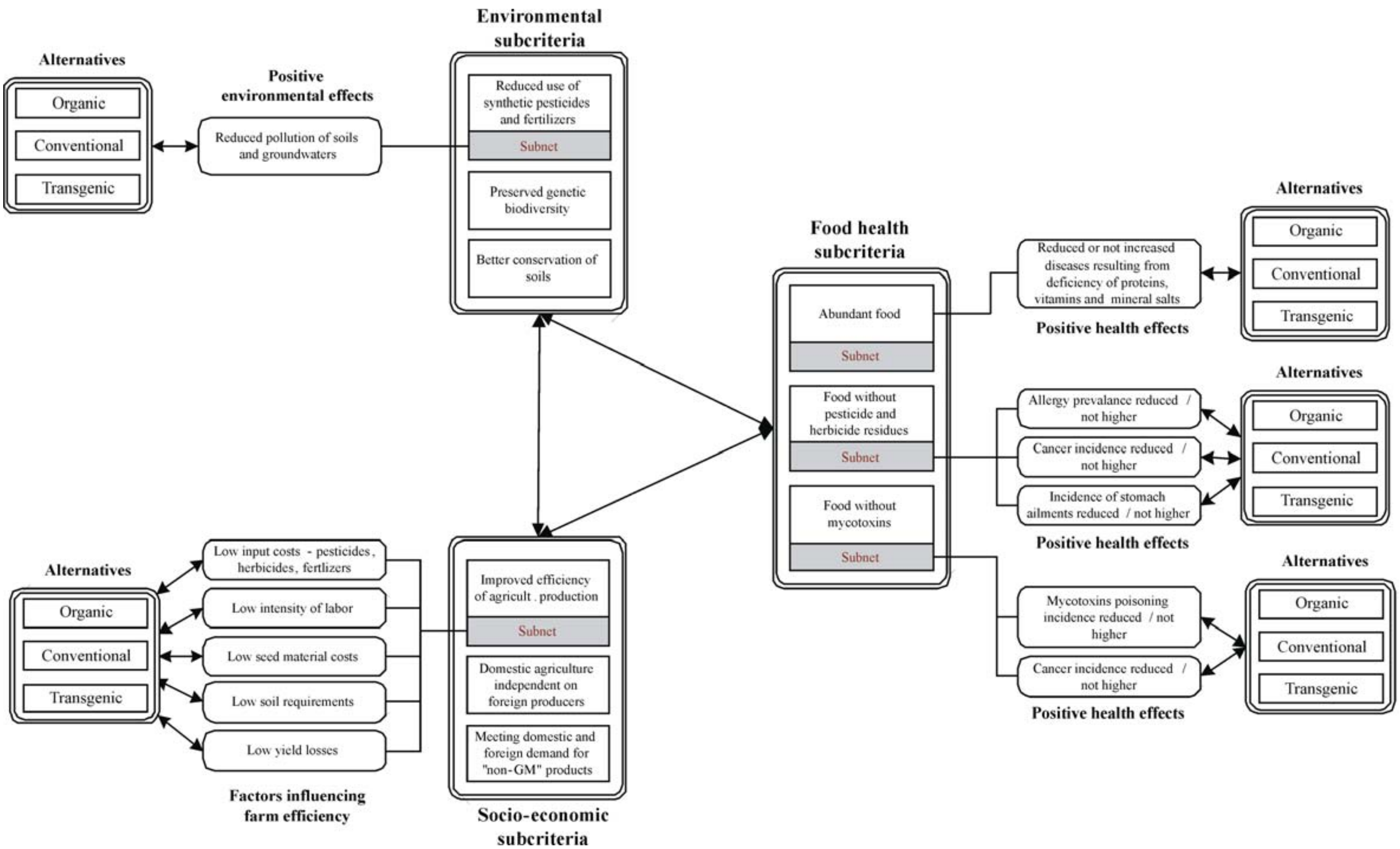

Figure 17.3: Model for Benefits

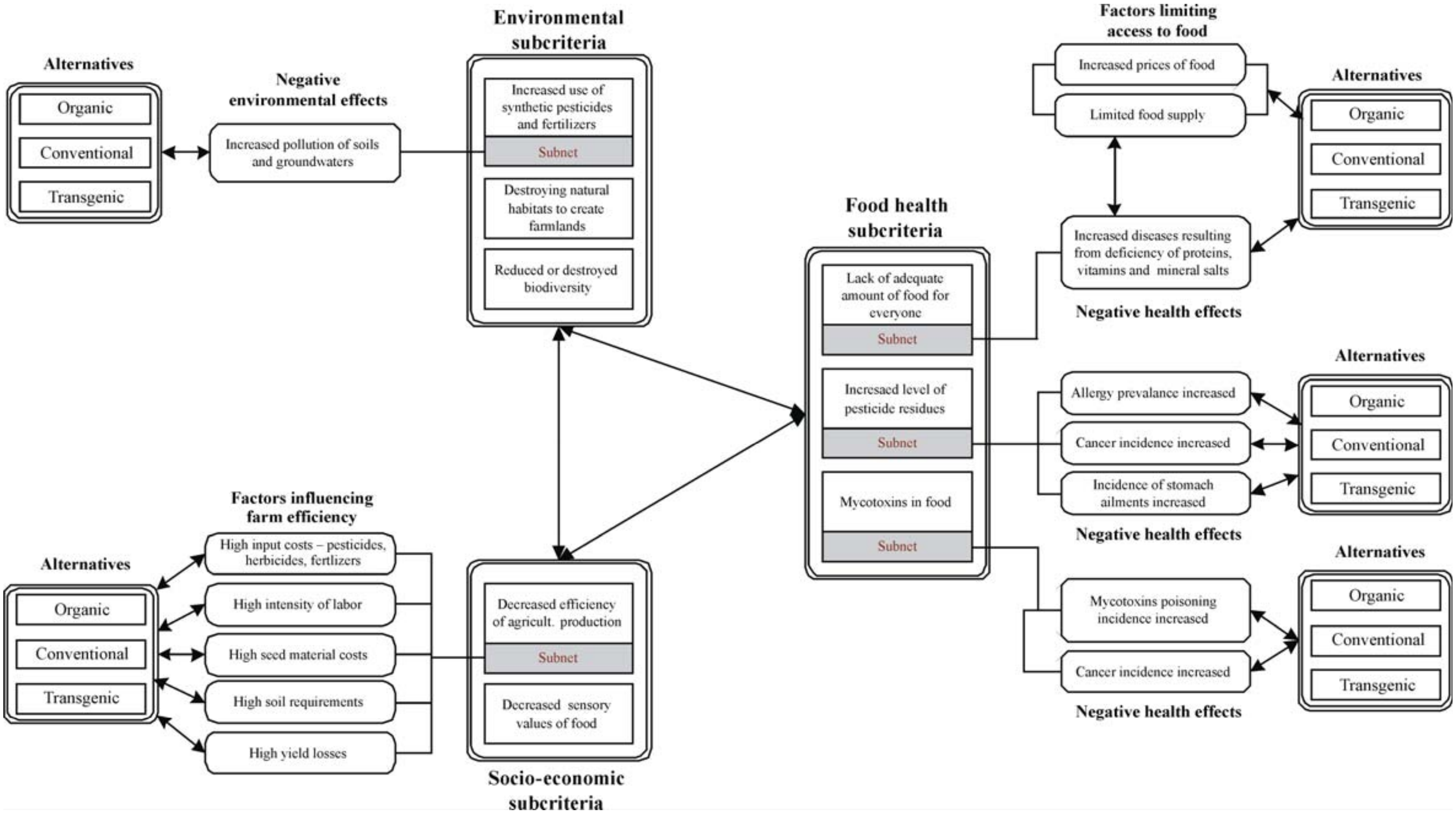

Figure 17.4: Model for Costs

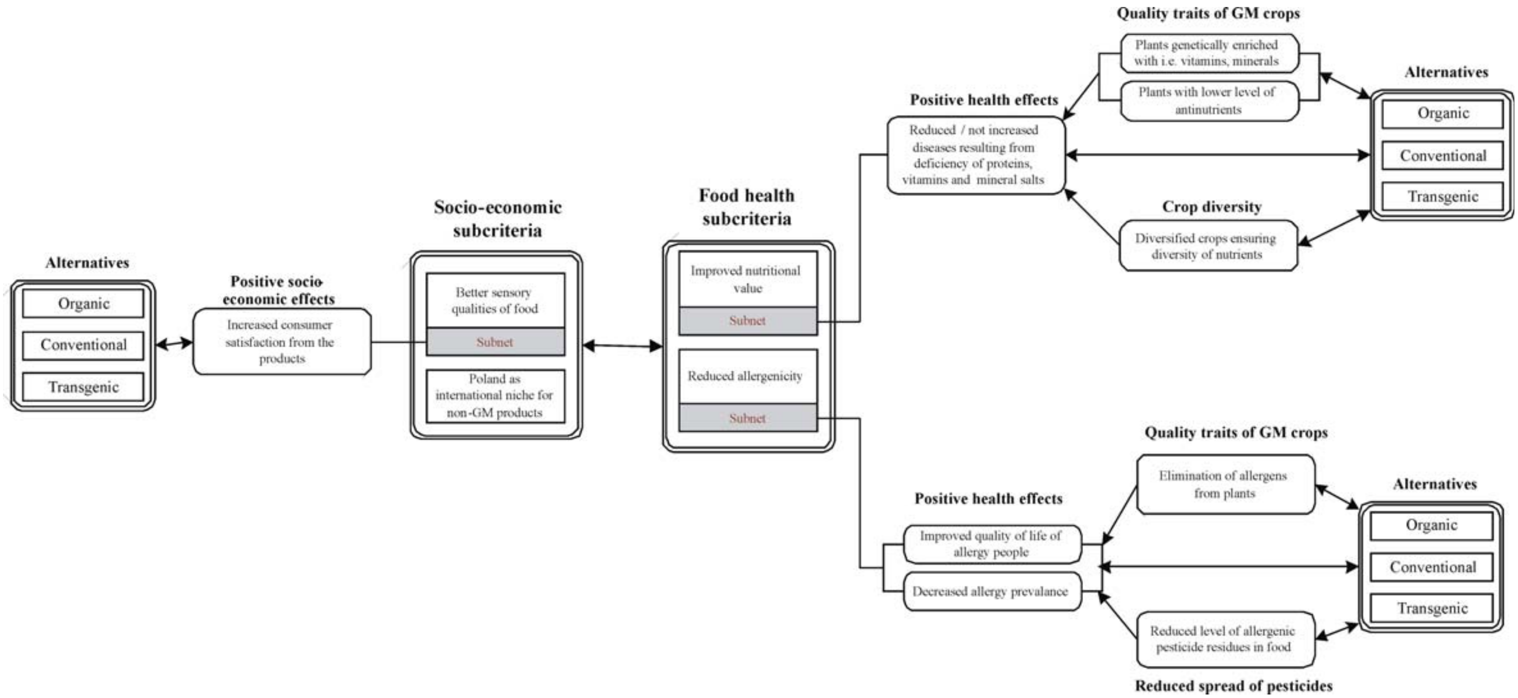

Figure 17.5: Model for Opportunities

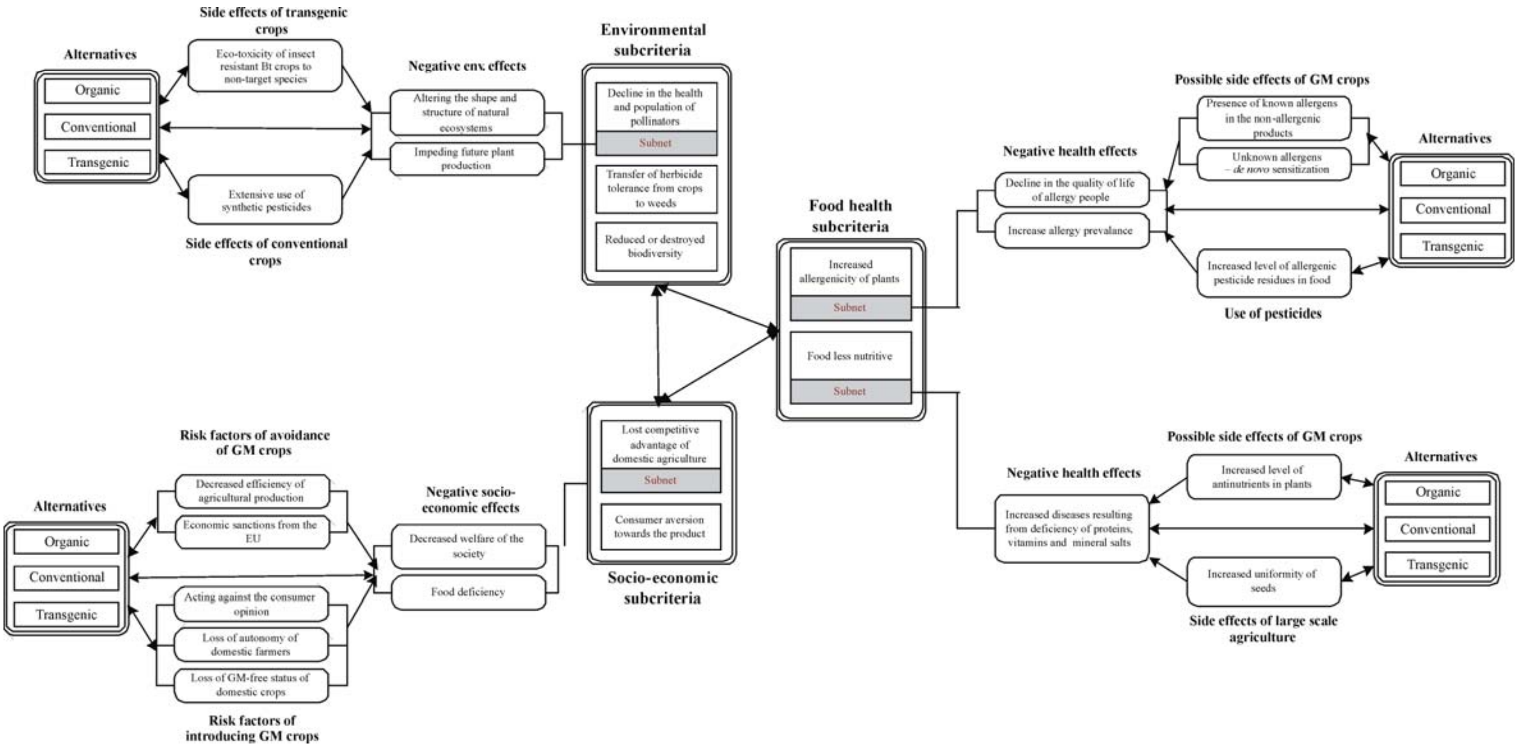

Figure 17.6: Model for Risks

5% in the AHP results (**Table 17.3**). Socio-economic benefits also included three aspects ("Increased efficiency of agricultural production", "Domestic agriculture independent on foreign producers" and "Meeting domestic and foreign demand for non-GM products"). Only "Increased efficiency of agricultural production" was analyzed as the subnet involving factors that influence farm production efficiency. These factors comprise costs of agricultural input (fertilizers, pesticides), intensity of labor, costs of seed material, soil requirements and yield losses. This category was in fact the most apparent to pairwise comparisons against organic, transgenic and conventional production. For example, organic crop production requires low input of pesticides, but at the same time is labor intensive. Conventional agriculture represents the other way round. Each model was constructed using this pattern of thinking.

Once the BOCR models were built, the pairwise comparison analysis was performed for each subnet using the Super Decision software. The overall results for the priorities of criteria and sub-criteria, for Benefits, Costs, Risks and Opportunities, are presented in **Table 17.4**. In case of Benefits, "Food without pesticides residues" obtained the highest global priority (0.547), while in case of Costs "Increased level of pesticide residues" (0.485). "Reduced allergenicity" received the highest weight under the Opportunity merit (0.643), while "Increased allergenicity of plants" was also the most important among the risks (0.609).

Table 17.4: Prioritization of Criteria and Sub-Criteria

Merits (subnets)	Criteria	Sub-criteria	Local priorities	Global priorities
Benefits	food health quality (0.715)	food without pesticide residues	0.765	0.137
		food without mycotoxins	0.073	0.013
		abundant food	0.162	0.029
	environment (0.187)	reduced spread of synthetic pesticides	0.784	0.037
		preserved genetic diversity	0.135	0.006
		better conservation of soils	0.081	0.004
	socio-economic (0.098)	increased efficiency of agricultural production	0.740	0.018
		domestic agriculture independent on foreign suppliers of seeds, pesticides and fertilizers	0.094	0.002
		meeting demand for "non-GM" food	0.167	0.004
Costs	food health quality (0.648)	increased level of pesticide residues in food	0.748	0.121
		mycotoxins in food	0.076	0.012
		lack of adequate amount of food for everyone	0.176	0.029
	environment (0.122)	increased spread of synthetic pesticides	0.546	0.017
		destroying natural habitats to create farmlands	0.125	0.004
		reduced or destroyed biodiversity	0.329	0.010
	socio-economic (0.230)	decreased efficiency of agricultural production	0.875	0.050
		decreased sensory values of food	0.125	0.007
Opportunities	food health quality (0.857)	reduced allergenicity	0.750	0.161
		improved nutritional value	0.250	0.054
	socio-economic (0.143)	better sensory qualities of food	0.833	0.030
		poland – international niche of non-GM foods	0.167	0.006

Merits (subnets)	Criteria	Sub-criteria	Local priorities	Global priorities
Risks	food health quality (0.731)	increased allergenicity of plants	0.833	0.152
		food less nutritive	0.167	0.031
	environment (0.188)	decline in the health and population of pollinators	0.740	0.035
		loss of biodiversity	0.167	0.008
		transfer of herbicide tolerance from crops to weeds	0.094	0.004
	socio-economic (0.081)	lost competitive advantage of domestic agriculture	0.875	0.018
		consumer aversion towards the product	0.125	0.003

As regards the prioritization of alternatives (conventional, organic and transgenic crops), the results have been presented for each model, criteria and sub-criteria, as ideal and normalized values, calculated for each subnet. **Table 17.5** presents the scores for Benefits network. For the subnet of "Food without pesticide residues", "Organic" obtained the highest weight (0.611 normalized or 1.000 ideal), which indicates that it is

Table 17.5: Prioritization of Alternatives for Criteria and Sub-Criteria: BENEFITS

Criteria	**Food health quality 0.715**						**Environmental 0.187**		**Socio-economic 0.098**	
Subcriteria	food without pesticide residues 0.765		food without mycotoxins 0.073		abundant food 0.162		reduced spread of synthetic pesticides 0.784		increased efficiency of agricultural production 0.740	
Alternatives	normal	ideal	normal	ideal	normal	ideal	normal	ideal	normal	ideal
Conventional	0.073	0.119	0.263	0.399	0.231	0.326	0.059	0.088	0.252	0.511
Organic	0.611	1.000	0.079	0.120	0.060	0.085	0.663	1.000	0.256	0.521
Transgenic	0.317	0.518	0.659	1.000	0.709	1.000	0.279	0.420	0.492	1.000

the most beneficial alternative (or the most sustainable in this respect). In a similar vein, "Transgenic" was the most beneficial in case of "Food without mycotoxins" (0.659), as well as in case of "Abundant food" (0.709). Regarding the network of Costs (**Table 17.6**), "Organic" production appeared the most costly in terms of "Mycotoxins in food" (0.770), "Lack of adequate amount food for everyone" (0.710) and "Reduced efficiency of agricultural production" (0.441). "Conventional" was the most costly alternative in terms of "Increased pesticide residues in food" (0.694) and the related "Increased use of pesticides" (0.603). "Transgenic" production was either in the middle or having the lowest costs within the analyzed Cost subnets. As regards Opportunities (**Table 17.7**), "Transgenic" crops offer the most opportunity for "Reduced allergenicity" (0.483) and "Improved sensory qualities of food" (0.625), while "Organic" for the "Improved nutritional value" (0.615). Finally, in the subnet of Risks (**Table 17.8**), "Transgenic production" is the most risky in terms of the "Increased allergenicity" (0.556) and "Decline in the health and population of pollinators" (0.646), "Organic" appears the most risky in case of "Lost of competitive advantage of domestic agriculture" (0.642), while "Conventional" in terms of "Food less nutritive" (0.709).

Table 17.6: Prioritization of Alternatives for Criteria and Sub-Criteria: COSTS

Criteria	**Food health quality 0.648**						**Environmental 0.122**		**Socio-economic 0.230**	
Subcriteria	increased pesticide residues in food 0.748		mycotoxins in food 0.076		lack of adequate amount of food for everyone 0.176		increased use of synthetic pesticides 0.546		reduced efficiency of agricultural production 0.875	
Alternatives	normal	ideal	normal	ideal	normal	ideal	normal	ideal	normal	ideal
Conventional	0.694	1.000	0.145	0.188	0.195	0.274	0.603	1.000	0.274	0.622
Organic	0.108	0.156	0.770	1.000	0.710	1.000	0.082	0.137	0.441	1.000
Transgenic	0.198	0.286	0.085	0.111	0.096	0.135	0.315	0.523	0.285	0.646

Table 17.7: Prioritization of Alternatives for Criteria and Sub-Criteria: OPPORTUNITIES

Criteria	**Food health quality 0.784**				**Socio-economic 0.081**	
Subcriteria	reduced allergenicity 0.680		improved nutritional value 0.227		better sensory qualities of food 0.833	
Alternatives	normal	ideal	normal	ideal	normal	ideal
Conventional	0.095	0.196	0.093	0.150	0.239	0.382
Organic	0.423	0.876	0.615	1.000	0.137	0.218
Transgenic	0.483	1.000	0.292	0.475	0.625	1.000

Table 17.8: Prioritization of Alternatives for Criteria and Sub-Criteria: RISKS

Criteria	**Food health quality 0.731**				**Environmental 0.188**		**Socio-economic 0.081**	
Subcriteria	increased allergenicity 0.833		food less nutritive 0.167		decline in the health and population of pollinators 0.740		lost competitive advantage of domestic agriculture 0.875	
Alternatives	normal	ideal	normal	ideal	normal	ideal	normal	ideal
Conventional	0.352	0.633	0.709	1.000	0.289	0.447	0.254	0.395
Organic	0.092	0.165	0.113	0.159	0.065	0.101	0.642	1.000
Transgenic	0.556	1.000	0.179	0.252	0.646	1.000	0.104	0.161

In order to synthesize the priorities for alternatives at the top level and define the optimal one (most sustainable crop production method in Poland), the next step is to combine the priorities for Benefits, Opportunities, Risks and Costs. As mentioned above, there are five formulas which allow calculation of the overall priorities of alternatives, but two of them are applied the most frequently: multiplicative formula (BO/CR) and additive-negative formula ($bB + oO - cC - rR$). As regards the multiplicative formula (BO/CR), priorities of benefits and opportunities are divided by the respective priorities for risks and costs. The best alternative is the one with the highest value. However, this formula is used only if Benefits, Costs, Risks and Opportunities are considered equally important. If not, additive-negative formula should be employed. In this case, it is necessary to first define the priorities for Benefits, Costs, Risks and Opportunities. In order to do so, a new "general" hierarchy needs to be built, as presented in **Figure 17.7**. The analysis was similar to the AHP, while Benefits, Costs, Opportunities and Risks were used instead of the Alternatives at the bottom level of the hierarchy.

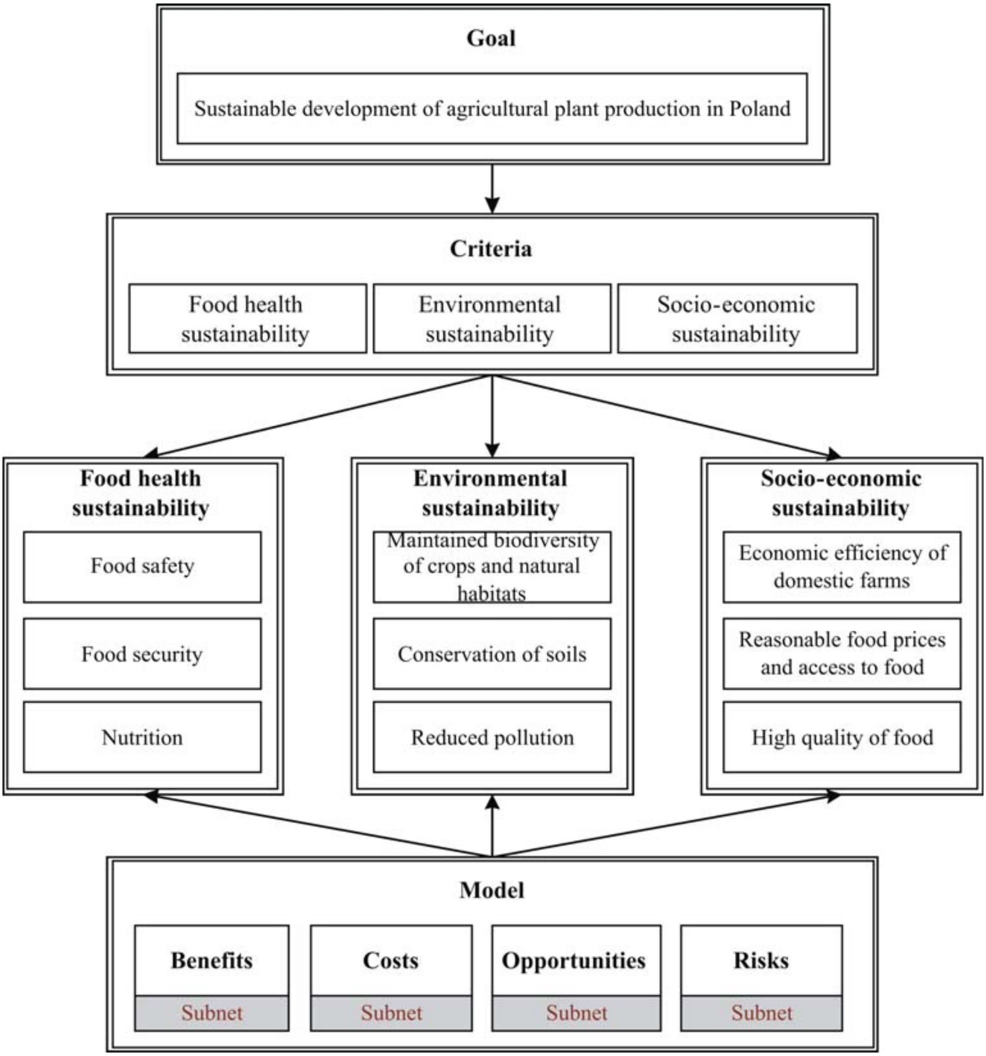

Figure 17.7: Hierarchy of BOCR

Table 17.10 synthesizes the overall priorities for alternatives using two formulas: multiplicative and additive-negative. Both scores indicate "Organic" agriculture to be the optimal one (it received the highest priorities), followed by "Transgenic" production and "Conventional" as the "worse" alternative. In this way, the results are in line with the AHP outcomes presented in the previous chapter, also indicating "Organic agriculture” to be the best alternative, under the Polish conditions, to fulfill the main goal: sustainability of agricultural development, while “Conventional” as the least preferable one in this respect.

Table 17.9: Assessing the Importance of Benefits, Risks, Opportunities and Costs (v. high = 0.42, high = 0.26, medium = 0.16, low = 0.10, v. low = 0.06)

Criteria	Subcriteria	Benefits	Costs	Opportunities	Risks
Food health sustainability (0.687)	food safety (0.522)	high	v. high	medium	v. high
	food security (0.099)	high	v. high	high	medium
	nutrition (0.066)	high	medium	medium	medium
Environmental sustainability (0.186)	maintained biodiversity of crops and natural habitats (0.025)	medium	high	medium	v. high
	conservation of soils (0.015)	high	high	v. high	v. high
	reduced pollution (0.146)	v. high	medium	v. high	v. high
Socio--economic sustainability (0.127)	economic efficiency of domestic farmers (0.068)	v. high	v. high	medium	v. high
	reasonable food prices (0.046)	medium	high	medium	medium
	quality of products (0.013)	medium	medium	v. high	low
	Priority (normalized)	**0.236**	**0.288**	**0.178**	**0.298**

Table 17.10: Final Scores – Prioritization of Alternatives

Merits	**Benefits**		**Costs**		**Opportunities**		**Risks**		**Multiplicative formula BO/CR**		**Additive formula** ***bB + oO – – cC – rR***	
Alter-natives	normal	ideal	normal	ideal	normal	ideal	normal	ideal	normal	ideal	normal	ideal
Conven-tional	0.122	0.259	0.476	1.000	0.105	0.230	0.375	0.756	0.009	0.011	–0.551	–1.923
Organic	0.472	1.000	0.316	0.664	0.437	0.956	0.129	0.259	0.773	1.000	0.287	1.000
Trans-genic	0.406	0.860	0.208	0.437	0.457	1.000	0.496	1.000	0.218	0.282	–0.162	–0.565

In order to check the stability of the whole model, sensitivity analysis was conducted for Benefits, Risks, Opportunities and Costs). Its goal is to check how the ultimate priorities solution would change if the values of BOCR increase of decrease. It is demonstrated that Opportunities (**Figure 17.10**) is almost perfectly insensitive to the changes. Risks and Benefits display higher sensitivity in case of lower values, while the sensitivity of Costs is low and steady for all values. In all cases, Conventional agriculture appears insensitive to any changes.

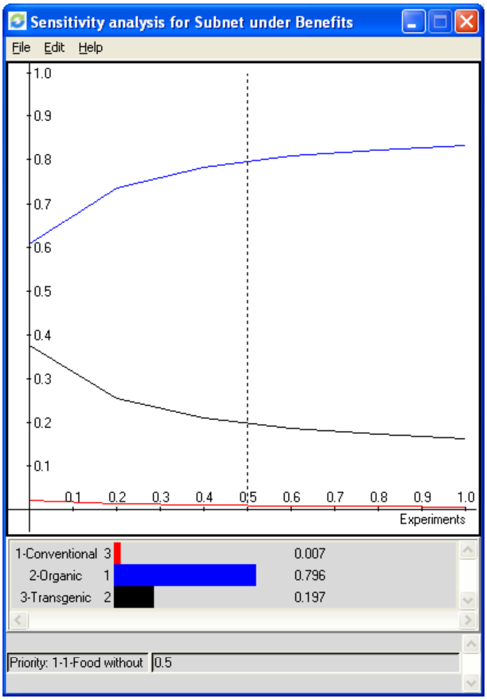

Figure 17.8: Sensitivity Analysis for Benefits

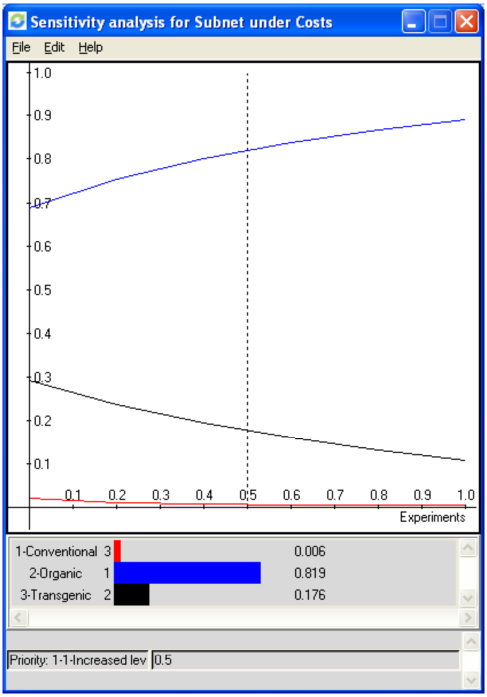

Figure 17.9: Sensitivity Analysis for Costs

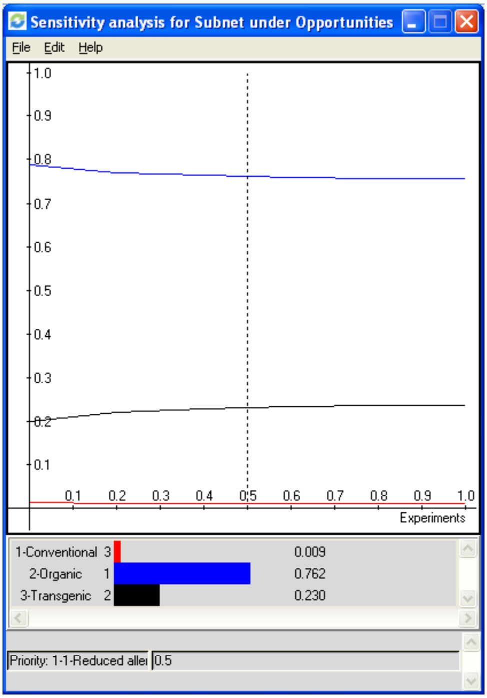

Figure 17.10: Sensitivity Analysis for Opportunities

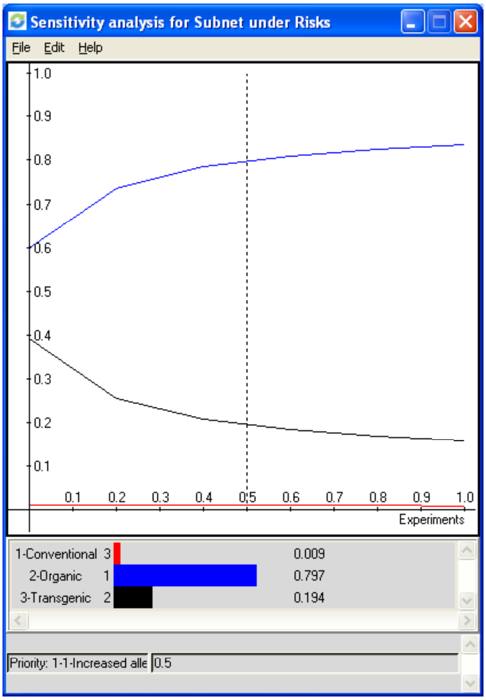

Figure 17.11: Sensitivity Analysis for Risks

5. CONCLUSIONS

The main goal of this study was to obtain priorities for selected agricultural alternatives of food crops in Poland ("conventional", "organic" and "transgenic") using the AHP/ANP technique as the multicriteria decision making aid. Such priorities were derived following a three-stage process, namely: review of the existing literature to produce an integrated decision-making schema relevant to agricultural plant production, formulation and application of the AHP model to obtain priorities for the criteria and subcriteria, and formulation and application of the ANP model to derive priorities for alternatives. The study addressed three aspects of sustainability: food health quality, environment and socio-economic issues.

The total ANP model consisted of four separate models (subnets): Benefits (*B*), Costs (*C*), Opportunities (*O*) and Risks (*R*). The criteria and subcriteria under these subnets were in line with the main and specific objectives of the AHP model, and followed the same main goal: "Sustainable agricultural development in Poland". Both additive-negative and multiplicative formulas indicated that "organic" crops constitute the optimal solution for Polish sustainable agriculture. They represent the alternative which offers the most benefits and opportunities while at the same time, the least costs and risks. The second best alternative are "transgenic" crops, as shown by both formulas, whereas "conventional" agriculture was weighted as the worst variant. The overall preference towards organic farming owes mainly to the high weights assigned for the objectives commonly associated with organic production, such as i.e. "reduced exposure to pesticide residues in food" and "protection of pollinators".

The most straightforward implication is that Poland should make use of its favorable conditions and promote organic farming in the first place. However, "transgenic agriculture" should also be allowed. In fact, the coexistence rules do allow "organic" and "transgenic" crops being grown in the same region, and the results revealed that Polish experts are generally supportive for this method of plant cultivation. Such proportion of priorities led author to the conclusion that this combination may best satisfy the goal of sustainable agriculture in Poland, in terms of food security, health, environmental and socio-economic objectives. As it was stated earlier, "organic production" may be the most sustainable in terms of environmental or health objectives, but it fails to meet an increasing demand for food, especially in light of the growing food prices. "Conventional agriculture", on the other hand, presents a threat to the environment and to human health due mainly to the extensive use of synthetic pesticides. "Transgenic production" allows higher productivity with lower use of pesticides, however, it is a subject of controversy, particularly among the consumers. This fact offers a potential for future research and actions in risk-benefit communication from experts to the public.

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