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# MCDM approach for planning a sustainable livestock enterprise

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**Abstract**

Beside the livestock activity provides excellent nutritional ingredients for the human diet, growing conflict among stakeholders are caused by the sharing of the property rights about the environment. Traditionally livestock management was focused on profit maximization related to scale economies, however an increasing number of stakeholders are concerned about the negative side effect of environmental externalities and solicit to adopt sustainable technologies to curb the natural resource depletion, soil and water pollution, gaseous emissions and others. Purpose of this paper is to introduce a revisited multi-criteria decision making approach based on solid theoretical fundaments to produce sustainable solutions to achieve economic, social and environmental objectives.

Key word: livestock, multi-criteria decision making, WGP, externalities, sustainability.

## Introduction

In many EU countries is growing the pressure to adopt practices to achieve the sustainability of livestock farming and maintaining efficiency and competitiveness by producing foods of good quality at reasonable costs, avoiding the growth of negative externalities. In the European Union, policy-makers have set nine objectives of the common agricultural policy (CAP) after 2020 to 'ensure access to high-quality food and strongly support the European farming model' that will match production with ecology (European Commission, 2020). These objectives were progressively integrated in the sustainability principles embedded into the 'eco-schemes' for Pillar 1 the 'agri-environment-climate measures' and in Pillar 2 for voluntary farmer participation (European Commission, 2020). The negative side effects of livestock intensification, are caused by greenhouse gas (GHG) emissions, land and water contamination are becoming a political matter as private and public interest are in conflict. (Sok et al, 2020). On a global scale the livestock sector is responsible of environmental impact with exploitation of the agricultural land, (70%) for grazing and feeding, consumption of freshwater (80-90%, (Steinfeld et al., 2006; Leip et al.,2010) and GHG emission: in 2017 the EU-28 agri-sector generated GHG aggregate emissions (carbon dioxide, nitrogen, sulphur, phosphorus) estimated to 9.8% of the total regional amount of GHG emissions[2] (European Environment Agency, 2019). Beside a quarter of all food production, measured by calorie content, is wasted from "farm to fork", and 8% of the losses occur in the upstream of the supply chain the livestock

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[2] Data from FAO-19 provides an estimate of 8.1 Gt $CO_2$-eq: Methane ($CH_4$) accounts for about 50 percent of the total followed by nitrous oxide ($N_2O$) and carbon dioxide ($CO_2$) that represent almost equal shares with 24 and 26 percent, respectively. Emissions in the EU come from enteric fermentation (mainly ruminants) and manure management.

intensification seems to be the prevalent strategy adopted by farmers to face the explicit cost increase, while non financial environmental costs are left behind because non quantified by market transactions (Darnhofer et al., 2005, Gocsik et al., 2014). The positive counterpart is that livestock provides the 50% supply of human protein in the EU27; in 2020, each European inhabitant consumed on average 69.5 kilograms of meat annually (in retail weight equivalent) and 236 kilograms of milk equivalent. Several studies suggested that the reduction of 50% the current consumption of livestock] products in the EU would contribute to reduce the nitrogen emissions by 40% and the cropland area by 23% that would be available for other uses. The Sustainable Development Goal (SDGs), envisaged by the 2030 Agenda requires additional efforts to reduce the negative externalities caused by intensification of and livestock breeding [3]. Sustainability means to achieve a compromise between the private goal of profit versus mixed goals embedding the social and environmental goals of population across a range of spatial and institutional scales, for a suitable and resilient livestock activity.

## 1 – The milk production today

The milk production is the most important livestock activity for ruminants (cows) specialized in converting the rough feedstuffs rich in cellulose into higher biological value proteins[4] with higher quantity of essential amino acid of good nutritional value. However, the conversion rate in some countries like Argentina is very low, (about 2%), due to diffused wild breeding practice with ruminants (beef, cattle, sheep) pasturing in land with poor forage, hull vegetable waste, cookie dough and other prevalent ligneous and cellulosic feeds.

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[3] To regulate environmental impact, the EU has introduced a regulatory legislation to reduce environmental and climate impacts (i.e. the Industrial Emissions Directive 2010/75/EU) in 2010.In 2016 it was signed the Paris Agreement, with the United Nations about the Framework Convention on Climate Change (UNFCCC) targeted to long-term goal of limiting the increase in global average temperature. The Cap strategy reports a list of environment, landscape climate and animal welfare actions to improve the livestock sustainability:

a. Climate change mitigation, including reduction of GHG emissions from agricultural practices, as well as maintenance of existing carbon stores and carbon sequestration;

b. Climate change: including actions to improve resilience of food production systems, and animal and plant diversity for stronger resistance to diseases and climate change;

c. Natural resource conservation: maintain water quality and reduce water consumption; prevent the soil degradation, maintain the soil fertility with organic matter and rotation;

e. Protection of biodiversity, conservation or restoration of habitats or species, including maintenance and creation of landscape features or nonproductive areas;

f. Reduction of pesticides, particularly those that present a risk for human health, animal feeding, biodiversity and environment;

g. Actions to enhance animal welfare or address antimicrobial resistance.

[4] Biological value (BV): is the proportion of absorbed protein provided by foods and incorporated into the proteins of the organism's body. It captures how readily the digested protein can be used in protein synthesis in the cells of the human organism. The BV is measured indirectly using this formula: BV = retained N/ absorbed N = ( ( Ni - Ne(f) - Ne(u) ) / (Ni - Ne(f)) ) * 100. The Ni is the nitrogen intake in proteins on the test diet; Ne(f) = (nitrogen excreted in faeces whilst on the test diet) - (nitrogen excreted in faeces not from ingested nitrogen); Ne(u) = (nitrogen excreted in urine whilst on the test diet) - (nitrogen excreted in urine not from ingested nitrogen). The three properties of BV are: i) amino acid composition, and the limiting effect of essential amino acid; ii) preparation (cooking); iii) vitamin and mineral content. Another way to measure the BV is the edible fraction of aminoacidi using the conversion with the amino acid score using the formula: C = Aj / Sj where C - is the amino acid score, expressed in %; Aj - the content of the "j" essential amino acid in the protein of the product being evaluated in g / 100 g of protein; Sj - is the content of the "j" essential amino acid in the "ideal protein" (standard), g / 100 g of protein. The result of C is: Leucine, 4,52; Isoleucine, 4,52; Lysine, 4,61; Methionine, 2,49; Threonine, 3,68; Tryptophan, 4,57; Phenylalanine, 3,07, valine 3,63. Therefore, it is difficult to guarantee the RDA of all the EAAs using only vegetal, rather than animal protein sources; this is relevant both for human nutrition and the environmental footprint from land surface required for crop production, water use and GHGE.

In the EU countries the milk production system incorporates many scientific and technological progresses that have improved consistently the productivity signaled by the crop conversion index;[5] however, the need to improve further the capital and labor productivity has forced to adopt higher intensive breeding techniques based on maize silage, cereal flour and integrators to enhance the nutritional value of the diet[6]. The consequences are the increase in GHG emissions, a combination of CO2, CH4, N2O responsible of the GHE (green house effect) due to crop and animal metabolism. The negative externalities are causing growing conflicts with stakeholders outside the farm and consumers demanding genuine products and pose the question if this progress is in contrast with the fulfilment of the economic, environmental, and social principles of sustainability (Lebacq et al.,2013). New entrepreneur profile with higher personal, social and moral values, justify the change of the traditional profit maximizing attitude versus the achievement of non material environmental and social goals7. The methodological questions is how to combine in multi-attribute utility function the value attributes quantified by economic transactions and non value attributes subjectively evaluated by farmers' preferences, motivation, attitudes, embedded into ethical and moral considerations converted into strategic and tactical decisions, taking account of risk aversion, financial capacity8 farm organization, and external conditions such as the institutional regulation of emissions, soil and water pollution, incentives and others (Lagerkvist et al., 2011; Flachowski et al., 2017). To specify this decisional contest it is assumed the milk production based on crop produced in one Ha of land: i) able to satisfy the nutritional needs of a dairy cow, 600 kg live weight (LW), producing 30 Kg milk a day with 3,5% fat and 3,3% protein content in the lactation cycle lasting 310 days for a total of 9300 Kg of milk. To evaluate the nutritional needs it is used the "French method" based on milk forage unit (MFU) that represents the amount of energy provided by nutrients in the ration converted into milk production. The MFU accounts for the energy spent for maintainance and production of a dairy cow: 6-7 UFL are needed for the methabolic energy spent to support the vital functions (maintenance) and 1/3 MFU/liter is required for milk production. It is is estimated that this production will need a total consumption of 18-19 UFL/day for the entire lactation cycle (5735 MFU) and a total feed weight estimated 15,25 ton. For the remaining 55 days of the year, the diet is reducd to 5,5 UF for a total of 300 UFL, hence the total annual consumption of feed per year is estimated 15,265 ton composed by crops to supply the energy and protein and 40 cubic meters of fresh water. Information from different sources are used to evaluate the nutritional needs, the costs and externalities caused by land use, water use and GHG emissions. The CO2 equivalent emission including the sources of greenhouse gas emission (GHG) in breeding: enteric methane

[5] It takes an average of 6 kg of vegetable protein (with a range varying from 2 to 10 depending on the species and farming systems) to produce 1 kg of animal protein

[6] The milk production of Friesian-Holstein, has more than doubled in 50 years from 4,500 kg / lactation in 1970 to over 9,600 kg in 2017 and more. In the EU the number of dairy farms in activity was in 2019 26500 with 1,5 million heads and 57 heads per farm on average. A common trend is the decrease of dairy farm, constant number of dairy cow in lactation, increase in milk production yield, and ration based on caloric (maize silage, hay) and protein feedstuff (soybean) and flour.

[7] These are defined non use values because non quantified by market transactions.

[8] Strategic decisions imply a new way to produce, consequent to innovations in feeding ,automatization or chain relations and usually are projected in long period while tactic decisions imply adjustment on a current management routines.

production (CH4), nitrogen dioxide from manure (N2O) [9] (van Wagenberg al., 2016). Tab 1 - Ingredients of a daily cow ration L.W. 600 Kg, production: 30 kg milk/day, 3,5% fat; 3,3% protein, 9300 Kg milk production per cycle.

| Ration components | Measure | Alfa-alfa forage | Alfa alfa hay | Corn Silage | Wheat flour | Sunflower flour | Total |
|---|---|---|---|---|---|---|---|
| Fresh Matter (FM) | Kg intake/day | 8 | 10 | 28 | 10 | 0,9 | 56,9 |
| U.F L. | 1 Kg crop | 0,14 | 0,40 | 0,12 | 1,00 | 1,00 | 2,66 |
| U.F.L. | daily intake | 1,12 | 4,00 | 3,36 | 10,00 | 0,90 | 19,38 |
| Unit cost | 1 kg feed | 0,11 | 0,15 | 0,04 | 0,32 | 0,34 | 0,96 |
| Total cost/day | cost per 30 l milk | 0,88 | 1,50 | 1,12 | 3,20 | 0,31 | 7,006 |
| DM crops lact | % weight FM | 0,25 | 0,85 | 0,20 | 0,92 | 0,92 | 2,22 |
| DM crops lact | Kg | 2,00 | 8,50 | 5,60 | 9,20 | 0,83 | 25,3 |
| DM crop dried cow | Kg | | | 3,00 | | | 6,4 |
| Feed total | Kg (days = 310) | 2480,00 | 3100,00 | 8680,00 | 3200,00 | 279,00 | 17460 |
| Crop Yield | Kg/ha (x000) | 40,00 | 15,00 | 60,00 | 6,00 | 6,00 | 121 |
| Protein content | Kg/day | 0,31 | 1,70 | 0,10 | 1,13 | 0,32 | 3,24 |
| Land use | 1 head/ha | 0,06 | 0,21 | 0,14 | 0,53 | 0,05 | 0,99 |
| Water use | m3/ha (x000) | 12,00 | 0,00 | 6,00 | 1,50 | 1,50 | 19,50 |
| GHG emission | Kg CO2 eq/head | 1,57 | 1,80 | 1,77 | 1,56 | 0,82 | 6,70 |

Source: our elaboration on different sources

This work is developed in three parts: the first one is dedicated to illustrate the sustainability concept; the second part illustrates the methodology used to elaborate the NCDM and Multi-utility function (MUF) embedding value and non value attributes, and ranking their importance; the third part is dedicated to an empirical application of milk production to demonstrate the difference between traditional profit maximization and MCDM approach with discussion of results and regulation of the livestock activity to achieve the optimal utility level**.**

## 2- The paradigm of sustainability: an overview of theories

The sustainability approach assumes the livestock decision makers (LDM) change their attitude versus the environment becoming more responsible of the impact caused on natural resources, more concerned about the complaints of the out of farm stakeholders and aware of the risk of penalties imposed by EU agricultural policy. This means that they must change their decisions including value and non value attributes combined after the elicitation based on their perceived importance. This poses two methodological questions: the first is to select the attributes' in LDM strategy and second to measure their utility value coherent with homogeneous scalar measures. The social psychological theories (SPT) contribute to explain the perceived importance of the attributes using motivation and attitude to measure social-psychological

[9] The table reports the findings of a case discussed in Journal of Dairy Science Vol. 101 No. 7, 2018 completed with data retrieved in other sources. The rearing plant is composed by 300 cows (average per capita BW = 625 kg) plus heifers in random calving herd producing 10,500 kg/cow per year (3.5% fat) on 275 ha of land composed by clay loam soil in central Pennsylvania invested in the following crops: 85 ha of alfalfa, 10 ha of grass, 170 ha of corn, and 10 ha of wheat. Cattles are housed in naturally ventilated free-stall barns with slurry manure stored in a bottom loaded tank emptied spring and fall. CO2 emission: equivalent to 1,20 Kg CO2/l milk a day for a total emission (direct + indirect) equal to 12000 Kg CO2 eq/cow/year; similar results are reported by Perreira et al. while Solazzo et al estimate the total CO2 eq to 5 Kg/l/day. The slurry production (faeces + urine ) is 79 liters/cow/day (l/c/d) of which: rainfall = 5,7; (l/c/d); milk parlour waste water: = 16 l/c/d; bedding material = 2,43 kg/c/d. The slurry composition in gr/Kg DM (DM = 10,4% of the slurry weight) is: N = 35,5; P = 6,9; K = 38,3. The water consumption for 30 l/day milk production is estimated varying in a range between 110-150 liters/day; the total water consumption for 1 Ha of irrigation of crops component of the diet and cow ingestion is m3 (19450 + 50) = 19500 m3 per year. The MFU ingested daily for a cow 600 Kg weight, 2.nd lactation, producing 30 kg milk daily with 4% fat are estimated 18,6 UFL and require 3,5 Kgr Protein a day. Protein containt in 30 liters milk with 3,4% protein composition is is 1,02 kg/day.

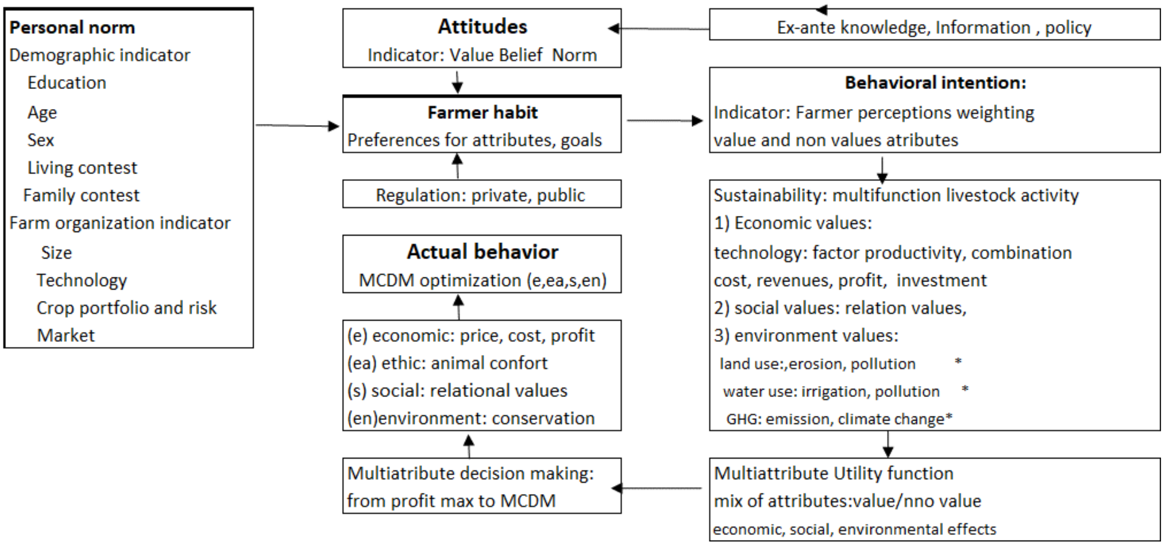
constructs as goals, target, values and benefits (Gocsik et al, 2014; Brake et al., 2005; Harper et al, 2002). This approach allows to take into account the environmental attributes that suggest to the LDM to adopt softer techniques and to the consumers' to manifest a willingness to pay (WTP) for the livestock products perceived as environmental friendly. (Hempel et al., 2021; Menozzi et al., 2017) Some authors described "the pasture-raised method potentially able to procure additional value to perception of quality beyond the value of intrinsic attributes, raising the question about the role of credence cues in quality perceptions of dairy products obtained in specific environmental conditions". (Stampa et al.,2020). Among the SPT, the Theory of Planned Behavior (TPB) is often used to predict the behavioral intention of agent as it helps to identify the relevant attributes influencing the LDM assuming that the moral obligation is driving the behavioral intention. Ajzen, (1991). In the TPB, socioeconomic characteristics and background variables such the policy environment, are able to influence the intention through attitude, subjective and moral norms in turn affecting the perceived behavioral control. The TPB framework has shown to provide a structured yet flexible framework that can explain the farmer decisions to adopt agricultural practices by including in decisional model sociodemographic such as farmer age, education, sex, farm size and organizational variables. The elaboration of attitudes, driving to behavioral intention, is explained by the Value-Belief-Norm (VBN) Theory (Stern et al., 1999) based on the socio-psychological motivation, with the contribute of the Norm Activation Theory (Schwartz, 1977), the Value Theory (Schwartz, 1994), and the New Ecological Paradigm (Dunlap & Van Liere, 1978) all focused on the role of external attributes. These theories are combined in the Alphabet theory (Zepeda & Deal, 2009) to assess the influence of perceived quality of the environment with the adoption of specific livestock management strategies. The emerging conscience for "greener sensitiveness" has reinforced this approach for a more inclusive LDM and support the elaboration of a multi-utility function (MUF)[10]. In the following model are reported five types of constructs to apply the TPB: personal norms, attitudes, subjective norms farmer habits and behavioral intention concurring to model the decisions of livestock.

A brief construct description: constructs are latent variable (LV) defined in conceptual terms: i.e. the livestock activity fulfil economic and social functions corresponding to the symbolic values associated to each species and the use of animals for the achievement of a set of rituals and social obligations of families and communities. The construct, beside not directly quantifiable can be measured indirectly with specific indicators. The TPB constructs are assessed by means of reflective indicators: personal norm are conditioned by socio-demographic and farm organization factors and integrate pro-social and self-interest factors affecting the LDM. Attitude is a psychologic motion that drives the behavior toward choices reflecting the achievement of values belief and norms related to intrinsic and extrinsic attributes. (Fishbein and Ajzen, 1974). They suggest that, instead of broad attitudes, the intention to perform a given behaviour is the most immediate antecedent and best predictor of actual behavior performance. A farmer attitude versus profit maximization will drive the behavior versus livestock intensification that will determine a cow exploitation to two or three lactations, and

[10] The MUF includes attributes, objectives, goals and targets as instruments of farmers' decision makers to be organized in a function to take account of the livestock sustainability expressed with multiple goal and target in substitution of the traditional profit maximization approach quantified with cost and revenues. MCDA is the method that uses a MUF amenable to capturing the complexity of natural systems, the plurality of environmental values and value given to sustainable livestock activity by many stakeholders.

higher impact on land and water pollution; an ecological attitude will drive the LDM versus softer exploitation of natural and biological resources (Fishbein and Haizen, 1975). Subjective norm determine the total set of accessible normative beliefs concerning the expectations of important social referents. The strength of a normative belief for a given referent is weighted by the person's motivation to comply with the referent in question while the social norms are influenced by the norms shared in the reference group. The behavioral intention reflect the cues of internal/external attributes in making personal judgement driving to select a strategy responding to question like: do I comply with a sustainable strategy allowing to survive economically in long period? To explore the most influential beliefs behind attitude, subjective norm and perceived behavioral control, it is required to build a multidimensional model giving priorities and measuring the attributes to assess their role in the achievement of sustainability. The following figure represents the model's predictive validity and the relative impact of attitude, subjective norm and perceived behavioral control on intention. Behavioral control is related to entrepreneurial skills, capacity to evaluate the risk of undertaken action that will impact of farmer's organization and external resources involved in farmer's decisions. Related to constructs there are indicators drawn from literature or by specific survey; selected set of indicators mainly includes (1) environmental indicators focusing on farmer practices; (2) quantitative economic indicators; and (3) quantitative social indicators with a low degree of aggregation (Lebacq et al, 2013). The attitude change the ranking importance of the value and non value attributes with consequences for the farm management and achievement of goals in a given time horizon. Commonly are used three dimensions of sustainability into various issues of concern named objectives, attributes, or themes (Alkan Olsson et al.2009, assessed by using indicators defined "a variable which supplies information on construct which are difficult to access directly by using benchmark to make a model and decisions. Among the various method to select the indicators we follow the "the data-driven approach", which consists of selecting and calculating indicators from existing data referred to livestock breeding system ((Darnhofer et al. 2010; Lebacq et al., 2013). The second question is to select the appropriate indicators that best fit with the research target that is to offer to an entrepreneur a sustainable diet with indexes satisfying the conditions of parsimony, consistency, measurability sufficiency, feasiblility in the spatial and temporal dimension of the analysis. Indicators are recommended to be expressed per amount of product and per hectare in order to evaluate the systems according to both functions. For indicators concerning global impacts, e.g., greenhouse gas emissions, should be expressed per unit of product (i.e $lCO_2$/lmilk) for water consumption is suggested the m3water/Ha. (van der Werf and Petit 2002).

Fig 1. Description of socio-psychological model for LDM focused concerned about sustainability of livestock activity using constructs values, and indicators




* monetization of negative externalities: Gocsik et al., p 295; Baltussen et al., p 37-40 define the natural capital costs the costs resulting from resource use and pollutant emissions.

## 3 - A multi-criteria decision making approach (MCDM) to frame the livestock sustainability

The theoretical background provided by SPT is made operational using the multi-criteria decision making approach (MCDM) to compose the internal and external factors to achieve the optimal sustainable condition.[11] The multi-criteria analysis, (i.e multiple criteria decision making, (MCDM) or multi-criteria decision aid (MCDA), is the instrument used to solve these types of agricultural and policy modeling problems in a discrete decisional space (Hayashi,2000). By ranking few pre-determined alternatives it has been demonstrated its suitability in various decisional contests (Dillon and Perry,1977; Romero and Rehman, 1989,1996). The MCDM assumes: i) a rational decision maker able to make a trade off among different combination of attributes; ii) an explicit or implicit preference structure about attributes; iii) the existence of an optimization process that is quantitative in nature. The definition of indicators and preference is particularly important for non value attributes because the absence of transactions makes their value more dependent on personal preferences and subjective judgement; to make this choice more neutral the quantification of non value attributes is done with indicators provided by data sources[12]. Multi-objective

[11] The literature reports that the livestock causes the 80% of soil acidification, air pollution (ammonia and nitrogen oxides emissions) and global warming, the 73% of blue water pollution (N and P).

[12] The literature classifies two groups of models: i) multi-objective optimization (MOO) models used to find the optimal solution in a continuous space; ii) multi-attribute optimization (MAO) that find the solution in a discrete space. Both approaches are quantitative and require the decision maker's preferences. Stated preferences are expressed with weighting or scaling methods or indicators reflecting the importance assigned to farmers for the attributes. The preference elicitation reflects the comparative value judgement for attributes and attribute trade off and the weight reflect the relative value of unit change in value function. This is made directly by posing questions to farmers or indirectly by using indicators (Gocsik et al, 2013; Baltussen et al, 2017). Mathematical programming models use various types of weights for decision variables (attributes expressed by goals and target values (Greening et al., 2004). the elicitation can be more complex in MAO because it is required to explicit a functional form while the MOO uses simpler methods to consider the farmers preferences (Qiu, 2005).

optimization allows to use alternative methods to evaluate the farmers' preferences instead of using an explicit functional utility form. Since the 80'es, methodological efforts have been made to include in MUF technical, economic and environmental attributes with cues about sustainability, related to attitudes, motivations, education and other ethical values, [13] (Keeney and Raifa, 1976; Galioto et al., 2017; Gocsik et al, 2015).

Measurability. A problem concerning the mix of use and "non use value attributes" is the measurability of their utility. In the traditional profit maximization, revenues and costs are measured by market transactions and bock value indicators; the non valued goods like externalities are quantified by preference that change with method used and farmers' attitudes while their value (Baltussen et al., 2017; Lebacq, 2013). Negative externalities are classified non value attributes because they represent "natural capital costs" responsible of decreased productivity of ecosystems resources (water pollution, soil fertility, GHG emissions others) or reduced benefic effects for the society.[14] The three main sources of "natural capital dependencies" for milk production measurable with indicators are: i) greenhouse gas (GHG) emissions, ii) water use, iii) soil use. The negative externalities and dependencies are valued with local data wherever possible or statistics from dedicated institutions and literature. The approach proposed by Baltussen (2017) with Trucost method bypass the problem of measurability with measurable indicators (cubic meters for water consumption and pollution of major contaminant as nitrogen; ton of GHG emissions in $CO_2$ equivalent per cow, per hectare of land for crop production). These physical measures are converted into monetary value (2015, US dollars) that integrate biophysical and economic impact, (Keeler et al. (2012). Here following are discussed the most common externalities and measures proposed by Baltussen et al. (2017).

1 - GHGs externalities (from energy and non-energy sources). Estimated 1,20-1,40 Kg$CO_2$ eq/kg milk or 14000 Kg $CO_2$ eq/Ha/year with an estimated cost of 0,11 €/Kg milk equivalent to 1048 €/Ha. The GHG is responsible of multiple impacts, including but not limited to changes in net agricultural productivity, human health and climate changes. The most common emission are: $CO_2$, $CH_4$, $NO_x$ procuring different impacts on global warming. [15] The impact quantification is based on different sources: in Netherland with agricultural conditions quite similar to Padania region, the total costs of GHG emission is 5,4 USD/Kg protein for dairy production; this cost is decomposed in: Organic fertilizer use $N_2O$: 1,40; Transport: 0,82; Manufact. fuel /electricity:

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[13] Attributes are classified in: i) use values quantified by market transactions; ii) non-use value referred to attributes related to the livestock independent of any use, present or future, that are the consequences of the livestock rearing.

[14] The dependency of a good on natural capital asset is the contribution of that asset to the value of a good in terms of inclusive wealth.

[15] The impact on the temperature is estimated $8.5\ 10^{-15}$ °C yr kg-1 $CO_2$ for a 20-year time horizon. The three main greenhouse gases (along with water vapor) and their 20-year global warming potential (GWP) compared to carbon dioxide are: i) $CO_2$ (carbon dioxide) = 1 x,; any carbon dioxide added to the atmosphere will stay for a long time: between 300 to 1,000 years. All this time, it will be contributing to trapping heat and warming the atmosphere; ii) $CH_4$ (methane ) = 84 x $CO_2$ equivalent Releasing 1 kg of $CH_4$ into the atmosphere is about equivalent to releasing 84 kg of $CO_2$. Methane's 100-year GWP (global warming potential) is about 28x $CO_2$ – but it only persists in the atmosphere for a little more than a decade. The 100-year GWP is used to derive $CO_2$; iii) $NO_2$ (nitrous oxide) 298 x $CO_2$ equivalent I.e. Releasing 1 kg of $N_2O$ in the atmosphere is about equivalent to releasing about 298 kg of $CO_2$. Nitrous oxide persists in the atmosphere for more than a century. It's 20-year and 100-year GWP are basically the same. There are other very powerful gas with 100 year GWP as: Sulphur hexafluoride ($SF_6$) = 22,800; Hydrofluorocarbon-23 ($CHF_3$) = 14,800; Perfluoro-ethane ($C_2F_6$) = 12,200.

0,22; Enteric fermentation: 2,40; Organic waste /manure - storage CH4: 0,29; Organic waste/manure - storage N2O: 0,23; Land-use change: 0,08. The highest cost for enteric fermentation are similar in other countries. CO2 emission for milk production are disaggregated in: use of organic and synthetic fertilizer N2O: 0,26; fossil fuel use transport and fertilizer: 0,15; enteric fermentation in ruminants: 0,44 (Baltussen p 95, 160).

2 - Air Pollutants: the estimated range for the all air pollutants varies from 936 - 12682 EU/ton milk or 9167 – 124167 EU/ Ha. The impacts of air pollutants on human health includes impacts from the emission of SOx, NOx, PM10, VOCs and ammonia from sources such as fuel use, fertilizer application, pesticide application and manure application. (see tab. 2)

3 - Water use and pollutants (from fertilizer application). Cost: water use: 45 USD/000m3 (range, 6_1175); water pollution: 11552 USD/m3 (range, 2300-52136). In Netherland this cost is 0,9 USD/Kg milk or 8900 USD/Ha. Water pollution costs are caused by: nitrogen (N) (more important) and phosphorus (P) nutrients surplus contained in faeces excretion and synthetic fertilizer input at the farm level leaching into water, (IPCC-statistics). It is valued on global monetary coefficients of the natural capital cost of eutrophication, whose impacts on ecosystems and human health are associated with algal blooms and drinking water quality. This valuation includes the impacts from the emission of nitrogen, nitrates, phosphates and phosphorus.

4 – Land use and soil pollution. 16520 USD/m3 range 3043-34812; Land use 1164 USD/Ha (range 22-7127). Land use is related to the values the ecosystem services lost from the conversion of natural ecosystems to agricultural land (from pesticide application). Land use measured in mq/Kg protein varies widely with the rearing method used: cropland, grassland grazing (with animals grazing mainly in fenced pastures); in Netherland are estimated 23 mq/Kg protein in Padania 31 mq/kg protein  Soil pollution includes the impacts of over a large number of pollutants, including pesticides such as atrazine, herbicides. Netherlands: Chemical input Kg /ha: N (feed and fertilizer) 258, N surplus: 163; P (feed and fertilizer) 33, P surplus: -8; NH3 emission/Ha: 79;

The following table reports the monetization of natural capital costs for each impact covered in the analysis, providing insight on the magnitude of the different impacts. These costs will be used in the next part of the analysis.

Tab. 2 Global natural capital impacts monetized in US$ per unit)

| GHG emission (US$/ton | | | Air pollutant (US$/ton) | | | | | Water use | Water pollut | Soil poll | Land use |
|---|---|---|---|---|---|---|---|---|---|---|---|
| CO2 | CH4 | N2O | NH3 | SO2 | NOx | VOCs | PM10 | US$/000m3 | US$/m3 | US$/m3 | US$/ha |
| 128 | 3200 | 38148 | 4390 | 2730 | 3051 | 6210 | 13918 | 45 | 11552 | 16520 | 1164 |
| | | | | | | | Variability | | | | |
| n.a | n.a | n.a | 42 - 178 | 26 - 111 | 29 - 124 | 893 - 9171 | 133 - 563444 | 6 - 1175 | 2300 -52136 | 3043 - 34812 | 22 - 7127 |

source: Baltussen, 2015 p 41

Baltussen reported the average natural capital intensity (NCI) of milk production equivalent to the natural capital cost per protein content (for milk the world average was 25 USD/Kg protein, for the EU-28 the average cost of NCI was 19 USD/Kg protein. The various components of NCI for EU were: land use change (10 USD =53%), soil pollution (0,5 USD), water pollution (0,5USD), water consumption (1 USD), air pollution (4,5 USD=24%), GHG (3,5 USD = 18,4%).[16]

**3.1 - The multi-utility function**

The multi-utility function is used in the MCDM to optimize the value of many attributes with different nature: monetary or value attributes generated by market transactions and non monetary or non value attributes generated by preferences of the stakeholders or by imposed restrictions and enforced by public authorities. The early models (80'es) of livestock optimization used only value attributes based on explicit economic values defined by market transactions such as the gross margin, cost minimization, capital investments, labor allocation, risk minimization and others. (Gomez-Limon et al., 2003). The growing interest for the sustainable approach has solicited to introduce the environmental non value attributes in the decision making and search tools for their quantification. (Weber, 1988; Goecsik et al, 2014; Drynan, 1985; Foltz et al., 1995; Lagerkvist et al., 2011);van Calker et al.,2008). The first problem is to select reliable indicators signaling the creation or destruction of resources due to livestock activity and related to attributes. (Ahlheim et al, 2001). The MCDM and MUF allows to elaborate the optimization based on relevant value and non value attributes whose importance has been previously ranked with statistical method (Lohrke et al., 2009), into a measurable utility function satisfying the conditions of additivity, non exclusion [17].

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[16] In comparing the different species of animal rearing, the production of poultry meat has the lowest natural capital intensity of the three commodities (US$21 per kg of animal protein); 88% lower than beef (US$ 39,5 per kg of animal protein) and 18% lower than milk (US$25 per kg of animal protein). Comparing production systems across regions and species, natural capital costs fall in the range of 3%-161% of retail prices for GHG and 1%-5% for water pollution. dairy production in the Netherlands dairy specialized system (snapshot 9) has natural capital costs that are in the same order of magnitude as poultry for land use and GHG emissions (Baltussen).

[17] The MCDM requires the definition of some preliminary concepts: **The attribute** is a measurable value of material (value) and immaterial (non value) components related to an object that generates utility in form of physical satisfaction and pleasure. Formally the utility value is a mathematical function of a vector of decision variables Xi, expressed formally: u (ai) = $f(\overline{Xi})$. The decision variables are referred to the multi-dimension of attributes: i.e: $f(\overline{Xi})$ for I = 1..n representing economic dimensions such as cost, revenue, profit, capital etc.then $f(\overline{Xj}$ for i = 1..m is referred to cow sustainable feeding that is the social dimension i.e.: DM, MFU, crop ingredients, protein content, metabolic energy; $f(\overline{Xk}\ for\ k = 1..q$ is referred to the environmental dimension (non value attributes) as: land, depletion, water pollution, GHG emission. These attributes concur together to achieve the **objective** of sustainability with the optimization of the Multi-Utility function depending on the combination of partial utility of the attributes; formally is: U(aijk) = [$f(\overline{Xi}), f(\overline{Xj}), f(\overline{Xk})$]. **The target** is defined an acceptable level or achievement of a set of attributes. For instance the limitation of the emission of GHG to a specific value level represents the target of GHG attribute and the combination of various target attribute represents the goal. **The goal** expression is very similar to the constraint equation and can be defined a flexible constraint formulation in a way to relax the traditional constraint rigidity that often cause infeasible solution. The goal is written as: f(x) <= 0 or >= t where t is the parameter representing the aspiration level or the target value. The removal of the constraint rigidity can be obtained with **deviation variables (DV).** The DV measure the lower achievement (deviation variable q) or the over achievement (deviation variable p); in a common solution it is considered only the variable p causing extra costs. The amount of p deviation can be specific to a one category of attributes as cost or profit or to be generalized to different categories like the land use, the exploitation of water resource, the level of externalities: pollution, fertility, odor, GHG emission and others. Goal and constraints have the same mathematical structure: (aij xi <=, =, >= bi); and the same position in the problem formulation. The difference is that the goal value is not defined "ex ante" but is a flexible value target which can or can not be achieved and the level of achievement is measured with deviation variables n and p. The goal is defined a flexible constraint and fulfilment of constraint value is measured with deviation variables. The goal constraint is represented as it follows: ai1X1 + ai2X2 +… ainXn + $n_i - p_i$ <= (or >= or =) bi where n and p are deviational variables representing the under and overachievement of a given value. The objective function is the minimization of undesired weighted deviation of p variables from the

The theoretical background of multi-Attribute Utility Theory (MAUT) is the cardinal utility function that combines the various attributes representing the sustainability (Keeney and Raiffa, 1993, see appendix 1). [18] This approach is based on the following assumptions: i) the attributes are quantified with measurable indicators ; ii) the value (economic) attributes are measured with market transactions, iii) the non value attributes causing negative externalities, independent of any current or future use of animal rearing are measured with indicators and weighted by preferences. These two groups of attributes enter in the overall farmer's utility function subjected to economic, social and environmental constraints. (Nijkamp et al.1980). The multi-attribute utility function assumes the following conditions: i) the utility function fulfil the conditions of additivity, linearity and quasi convexity; ii) farmers are rational decision makers; iii) the preferences for attributes are transitive, monotonic, continuous, convex, and non-satiable; iv) preferences are expressed with weights to influence the trade off among attributes; v) the selected case is referred to a typical livestock situation with specific farmers' attitudes and preferences; vi) stated preferences are based on the livestock scenario hypothesized by the case study and allow to account also of moral and personal values affecting the decisions. (Mas-Colell et al., 1995, Gocsick et al., 2014; allenius et al, 2008). The livestock sustainability is a typical farm management problem framed in a multi-dimensional space, to account for the economic, social and environmental implications of this activity [19]. The ordering of preferences is assumed the same for all individuals and consistent with Pareto criterion (Feldman, 1980); this requires the attributes be measurable by assigning a cardinal value to each alternative use, so the aggregate effect of all attributes and preferences can be converted in decision variables. (Lahdelma et al., 2000); Gomez and Limon, 2003; Greening and Bernow, 2004). The aggregate utility function is represented now:

$$U = U(r1, r2..rn)$$

U (◦) is the overall utility function encompassing the partial utility function of all attributes' activities u (ri); a single attribute utility can be represented as: u(ri) = fi ( $\overline{X)}$ . with ( $\overline{X)}$ is the

desired or assigned value of the goals. To be operative this approach need the following conditions: i) identify the technology, the various categories of attributes, the objectives of the MAUF; iii) select the indicators (decision variables) of attributes and their measurability; iv) identify the preferences and weights of stakeholders; v) set the goals and target values v) find the optimal solution in terms of distance from target value. The problem is formalized as it follows:

F.O min $w_1 * d_1*p_1 + w_2* d_2*p_2 + \ldots w_n* d_n*p_n$ (minimize the distance from weighted target)

s. t.

$a_{11}*X_1 + a_{12}X_2 + ..a_{1m} X_m + n_1 - p_1 = b_1$; (economic target group)

$a_{21}*X_1 + a_{22}X_2 + ..a_{2m} X_m + n_2 - p_2 = b_2$; (technical targets group)

..88

$a_{n1}*X_1 + a_{n2}X_2 + ..a_{nm} X_m + n_n - p_n = b_n$; (environmental targets group)

With these premises is elaborated the WGP that will be used in our problem. It considers all the goals simultaneously within a composite multi-objective function that in our case will minimize the sum of positive deviations of the all goals weighted in relation with the relative importance of each goal.

[18] The multi-attribute utility analysis, deals with decision making problems with multiple attributes and select the most effective solution among several alternatives by deriving preference of the decision makers. A method of weighting is the analytical hierarchical process (AHP) that ranks the importance of the attributes from the most to the lower important and another one is the contingent valuation.

[19] Land can be used for intensive crop production, less intensive prairies or landscape, livestock can be intensified by taking account of side effect as the GHG emission, water can be used in different volumes and cause variable impact.

vector of resources. In our case, U is the utility of a milk production[20] derived from attributes represented by use of resources: crops, labour, land, capital. By assigning a direction of improvement to fi ( $\overline{X)}$ , all attributes contribute to determine the value of the multi-utility function. $\overline{X)}$ is the vector of decision variables corresponding to resources used to perform a given activity, then ri can be expressed as a function of the quantity of input used: ri = gi ( $\overline{v}$ ) The activity level, related to input used ri = gi( $\overline{v)}$ ) means that the Utility is a production function variable in function of the input used[21]. The difficulty to elicit the utilities' attributes of the MAUF function is reduced by assuming the conditions of linearity, additivity and mutually independency of the attributes. Some authors (Rehman and Romero, 1993; Huirne and Hardaker, 1997, 1998), have demonstrated that the assumption of linearity and additivity conditions yields extremely close approximations to the hypothetical true utility function, even if the above conditions are not completely fulfilled. (Gomez-Limon et al, 2003). This is a realistic assumption in many agricultural decisions, (avoiding risk considerations, see appendix 1) and the cardinal MAUF can be rewritten in function of the weighted attributes:

1) U = $\sum_{i=1}^{n} wi * ui\ (rk)$ in case the variable input k=1: U = $\sum_{i=1}^{n} wi * rk$; this is the case of profit maximization

Where U is the MAUF of aggregated attributes and alternative uses k, wi is the weight assigned to the attribute i and ui (rk) is the utility value of attribute i used in the alternative k.; when w < 1 and $\sum_{i=1}^{n} wi = 1$ for the U satisfies conditions of linearity and additivity. This formal representation of utility requires to assume linear utility-indifference curve, a rather strong assumption that is acceptable if the attributes vary in a narrow range (Hardaker et al., 1997). By substitution of rk with variable input vi it is obtained the utility as function of input used by attributes:

2) U = $\sum_{i=1}^{n} wi * gi\ (v)$ and Max U' = $\sum_{i=1}^{n} wi * \left(\frac{dgiv}{dvi}\right) = 0$ for all i

This condition demonstrates that the single objective utility optimization with a single attribute (profit) is a special case of the more general optimization when a larger set of attributes contribute significantly to the improvement of the value of the utility function.[22] Rather than assuming a single decision criterion, the MCDM approach assumes that many stakeholders are involved in the collective decision process with different preferences for livestock optimization

[20] This means that the milk production activity expressed by quantity of milk collected per day requires some amount of resources: land, water, labor, feeding input, machinery, working capital.

[21] The milk production is the objective measured by quantity of milk collected per day, based on decision variables $\overline{(vectorX)}$. requiring to perform activities related to input use: land, water, labor, feeding input, machinery, working capital; this allow to substitute decision variables with input use. To summarize the concepts of MAUT: U = f(r1..rn) ; ri) = fi ( $\overline{X)}$ ; $\overline{X)}$ = decision variables; activity level ≈ input use. This allow to convert the decision variables of the activity level into input use as requested by the math programming and ri = fi ( $\overline{X)}$ = gi( $\overline{v)}$ and the Utility function is U = U(gi( $\overline{v)}$ for I = 1..n; in case of max profit: U = U(π) = U(π, $\overline{v)}$ ) and the optimization with one attribute the profit max is: d U (gi( $\overline{v)}$ /dv = 0 and in extended form: d(Π*f(v) = d( P*f(v) - $\sum_{i=1}^{n} pvi * vi$)/dvi = 0 .

[22] In MAUF (U') the marginal utility of the input vi with these assumptions is calculated from shadow prices: using the amount of input as parameter the Utility maximum will be obtained for shadow price = 0 or: $wi * d\left(\frac{giv}{dv}\right) = 0$

(Jacquet-Lagreze and Siskos, 2001). This approach offers an alternative to the neoclassical assumptions underlying profit maximization as the unique objective consistent with the economic analysis (Hafkamp and Nijkamp, 1986). The socio-economic- environmental approach seems to fit better with livestock decisions in today contest that require a compromise between profit (value) and responsibility about the environmental disruption caused by intensive livestock.[23] The weight wi is used to rank the importance of the stated preferences of farmers. Following the weighted goal programming approach proposed by Dyer et al, (1977) the weights are used in the following separable and additive utility functions:

3) $$U = \sum_{i=1}^{n} wi/ki * ui$$

where ki is a normalizing factor and ui = fi $(\overline{X}) = gi(\overline{v})$.

The U function is normalized using the difference between the ideal $fi^*$ and worse $fi*$ utility values of the attributes, in function of factor xi:

4) $$U = \sum_{i=1}^{n} wj \frac{\mathrm{g(xi)} - fi_*}{fi^* - fi_*}$$

This function can be rewritten with a correction factor

5) $$\text{O.F. } U = \sum_{i=1}^{n} wi/ki * \mathrm{fi}\,(\overline{X})$$

constrained by the feasible set of solutions with sociaL, economic and environmental constraints to the use of all resources:

6) $$gj(x) \leq bj \text{ for all } j$$

The mathematical programming methods is used by MCDM to generate from many possible alternatives a small subset of non dominated solutions whose tradeoffs represent the most preferred combination of attributes. The decision variables used to achieve one or multiple objectives in the utility functions, are represented with a distance from a predetermined goal value from the objective and represented by $\mathrm{g\,(xi)} - fi*$ and weighted with preferences assigned to attributes (Tamiz et al., 1998). This approach allow to introduce in the objective function the monetary values of economic goalt, the social values of the physical inputs and the environmental values of land use (ha), water use (m3/ha, and GHG emission (m3/head) with ad hoc indicators (Mirasgedis and Diakoulaki, 1997). The stated preferences for attributes are determined with indicators and weights satisfying the condition that their sum will be equal to 1. (von Nitzsch and Weber, 1993; Rosato, and Stellin,1993; Qiu 2005).. Operationally, this model is framed in a mathematical programming method (MPM) that combine the monetary attributes represented by minimum cost of the ration, with the environmental non value attributes of water consumption and pollution, land use, GHG emissions quantified by physical measures reported in table 2 (FAO, 2018; Tamiz et al., 1998). Solution fulfilling these

[23] Gocsick et al, (2014) has framed his socio-psychological approach draft from the theory of planned behavior (TBP) that justify this approach to livestock and mention four categories of non market attributes that qualify the sustainability approach: (1) Personal Norms, (2) Attitude, (3) Subjective Norm, and (4) Perceived Behavioral Control. Variables within these categories determine the behavior directly or indirectly through the behavioral intention. An activities in livestock is referred to various feedstock components and environmental impacts that compose the vector of different economic and environmental attributes. Then the MAUT is U = u1 + u2 + …un and the elicitation among different attributes depends on monetary and non monetary evaluative factors

assumptions are defined Pareto efficient. [24] The optimal solution is obtained with minimization of deviation variables signaling the distance from the goals (attributes related to cost, diet ingredients and environmental impact.[25]

**4) The decision framework of sustainable livestock farming**

Livestock growers are now more aware of the environmental problems and are trying to adjust their objectives by moving from the traditional profit maximization to a broader multi-criteria approach (Lagerkvist et al.,2011; Brussaard et al. 2010). Since non value attributes are quantified by payments provided by EU 2.nd pillar with rural development policies this approach start to become economically more attractive.

Objective, goals and targets of the MAUF can be achieved with attributes can be constrained or can be assigned priorities used to improve the meaning of the OF in different scenarios. While the objective is the reference of decisions rooted on attributes, a target is an assigned level of attribute achievement and the goal identify the magnitude of decision maker's objective .[26]

The attributes are identified with measurable indicators representing the decision variables and the priority of achievement are assigned with weights in the MUF. Three categories of indicators are selected for the three groups of attributes: economic (value), social (value) and environmental (non value) representing the sustainability components. Balthussen et al, 2017 [27] suggest the conditions to obtain consistent results from this approach: i) risk evaluation generated by the variability of economic and climatic events and external provision for policy options; ii) existence of indicators for value and non value attributes; iii) selection of target values according with technical, economic and policy considerations.

**5) Target ranking:** there are two selection criteria to rank the importance of targets: compensatory and non compensatory methods. Weighting or scaling method are ''compensatory'' methods for the evaluation of tradeoffs with pairwise comparison between attributes of candidate alternatives. Attributes are grouped or ''bundled'' in groups, each one receiving a weight that emulate the partial contribution to the overall score, based on goal preferences such as: $w_i = v_i/\Sigma v_i$. The weights identify the preferences of individual decision makers for an objective, associated to decision variables related to input use and suggest how much the decision maker is willing to accept the tradeoff (using indifference curves and

[24] The Pareto efficient solution is a set of attributes combined in a way that no single attribute can be improved without degrading at least one of the other attributes. Pareto inefficient and unbounded solutions are also possible.

[25] The Multi-objective optimization methods determine the optimal solutions over continuous or discrete spaces, and require the decision makers to elicit their preference (Dyer et al. 1992); then the important feature of weights regard the definition and evaluation: definition about the hierarchic importance of attributes, the range, the type of attributes (quantitative and qualitative); the measurement method adopted will influence the ranking preferences.

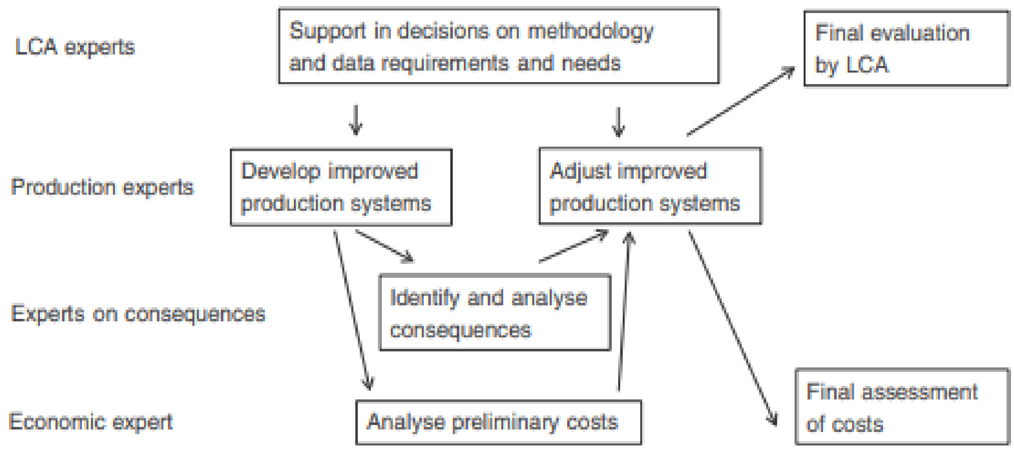
[26] The research about preferences in farm planning (Hayashi, 2000) for the period 1977- ahead suggests a ranking evolution from economic objectives (revenues including gross margin, incomes, expected revenues, cost, about 30 mentions) and labor (Labor utilization, employment, hiring, or leisure, 15 mentions), while the attention for environmental impact and sustainability (Nitrogen loss, biocide accumulations, and soil loss) is mentioned in only one work (Nibbering et al, 1998).

[27] De Boer et al (2002) have defined the four conditions for the indicators' sustainability: i) measurability, ii) address preferences of stakeholders to choice of alternatives on and off farm; iii) accuracy of information; iv) signaling target values.

marginal rates of substitution) between one attribute group and another. A method of weighting is the analytical hierarchical process (AHP) that ranks the importance of the attributes from the most to the lower important. The second step is finding the lower and higher attribute value used in computing the distance; finally the attributes are aggregated into an overall ranking scheme. This approach is possible with the presence of a utility functions and the weights will measure the relative unit changes in a specific attribute with another utility using cardinal value. Analysis of trade-offs between market valued and non-market valued attributes in development an optimal solution with hedging and trading strategies. Non market values are measurable with physical measure as the quantity of GHG generated by one head and weighted accordingly.

After having defined the components of decisions the multi-objective optimization model can be proposed by using the different alternatives of goal programming that best fit with the problem. (Romero et al., 1987; Bergevoet, R.H.M., 2005).

Fig 2. Scheme of a multi-criteria decision making applied to livestock farming




## 6 - Methodology

Operationally the approach is structured in three-steps: i) description of methodology based on multi-criteria approach: value tree, criteria, alternatives; ii) definition of preference order to formulate the multi-criteria objective function, with goals and weights to selected criteria; iii) simulations and analysis of the results (reliability and sensitivity analyses). (Romero & Rehman, 1989; Marttunen & Hämäläinen, 2008). All performance indicators of attributes are grouped accordingly with their nature (economic, social, environmental). The values of the economic indexes are estimated as the average value of the xi indicators and the same procedure is followed for social and environmental indicators. Within this framework it will be also possible to evaluate the performance of: (a) - the current resource allocation and (b) - various policy measures (e.g., water pricing, GHG emissions), under condition that the impact of these measures can be previously simulated in terms of the same decision variables (or directly in terms of the selected criteria).

The table 3 identifies the problem with different attributes (ration ingredients) and levels.

Table 3 – Matrix of the optimal ration at minimum cost: daily consumption of feedstock for a dairy cow, 600 Kg weight, daily milk production 30 Kg, 3,5 % fat; five activities Xi I =1..5 for five attributes and seven indicators: 1 = economic; 2,3,4 = social; 5,6,7 = environment.

| Daily ratio: level of input use | Unit | Attributes used in the activity milk production level =30 liters milk/day (Kg DM) | | | | | Total |
|---|---|---|---|---|---|---|---|
| | | Alfa alfa forage | Alfa alfa hay | Corn silage | Wheat flour | Sunfl. cake | |
| | | 140 €/ton ss | 160 €/ton ss | 30 €/ton ss | 150 €/ton ss | 220 €/ton ss | |
| | | X1 | X2 | X3 | X4 | X5 | |
| (i.1) Cost per day | cent | 0,28 | 1,36 | 0,12 | 1,55 | 0,18 | 3,48 |
| (ii.1) Dry matter intake | Kg DM | 2,00 | 8,50 | 4,00 | 10,30 | 0,80 | 25,60 |
| (ii.2) Energy intake (UFL | UFL/day | 1,12 | 4,00 | 2,40 | 11,20 | 0,90 | 19,62 |
| (ii.3) Protein content | Kg/Day | 0,31 | 1,70 | 0,10 | 1,13 | 0,32 | 3,57 |
| (iii.1) Land use (Ha) | Ha | 0,06 | 0,21 | 0,10 | 0,58 | 0,05 | 1,00 |
| (iii.2) Water use (m3) | m3 | 2,40 | 0,00 | 20,00 | 1,68 | 0,34 | 24,42 |
| (iii.3) GHG | Kg CO2 eq/head | 1,57 | 1,80 | 1,77 | 1,56 | 0,82 | 7,52 |

Source for CO2eq/ton tal quale see: AAVV, CRPA, 2016, Progetto life + climate change. Computation Carbon footprint forage crops and and Roberto Solazzo et al. To the crop emission must be added the milk production equal to 36 Kg CO2 per cow. Estimated climate impact of CO2 equivalent per kg production are: 0.6 Kg for soybeans, 0.7 for soymeal, between 16 and 22 for beef.For cost see table. Water use is inclusive of the crops' consumption and animal consumption

. Attributes and level: U = fi(x°)

In table 3 are reported in column five components of the daily ration: alfa-alfa flour, alfa-alfa hay, maize silage, wheat flour and sunflower cake that are the five attributes x1..x5; in row are reported the level of input use for the daily milk production that are target level for each ingredient and in the last column is indicated the value that is the goal constraints, These are: i) monetary (Mt) grouped into cost of the ration's ingredients; ii) technical, indicated with: ii.1 – maximum dry matter per day; ii.2) (UFL) energy intake (UFL); ii.3 protein content; environmental: iii.1 – land use; iii.2 – water use; iii.3 – GHG eq ) These values are obtained with a previous simulation of the optimal combination of attributes at minimum cost.

The second step of the problem is the formulation of multi-utility function, with attributes Xi and their levels of use of decision variables fi $(\overline{X})$ represented by the input use i $(\overline{v})$. For all attributes are defined the partial utility function with maximum target values and allowed flexibility by using deviation variables.

Constraint values: the values for the first group of attributes are given by ration methods broadly diffused, while for environmental attributes the values are drawn from different sources. The purpose of the soil use is to maintain the soil fertility with chemical inputs; there are not restrictions as well for water use; data on GHG emissions are obtained from regional data and all constraints will be weighted.

The analytical framework is based on multiple attributes referred to the three groups of attributes for sustainability and aggregated scores of indicators are used to rank different farming alternatives. Composite indicators are used to reduce the number of variables; for example, productivity indicators include detailed information about yield (t/ha), energy (kcal/ha), protein (kg/ha), income ($/ha), GHG emission (m3/head or m3/ha). In MCDA analysis, there is a general agreement to generate the outcome scores on a 0 to 1 scale.

Model synthetic description

10) F.O (attributes as decision variables) U = $\sum_{i=1}^{n} wipi$ for wi ≥ 0 and I = 1..7

11) s.t. (goal constraints) g(xj) ≤ bj for j = 1..7

**7 - Case study: ration formulation, intensification and environmental impact**

This case study is the simulation of the diet formulation for a dairy cow under constraints of value and non value attributes: the value attributes are quantified by collecting accounting and nutritional data (see table 9). The elicitation method of MCDM consist in simulate different level of restriction in the use of these resources and quantify the weight attached according with their importance.

The premises of this case study, are: a dairy cow lactation cycle, lasting 310 days with production of 30 kg of milk a day with 3,5% fat content. The ration is composed by five ingredients cultivated in one Ha of land. The utility function includes seven targets of which one is economic (cost value), three are technical and refer to nutritional features, three are environmental (non value); all these values are obtained from literature and experiment. The rows of the matrix report the equations of the goals to be achieved; the column vectors indicates the multi-utility function as U = f(ui, ) resulting from the composition of the attributes' utility ui for I = 1..5. The optimization assumes that that the positive deviation of the goals are minimized. The minimization of the distances from target values is the objective of the MCDM solution and represents a compromise among the seven weighted goals to be achieved by decision maker. These goals are divided in two groups: the first four goals are the value attributes of the ration: cost, dry matter intake, UFL and protein intake. The second group, the non value attributes referred to the environment impact directly related to the sustainability of the livestock activity: land use, water use and GHG emissions.

Description of goal, deviation and target.

The goals correspond to the constraints in the traditional LP solution with the difference that they are made flexible by using positive and negative deviations from the target value. Negative deviation variables ni (below the target value) do not affect the solution; the positive deviation variables pi (above the target value) affect the optimal solution value because exceeding the optimal use of resources requested to reach the target level and determine the increase in costs or environmental impact. The goal description and representation is following.

Goal g1 – cost ingredients. This is the objective to be minimized in the traditional LP optimization. It is converted into goal by setting a target value of variable costs of ingredients equal to 3,62 €/day/head for rations calibrated on an average daily production of about 30 liters of milk per day (see table 9). The equation is structured using the costs of ingredients reported in table 9. The ration equation assumes that the farm supplies itself for at least 50% of the forage and is reported below:

0.28*x1 +1.36*x2 +0.12*x3 +1.54*x4 +.18*x5 + n1 – p1 <= 5.5;

x1..x5 is the set of decision variables referred to the use of five ingredients; their coefficient values in €/ton are the ingredient costs of alfa-alfa flour, alfa-alfa hay, silo-maize, wheat flour, sunflower cake. The variable n1 measures the under-achievement while the variable p1 measures the over achievement of the target 1, to be minimized. The target value is set to 3,5 (see table 3) to let the cost positive change of the attributes used.

Goal g2 – dry matter content. All diet ingredients (see table 9) are allowed to enter into the diet. The value 25,6 is based on expert indications that suggested at least the DM Ingestion of 23.8 kg / head /day):

$$2.0*x1 +8.5*x2 +4*x3 +10.3*x4 +0.8*x5 + n2 – p2 <= 25,60;$$

To achieve the desired level of goal g2 the variable p2 must be minimized.

Goal G3 – Energy intake. Measured in MFU these values reported in table 3, suggest approximately 20 UFL for a production of 30 liter of milk per day during the lactation period:

$$1.12*x1 + 4.00*x2 +2.40*x3 +11.2*x4 + 0.90*x5 + n3 – p3 <= 20$$

To achieve the desired level of goal g2 the variable p3 must be minimized.

Goal g4 – Protein content. Crude protein requirements vary with the weight of the cow and the amount of milk produced.[28]A 600 kg cow producing 30 kg of milk containing 3.5% milk fat requires 0.40 kg of protein for maintaining herself and 2,7-3 kg of protein for milk production. The total crude protein requirement is 3.6 kg approximately the 17% 0f DM):

$$.305*x1 +1.70*x2 +.104*x3 + 1.133*x4 + .323*x5 + n3 – p3 <= 3.60$$

To achieve the desired level of goal g4 the variable p4 must be minimized.

Goal g5 – Land use by diet ingredients. The available land should not exceed 100% of the specified requirement that is 1 Ha. As the maximum quantity of N is 450 Kg / Ha, this imbalance goal should be specified as it follows:

$$0.06* x1 +.21 x2 +.10*x3 +.58*x4 +.05*x5) + n4 – p4 <= 1$$

To achieve the desired level of goal g5 the variable p5 must be minimized.

Goal g6 – Water used for production of diet ingredients and cow consumption. The coefficient of the goal equation are:

$$2.40*x1 +0.001*x2 +20*x3 + 1.68*x4 + .34*x5 + n5 – p5 <= 24,5;$$

To achieve the desired level of goal g6 the variable p6 must be minimized.

Goal G7 – GHG emission by diet ingredients. The coefficients for various crops are obtained from literature.

$$.26*x1 +.30*x2 +.05*x3 +.052*x4 +.20*x5 + n6 – p6 <= 7,5$$

To achieve the desired level of this goal the deviation variable p7 must be minimized.

The MOUF consists in the minimization of the weighted deviation variables pi for i = 1..7 the absolute positive deviation from the target values (t.v.). The different dimensions of target values (t.v.) to be comparable, are converted in relative values[29]: pi% = pi/t.v*100/1. Finally pi is

[28] For dry cows, there is an extra need for crude protein for the growing fetus that is added to the maintenance requirement. Growing animals have an extra need for crude protein for muscle development.

[29] The transformation assumes that 100 corresponds to the absolute target value (t.v. >=0 ), then the transformation in relative % value is obtained from the following proportion: pi/t.v % = pi/t.v *100

weighted with wi, whose magnitude depends on the importance assigned to the specific utility attribute I and is obtained from literature.

Following is reported the MCDM problem with O.F., constraints and goals

U = min Σ wj*pj/kj.*100/1; the numerical values of the O.F. are:

Deviation variable 1: Min w1*p1* 100/1 = w1*100/3,5*p1 = w1*28*p1

Deviation variable 2: Min w2*p2* 100/1 = w2 *100/25,6*p2 = w2*3,91*p2

Deviation variable 3: min w3*p3 *100/1 = w3*100/20,00*p3 = w3*5,00*p3

Deviation variable 4: min w4*p4*100/1 = w4*100/3,57*p4 = w4* 28,01*p4

Deviation variable 5: min w5*p5 *100/1 = w5*100/1/*p5 = w5*100*p5

Deviation variable 6: min w6*p6 *100/1 = w6*100/24,42*p6 = w6*4,09*p6

Deviation variable 7: - min w7*p7 *100/1 = w7* 100/7,5*p7 = w7*13,3*p7

s.t targets g(xj) ≤ bj for j = 1..7

0.28*X1 + 1.36*X2 + 0.12*X3 + 1.54*X4 + 0.18*X5 + n1- p1 <= 5.50 constr 1 - cost per DM content

2.0*X1 + 8.5*X2 + 4.0*X3 + 10.3*X4 + 0,83*X5 +n2- p2 <= 25,6 constr 2 - DM content

1.12*X1 + 4.0*X2 + 2.4*X3 + 11,2 X4 + 0,9*X5 +n3- p3 <= 20 constr 3 - UFL Energy

0.31*X1 + 1.70*X2 + 0.10*X3 + 1.13*X4 + 0.32*X5 +n4- p4 <= 3,6 constr 4 - Protein content

(0.06*X1 + 0.21*X2 + 0.10*X3 + 0.58*X4 + 0.05*X5) +n5- p5 <= 1 constr 5 - Land use 1 Ha

2.40* X1 + 0.01*X2 + 20*X3 + 1.68*X4 + 0.34*X5 +n6- p6 <= 24,5 constr 6 - Water use

0.26*x1 + 0.30*X2 + 0.05*X3 + 0.52*X4 + 0.20*X5 +n7- p7 <= 7,5 constr 7 – GHG

Tab 4. Simulation of the effect of maize quantity increase on seven attributes achievement

| quantity silage | cost | DM | cal | quantity | revenue | rev - cost | PC | land poll | water poll | CO2 emiss | Sum extern | Weighted |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| unit | euro | unit | UFL | liter | euro | euro | unit | N/Ha | unit/m3 | kgCO2 equiv | | profit |
| 2,00 | 5,10 | 14,00 | 12,85 | 21,42 | 6,43 | 1,33 | 4,00 | 120,00 | 30,00 | 25,70 | 175,70 | 0,75 |
| 3,00 | 5,16 | 18,00 | 14,00 | 23,33 | 7,00 | 1,84 | 6,00 | 150,00 | 63,00 | 28,00 | 241,00 | 0,76 |
| 4,00 | 7,00 | 26,00 | 19,00 | 31,67 | 9,50 | 2,50 | 6,50 | 180,00 | 70,00 | 38,00 | 288,00 | 0,87 |
| 5,00 | 7,74 | 29,00 | 21,00 | 35,00 | 10,50 | 2,76 | 6,70 | 228,00 | 77,00 | 42,00 | 347,00 | 0,80 |
| 6,00 | 8,75 | 30,00 | 21,50 | 35,83 | 10,75 | 2,00 | 6,80 | 240,00 | 80,00 | 43,00 | 363,00 | 0,55 |
| 7,00 | 10,60 | 31,00 | 23,00 | 38,33 | 11,50 | 0,90 | 7,10 | 276,00 | 87,00 | 46,00 | 409,00 | 0,22 |
| 8,00 | 13,39 | 32,00 | 24,00 | 40,00 | 12,00 | -1,39 | 7,40 | 290,00 | 91,00 | 48,00 | 429,00 | -0,32 |

Tab 10.2. % variation of data reported in tab. 10.1

| quanty | cost | DM | cal | quantity | revenue | rev - cost | PC | land poll | water poll | CO2 equiv | value att | non value att |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| unit | euro | unit | UFL | liter | euro | euro | unit | N/Ha | unit/m3 | kgCO2 equiv | | |
| 2,00 | 100,00 | 100,00 | 100,00 | 100,00 | 100,00 | 100,00 | 100,00 | 100,00 | 100,00 | 100,00 | 100,00 | 100,00 |
| 3,00 | 101,14 | 128,57 | 108,95 | 108,95 | 150,00 | 125,00 | 210,00 | 125,00 | 210,00 | 108,95 | 137,17 | 101,36 |
| 4,00 | 137,25 | 185,71 | 147,86 | 147,86 | 162,50 | 150,00 | 233,33 | 150,00 | 233,33 | 147,86 | 163,92 | 115,11 |
| 5,00 | 151,70 | 207,14 | 163,42 | 163,42 | 167,50 | 190,00 | 256,67 | 190,00 | 256,67 | 163,42 | 197,50 | 105,59 |
| 6,00 | 171,66 | 214,29 | 167,32 | 167,32 | 170,00 | 200,00 | 266,67 | 200,00 | 266,67 | 167,32 | 206,60 | 72,88 |
| 7,00 | 207,80 | 221,43 | 178,99 | 178,99 | 177,50 | 230,00 | 290,00 | 230,00 | 290,00 | 178,99 | 232,78 | 29,25 |
| 8,00 | 262,49 | 228,57 | 186,77 | 186,77 | 185,00 | 241,67 | 303,33 | 241,67 | 303,33 | 186,77 | 244,17 | -42,87 |

Tab 10.3. weighted p deviation from target

| quanty | cost | DM | UFL | PC | land use | water | CO2 | sum |
|---|---|---|---|---|---|---|---|---|
| 2,00 | 0,01 | 7,17 | 4,63 | 0,08 | 57,20 | 41,96 | 0,26 | 111,31 |
| 3,00 | 0,01 | 8,29 | 3,84 | 0,13 | 125,00 | 97,04 | 1,88 | 236,19 |
| 4,00 | 0,02 | 17,29 | 7,08 | 8,81 | 180,00 | 119,80 | 2,27 | 335,28 |
| 5,00 | 0,03 | 21,51 | 8,65 | 0,16 | 288,80 | 144,96 | 3,27 | 467,38 |
| 6,00 | 0,03 | 23,02 | 9,06 | 0,17 | 320,00 | 156,48 | 3,37 | 512,12 |
| 7,00 | 0,03 | 24,58 | 10,37 | 0,18 | 423,20 | 185,06 | 4,22 | 647,64 |
| 8,00 | 0,04 | 26,19 | 11,29 | 0,20 | 466,58 | 202,47 | 4,68 | 711,44 |
| mean | 0,03 | 18,29 | 7,85 | 1,39 | 265,83 | 135,40 | 2,85 | 431,62 |

## 7.1 - Comment about sustainability results

The MCDM – WGP approach suggests that the optimization process based on seven objectives represented with a target vector whose optimal achievement is measured with the minimization of the weighted distance W*P/CF between target value and real achievement. The sustainable solution is obtained with the target achievement representing value and non value attributes of the MAUF, weighted according with livestock farmers' preferences. The decision variables xi for i = 1 to 5 are the nutritional ingredients of the dairy cow ration, to be changed according with preference about sustainability. The results are obtained with seven parametric simulations of the diet by varying one unit of maize at each simulation while the other ingredients are left constant. The weighted cost changed in the seven target simulations from 0,01 to 0,04 comparable with the absolute cost values reported in table 4.1. The total utility increased faster respect the maize silage: non use attribute specifically land use and water use were the major responsible of the change in MAUF respect the value attributes. The land use weight increased by seven times while the water increased almost four times supporting the hypothesis that the environmental attributes are the most important contributors to the sustainability.

Target value. Different solutions are obtained by setting an initial target level obtained from an optimal diet obtained at minimum cost, and observing the rhs range value, that indicates the range variation of target values. The target achievement is measured with the deviation variable pi that is the distance between the desired target value and real achievement of the attributes xi that satisfies the optimal diet. The weights are selected according with the order of preferences of decision makers,[30] and are used in sensitivity analysis to add information on selecting the diet ingredients whose composition is a compromise between economic social and environmental goals. The weighted profit signals the importance of environmental attributes:. This value is the optimal and not reached by any other level of maize silage.

The level of production and revenues are reported in the column of MFU; the production in liters is determined by converting linearly the MFU/day in milk with the following relation: 18 UFL/day = 30 l milk at 3,5% fat. The revenues are derived by assuming the selling price equal to 30 cent/liter and the profit is measured by the difference revenue – cost. The limit to land use corresponding to one Ha is violated with 7 and 8 units of maize silage. The water use (l/day/cow) includes the consumption of cow beverage depend on milk production is causing an increase in cost passing from 1350 for 21 liter production to 4095 for 40 liter production.

Finally the CO2 emission varies from 2,70 min to 7,90 max; as it is expected, the values increase caused by the higher emission of CO2 equivalent as the production tend to intensify with increase of maize silage. Information about simulation are reported in table 4.1, 4.2 and 4.3.

With minimum use of maize silage at level 2, the all constraints (target) are satisfied but the production level fall to 30% below the potential optimal 30 liters/Ha while the externalities are the 60% below the optimal production level. The optimal production level for one ha using the traditional goal of maximum profit without considering externalities is reached with 5 unit maize silage but the weighted profit is 0,80. Considering the externalities the optimal weighted solution is reached with 4 unit silage and the weighted profit index value is equal to 0,85 the best among the weighted profit values obtained with simulation. The deviations from target are reasonably low for value attributes but very high for land and water use, beside remaining below the critical level. The lowering deviation value is compatible with less use of N/Ha then this parameter can be used by policy maker to impose limit to negative externalities. The simulation suggest that water use is more critical than land use in term of negative impact. The impact of CO2 becomes lower as larger threshold limits were adopted.

The changes in target values affect the pi deviations and suggest the direction to reduce the distance from actual to desired target value. For all non value attributes producing externalities to reduce the land and water use is imperative to reduce the impact of milk production. The weight of each goal represents the relative importance assigned by decision maker to the goals that contributes to the value of the multi utility function.

**8 - Conclusion**

The MCDM approach that was experimented in this case study represents an evolution moving from the traditional profit maximization approach to demonstrate that economic social and environmental attributes play an important role in the optimization process used in MCDM. This approach help to understand better the decision making approach of farmers concerned about environmental consequences of livestock decisions made on values, goal attributes' trade off, attitudes and preferences. The approach was worth to demonstrate that the milk sustainable production is possible and economically feasible only if the restricted profit optimization is performed. When non value attributes are included in MAUF the worsening

[30] The decision makers are: i) the private entrepreneur that has an objective function with many attributes and prevailing preferences for economic attributes like the cost of ration ingredients or environmental attributes

environmental quality due to depletion of land, soil fertility and pollution, water use and pollution require to revise the strategy of the sustainable milk production. The adoption of sustainable livestock production system is a challenging and complex endeavor, because any choice affects non-use value inputs that generate a trade off between farmers' costs and social benefits. The non-use value attributes as land depletion, water quality or GHG emissions must enter into the evaluation of the utility function, to affect the farmer's ultimate decision about the adoption of production technology mediated by the preferences expressed by a larger number of stakeholders that conflict in terms of appropriation of residual property rights on natural resources.

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Appendix 1

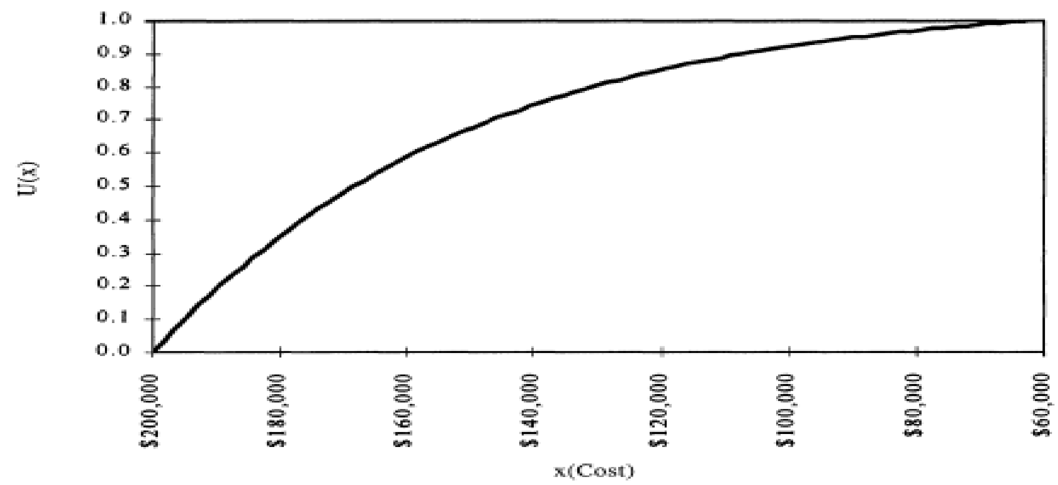
The MAUT function According to Keeney and Raiffa (1976), attribute i is defined to be utility independent of attribute j when the conditional preferences for lotteries on attribute i given the attribute j do not depend on the particular level of attribute j (p. 226).

There are many forms of MAUT functions that are theoretically valid; however, the multilinear utility function (la) is the most general form that is used with any regularity in applications of MAUT,

1) $U(X)=\sum_{i=1}^{n} wi\ ui\ (Xi) + \sum_{i=1}^{n} \sum_{j>i} wij\ ui\ (Xi)uj(Xj) + \sum_{i=1}^{n} \sum_{j>i} \sum_{m>j>i} wijm\ ui\ (Xi)uj(Xj)\ um\ (Xm)$

where X = (X1, X2, . . . Xj) is a vector of random variables over performance measures; n are the relevant atributes and preferences of decision makers for these atributes are represented by monoattribute utility function ui(.) for i = 1..n , U and ui (.) are normalized to be bounded between 0 and 1 (for 0 the worst possible value and 1 the best one); ui is a single attribute utility function over measure i that is scaled from 0 to 1, wi is the weight for measure i where 0 < wi < 1 for all i, and wij,,, are scaling constants that represent the impact of the interaction between attributes i, j, and m on preferences, for example. (Andre F.J, and Riesgo L., 2006)

**Utility Function for Cost of Project with $A_i = 1.064$, $B_i = 0.0195$, and $RT_i = 50{,}000$**

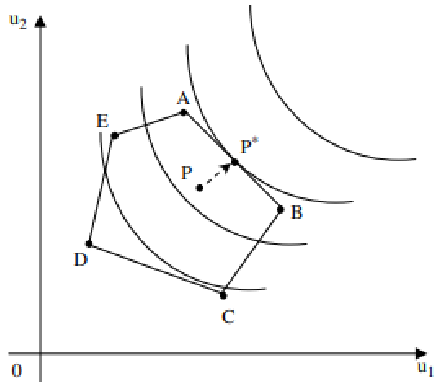



Once the existence of a MAUF is accepted, at least two important technical questions must be answered: first, a mathematical specification must be chosen and second the parameters of this function need to be elicited by some estimation or calibration procedure. Actually, both problems are strongly connected, because the availability of an elicitation procedure determines the selection of a specific function. In practice, most applied studies use linear specifications for MAUF because a linear function is easier to elicit and to interpret. One traditional way to elicit the parameters of the MAUF in applied studies is to use face-to-face surveys with DMs

To illustrate this idea, assume that a decision maker has a vector x of decision variables and two criteria over which his preferences are represented by two mono-attribute utility functions U(u1(x), u2(x) so that we postulate the existence of a multiattribute utility function U(u1(x), u2 (x)) fully known. For the decision maker the problem consists of choosing the value of x to maximize (3) subject to x 2 X, where X is the feasible set for the decision variables in x. The figure also shows the map of iso-utility curves of the decision maker (those combinations providing a fixed value of function U). If the decision maker is rational, the optimal solution will belong to the efficient set, which in this example is represented by segment AB. Specifically, the optimal decision is located at point P*, where an iso-utility curve (that one as far as possible from the origin) is tangent to the efficient set and the decision problem as the following auxiliary problem:

2) Max U(u1, u2 ) s.t  u1; u22 ∈AB; u1 + u2 <= b12

Fig Representation of a MAUT function: U = f(u1, u2) with a combination of two criteria generating two mono attribute utility function




The elicitation problem can be stated in the following terms: we can observe the decision actually made (in the example, point P*) and, typically, we also know the feasible set of attributes, from which we can construct, or at least approximate, the efficient set. Using this information we need to find a function such that the tangency condition holds exactly at the observed point P*. Given a specific parametric expression for U (u1,u2), the problem can be seen as finding the value of the parameters in this expression in such a way that the tangency conditions are satisfied at P* that represents the optimal combination of utility functions of attributes subject to .

Example

Assume the efficient set is given by the equation u1 + 1.5u2 = 1.9 and, by construction, the mono-attribute utility functions are bounded so that 0 ≤ u1, (u1 ≥ 0) and u2 ≤ 1. The condition above is satisfied: assuming u2 = 0,8, u1 = 0,7. Assume the following multiplicative power function for the MAUF:  U (u1; u2) = $(u1)^{w1} * (u2)^{w2}$ where w1, w2 are unknown parameters to be elicited. Assume, furthermore, that we can observe the decisions made by the decision maker providing the following values u1 = 0.7, u2 = 0.8, which can be understood as the solution for the problem of maximizing (2) subject to u1 + 1.5u2 = 1.9. From the first order conditions of the Lagrangean problem, we get u1/u2 = 1.5w1/w2 and, using the observed values for u1, u2, we can conclude that w2 = 12/7w1. Finally, using the common normalization w1 + w2 = 1, we get the estimates w1 = 7/19, w2 = 12/19.

Finding the optimal reference point

Ballestero and Romero (1991, 1994) showed that, under reasonable empirical conditions on the utility function, the compromise set can be interpreted as the piece of the efficient set where the utility function is maximized. The first step is to obtain the payoff matrix. If there are n criteria and fi(x) denotes the value of the ith criterion (i = 1,...,n) depending on the decision variables x, the first element of the first column in the payoff matrix can be obtained by optimizing f1(x) subject to all the relevant constraints. The optimal value f1(x) resulting from this problem, denoted as f *1 = f11, is the first entry of the payoff matrix. To obtain the other entries of the first column, we substitute argmaxf1(x) in fi(x), for i = 2,...,n. Let f * i denote the optimal value for attribute i and $f_{i*}$ the worst value for attribute i in the payoff matrix (i = 1,...,n). The vector containing the optimal The vector containing the optimal value for each attribute (f *1 ; ... ; f * n ) is known as the ideal point. The compromise set consists of that set of solutions which is as close as possible to the ideal point. the distance between each solution and the ideal point, we use the following family of distance functions Lh:

$$Lk = (\sum_{i=1}^{n} ((fi^* - fi(x)/fi^* - f_{i*})^h)^{1/n}$$ -

We propose to obtain the n solutions minimizing distances L1,L2,...,Ln1 and L1. Once these points have been obtained, we express them in terms of utilities by substituting each attribute into the mono-attribute utility functions.

See A non-interactive elicitation method for non-linear multiattribute utility functions: Theory and application to agricultural economics

Appendix 2

The criteria to evaluate negative externalities due to quality deterioration of these non market goods can be: i) direct using surveys typically the Contingent valuation (CVM) focused on one aspect of the good; people with face to face interview are asked their WTP for recuperate the original quality of the good. Another diffused method is the attribute based choice method (ABCM) methods that is multi-attribute valuation approach based on MAUT trying to value the different characteristics of such a good. Indirect method value public or non-market goods in analogy to market commodities by assessing the cost an individual incurs to utilize these goods. This cost is then interpreted as an individual's WTP for the public good (Hedonic Price Method (HPM), revealed preference method, stated preference (SP) methods rely on interviews in which people are asked hypothetical or contingent questions about their WTP or their potential utilization behavior in the future). Among the indirect methods, the HPM seems to be the most appropriate to our case. It is based on estimation of an hedonic price function which expresses the price of a public resource (water or air) as a function of its various attributes. Since it is estimated from market data it is supposed to represent market equilibria. The partial derivative of the hedonic price function with respect to one of the bundle of attributes leads to the implicit price of this attribute which indicates how much a buyer is willing to pay for its marginal increase (all other attributes remaining unchanged). This implicit price can also be interpreted as the individual marginal WTP for the respective attribute (e.g. clean water, land fertility, or land opportunistic use in production or recreation, GHG limit).