UNIVERSITÀ DEGLI STUDI DI MILANO
SCUOLA DI DOTTORATO
TERRA, AMBIENTE E BIODIVERSITÀ

Ph.D. in Agricultural Ecology
XXV Cycle

Development of expert systems for the mitigation of nitrogen pollution at farm and regional scale

Ph.D. Thesis

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Ph. D. Thesis
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Intensive agriculture and concentration of livestock activities represent critical factors in the environment, particularly in Lombardia region where nitrate vulnerable zones constitute 62% of Utilized Agricultural Area (UAA). In addition, the aquifer Po valley aquifer is one of the largest in Europe, for which it is estimated that over two-thirds of the nitrogen that reaches the surface and the subsoil is of agricultural origin. The problem of reduction of nitrogen losses into the environment, as leaching of nitrates into groundwater and ammonia emissions into atmosphere, can be only addressed through a critical and scientific analysis of manure entire production chain. As a consequence, the opportunity to develop software tools to analyze the current situation and the effects of possible scenarios arising from different regional policies relating to the release of nitrogen from agricultural sources. A decision support system (DSS) has been developed, to run simulation both at farm and territorial scale. The farm simulator is aimed at farmers and allows to analyze the management and technological alternatives available for the entire supply chain from animal feed to the distribution in the field for maximum utilization of the livestock waste. It is a free software downloaded from the website of the Lombardia Region, which collects the data of the structure and management of farm in the regional database; the speed of execution and the interface easily understandable make it "*user friendly*". The territorial simulator, available to

regional authorities, works on a regional scale it is completely resident on the web and allows the evaluation of the impact of any regulatory measures and incentives simulated from the agronomic, environmental and economic point of view. Below, has been analyzed the regional database and have been drawn up reference tables, were also collected, reviewed and made consistent models already existing and validated for the various phases of manure production. Were then assessed and defined the agronomic, plant and economic alternatives. The basic unit of simulation is made by the single cadastral parcel; in case of a territorial scale simulation model is applied to all the parcels of the sample selected. The DSS provides data both in detail and in the form of synthetic indicators. In the first months of activity the DSS at farm scale, introduced in November 2011, has been used by 200 users of which around 65% are professional agronomists and farmers of large companies; therefore it represents an important opportunity for the Lombardia agriculture to combine environmental protection with economic and technical sustainability.

Credits evaluation

Courses:

- Elements of statistics.
- Instrumental analysis.
- Biogeochemical cycles.

Attendance at international/national congress:

- 13th Italian Association of Agrometeorology Congress: Agrometeorologia nella gestione integrata dei sistemi agro-forestali dell'ambiente. 8-10 June 2012, Bari, Italy.

Oral presentation at technical workshop:

- Presentazione Sistema Esperto Valore. Regione Lombardia, 11 November 2011.
- Deroga Nitrati. Regione Lombardia – Brescia, 15 December 2011.
- Deroga Nitrati. Regione Lombardia – Mantova, 11 January 2012.
- Deroga Nitrati. Regione Lombardia – Milano, 26 January 2012

- Sistema Esperto Valore – alcune applicazioni. Regione Lombardia – Bergamo, 30 Junuary 2012.
- Agricoltura Conservativa. Coldiretti – Monza, 7 March 2012
- Agricoltura Conservativa. Condifesa – Brescia, 19 November 2012

Teaching activities:

- Training courses (16 hours) on ValorE software held by Ordine degli Agronomi di Milano.
- Practical lessons in Agricultural Ecology.

Poster presentation at international/national congress:

- Giussani A., **Alfieri, L.**, Provolo, G., Acutis, M. ValorE – Sistemi Esperti per la valorizzazione degli effluenti di allevamento, la salvaguardia ambientale e la tutela del territorio delle Lombardia. Proceedings of XLI Congress of the Italian Society for Agronomy, Bari, , 19-21 September 2012, 486-487.

UNIVERSITÀ DEGLI STUDI DI MILANO

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CONTENTS

Chapter 1

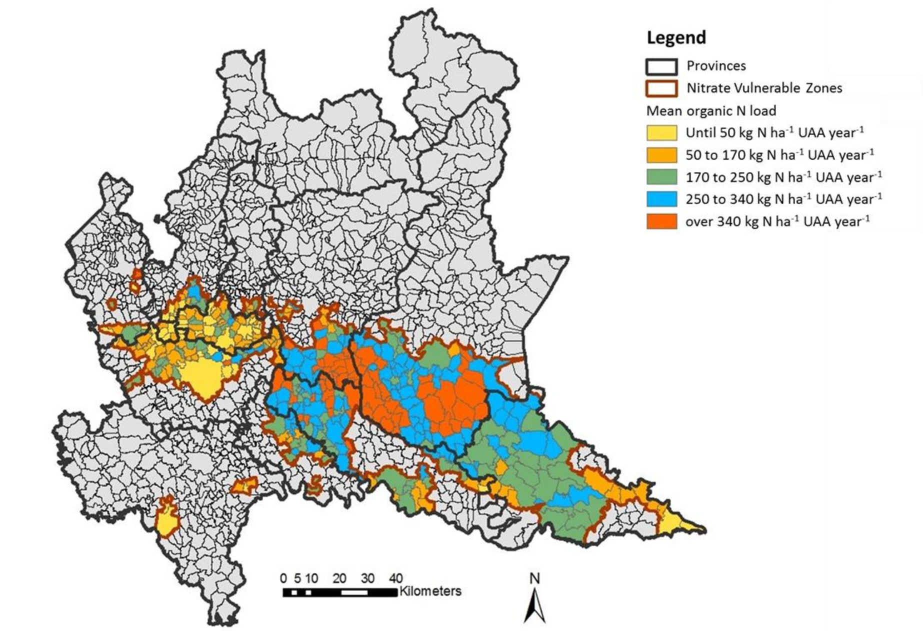
GENERAL INTRODUCTION

1.1 Which solution for a better livestock manure management in Lombardia region?

Livestock production determines serious environmental problems such as greenhouse gas (GHG) emissions, agricultural land use as grazing and feed production (Steinfeld et al., 2006) and emissions of reactive nitrogen (N) in atmosphere (Menzi et al., 2010) and water. These problems are getting much importance due to the stringent environmental targets required by the agricultural policies and regulations for preventing pollution of land, air and water.

The plain area of the Lombardia region (northern Italy) is characterised by an intensively managed agriculture with high livestock density and elevated use of production factors. Lombardia region accounts for a big part of the Italian livestock: in particular more than 27% of cattle and 45% of pigs. Animal manure is a source of valuable plant nutrients and renewable energy but also a potential problem for the environment and human health. In fact the Po Basin Water Board stated that more than two third of the N that reach the surface and the sub-surface water of the basin is determined by the livestock activities (AdBaPO, 2001). Sixty-two percent of the area is defined as vulnerable to nitrates (Regione Lombardia, 2006) that mainly included the areas with the highest organic N loads (Figure 1.1). Moreover the Po Valley is one of the major ammonia (NH_4^+) emitting regions of Europe, where the manure management causes high NH_4^+ volatilisation, reducing its agronomic value and becoming a potential cause of environmental concerns: in fact the agricultural sector account for almost 97% of the regional emission of NH_4^+ (Inemar, 2007).

Figure 1.1 – Nitrogen load (kg ha^{-1}) from livestock manure aggregated at municipality scale and vulnerable area to nitrates of the Lombardia region.



Recent studies have confirmed the potential impacts of the regional agricultural activities. Fumagalli et al. (2011) and (2012) highlighted the high use of production factors such as nitrogen, fossil energy and plant protection products to sustain animal and crop productions. Perego et al. (2012) reported how the intensive maize-based cropping systems based on the use of organic and inorganic fertilisers determine high risk of nitrate pollution as well as Carozzi et al. (2013a, b) showed how alternative low-ammonia emission techniques have to be prescribed during manure distribution on fields. However, nowadays is needed a whole farm perspective to deal with the environmental concerns due to livestock activities. The approach has to consider the strong links among feeding, housing, treatment processes, storage conditions and filed application practices along the manure management chain because it affects the soil, air and water quality, the crops growth and consequently the farm income. The selection of livestock manure management options is becoming a strategically important task that farmers and public policy makers have to face. As presented by Karmakar et al. (2010) several options of the manure collection, storage and land application are available. Yet, as discussed by Petersen et al. (2007) a variety of manure treatments with a specific target have been developed as well as improvements of the animal nutrition to control manure production and composition have been studied. Because of this, is necessary a support tool that could facilitate stakeholders and farmers on identification, evaluation, and selection of the suitable manure management option for a specific area and aim before investing money. In fact, each management has its advantages and disadvantages when considering environmental, agronomic, technical, energetic, cost and labour issues (Fumagalli et al., 2012).

A decision support system (DSS) is an interactive computer-based system or subsystem intended to help decision makers use communication technologies, data, documents, knowledge and/or models to identify and solve problems, complete decision process tasks with the overall objective of making well-informed decisions (Power, 1997). Several examples of development and application of DSSs in agriculture addressing a variety of domains, such as pest management (Perini and Susi, 2004), water management (Giupponi et al., 2005; Pallottino et al., 2005; Giupponi, 2007, Acutis, 2010) and nutrient management (Djodjic et al., 2002; Forsman et al., 2003; De et al., 2004), are available. DSSs specifically related to manure management are also available but as stated by Karmakar et al. (2007) most of them were developed with a focus on the nutrient management (De et al., 2004, De and Bezuglov, 2007). Only few DSSs consider the whole-farm manure management from the production to the land application providing support towards the choice of the suitable option. For example Karmakar et al. (2010) developed a specific DSS for swine farms of the Canadian Praires region: multiple combinations of management options can be evaluated considering different decision criteria such as environmental, agronomic, social and health, greenhouse gas emission, and economic factors. Even if the software MLCONE4 (Ogilvie et al., 2000) allows to evaluate alternative manure-handling systems of a greater number of livestock types (i.e. swine, dairy and poultry), it was specifically designed for Ontario Province's conditions.

The awareness of the environmental problem, of the requirement of the whole farm approach, and of the availability of tools to support decision making, led the Lombardia Regional Authority to fund the development of a DSS able to provide to stakeholders, such as policy makers, farmers and their consultants an assessment tool to evaluate different livestock manure management systems. The tool application under contrasting scenarios could allow for the identification of the best management which could be characterized by available techniques and technologies [Kropff et al., 2001; Ceplecha et al., 2004; Goodall et al., 2010].

An integrated decision support system is presented to be used for livestock farms in the Lombardia region (northern Italy) in order to address all the major components of manure management (production, collection, storage, treatment and land application) for a variety of livestock types. It was developed on the basis of the previous experience carried out in Provolo et al. (2005) to evaluate livestock manure management. The proposed system allows to conduct an integrated assessment at farm and territorial scale under a decision-making process. The DSS permits to know the current situation in terms of farm management systems being integrated with a regional database and to finally suggest management decisions. Several manure management options are available as well as the possibility to make changes at cropping system level. Stakeholders can evaluate management options through the results of a wide set of multidisciplinary indicators and visualise their spatial affects thanks to a coupled geographical information system (GIS).

1.2 Objective and organization of the research

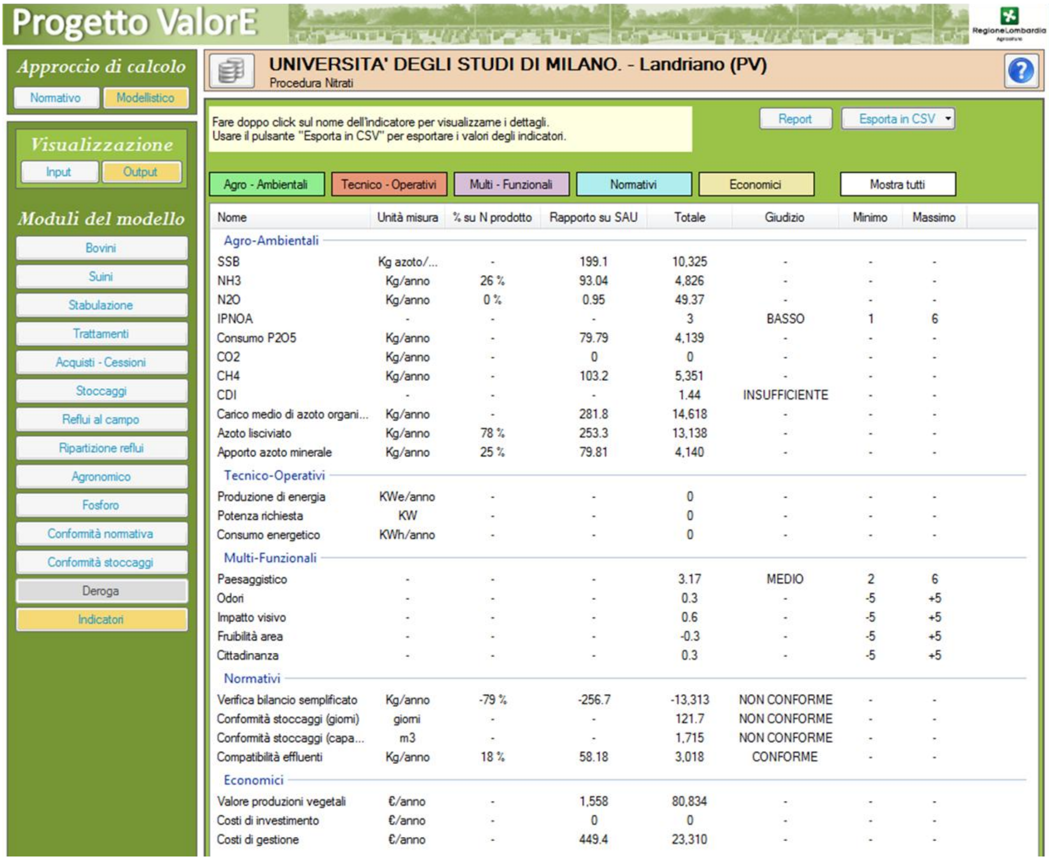
The objective of the present work is to present a DSS named ValorE which helps stakeholders (i) to find the best option in order to minimise the risk of environmental pollution (mainly from nitrogen), (ii) to valorise the organic manure from different livestock types in environmental, technical, agronomic and economic terms, (iii) to plan the building of new plants for the manure treatment, (iv) to evaluate the effects of new technologies and to check, *ante factum*, the possible effects of new policies. The work carried out with the collaboration of different experts to manage all the major components of manure management (production, collection, storage, treatment and land application) in a multidisciplinary and integrated approach, can be summarized in the following phases:

1. *Creation of the knowledge base of the DSS*: acquisition and analysis of the regional databases about (i) farm structure, (ii) meteorology, and (iii) pedological information and development a specific database containing default data derived from existing literature and farmers interviews about technical and agronomic management.
2. *Definition and development of the modelling*: for each component of manure management a specific model was developed. Then it was assembled the software that consists of different modular components relating a specific stage of the manure production process following the object-oriented programming (OOP) paradigm. The input data and the parameters of the model not included in the databases were obtained from literature.
3. *Definition of indicators*: to evaluate the actual and alternative management from a technical, agronomic, environmental, energetic, economic multi-functional and normative point of views a wide set of indicators

was selected. different alternative scenarios both at farm and territorial scale

4. *Definition of management options*: through intensive interactions among scientists a wide set of management options related to manure collection systems, manure treatments, storage facilities and manure land application as well as modifications at cropping system level were discussed and defined. Such recommendations for the users are useful to build a specific scenario both at farm and territorial scale.
5. *Improvement of DSS*: to get a better usability of the software, different aspects were carefully strengthened:
    - user-friendly interface: an easy management of the simulations at farm and territorial scale is guaranteed for all types of users (Figure. 1.2);
    - territorial simulation: the simulator is based on a WebGis interface;
    - farm simulation: the farm simulator can be installed and run on any computer no matter if internet connection is available;
    - data loading: the input data from databases are loaded in a short time (few seconds for each farm);
    - time of execution: the results of simulations are immediately available(few seconds for each farm);
    - normative compliance of the farms: possibility to check the respect of the limit values provided by regulations;
    - debug activities through intensive interactions with stakeholders.

Figure 1.2 – User - friendly interface of the ValorE DSS



1.3 Synopsis

Chapter 2 *(ValorE: a decision support system to enhance livestock manure management)* introduces the Valore DSS both as main software architecture and characteristics and main functionalities.

Chapter 3 *(Application of ValorE DSS in Lombardia region: case studia at farm and regional scale)* contains a detailed examples of application of ValorE in the Lombardia region (northern Italy – between 44°50'N and 45°50'N and 8°40'E and 11°80'E). Different management options at farm and territorial scale are described and the results are discussed.

Chapter 5 (*General discussions*) synthesises the results from the ValorE application. It focuses on the characteristics (novelty, advantages and limitations) of the proposed study and suggests the road for future researches.

1.4 Notes

All the maps exported from the software are in Italian language since it was not performed an English version.

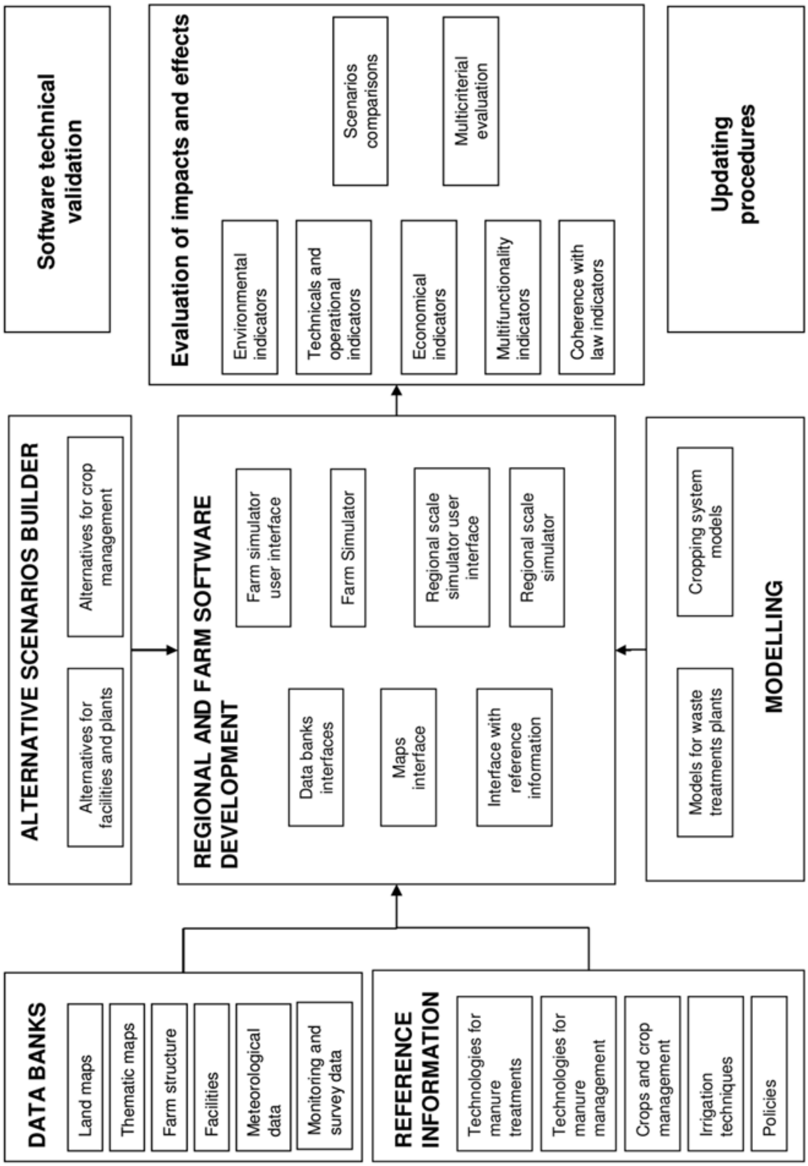
Chapter 2

VALORE: A DECISION SUPPORT SYSTEM TO ENHANCE LIVESTOCK MANURE MANAGEMENT

2.1 Introduction

ValorE is a user-friendly computer program developed to face with the livestock manure management that is becoming crucial in our region due to the strict environmental regulations. The DSS developed consists of three main parts: data management subsystem, model management subsystem and a user-interface. A simple representation of the DSS structure is reported in Figure 2.1. Different external databases provide the relevant information to DSS while a software package developed in the .NET environment and implemented using object oriented and component paradigm (Donatelli and Rizzoli, 2008; Donatelli et al., 2012) through the C # language, includes several linked models to simulate livestock manure management at farm scale, from the production by the herd to the land application. Two different types of a user-friendly interface allow to manage the simulation at farm and territorial scale. A linked GIS handles spatially distributed inputs and outputs of the DSS.

Figure 2.1 - Schema showing the general structure of the ValorE DSS



2.2 Databases and reference information

All the information to run the system is stored on available and wide databases, which are provided by Lombardia Government. Such regional data regard (i) farm structure, (ii) meteorology, and (iii) pedological information. Another database contains several tables of default data called thereafter "reference tables".

2.2.1 Farm structure

The database of the Agricultural Informative System of Lombardia Region (SIARL) contains a number of tables that are related to farms structure of the entire region. All the information is annually updated by farmers. In particular, farmers have to give details about the regulatory compliance on the matter of N management (Provolo, 2005) .

The database includes information on distribution of the animal herd in different age categories, animals housing, manure and slurry storage and treatment. Moreover, land use data of every cadastral plot are stored for each farm. Such information is fundamental for identifying the area allocated to the different crops over the years.

2.2.2 Meteorological database

The Lombardy Region has made available a twenty-year time series of daily meteorological data such as maximum and minimum temperature (°C) and precipitation (mm). The provided data were measured at 14 monitoring stations from 1989 to 2008, but measures are still undergoing (Figure 2.2).

Figure 2.2 - Map of the Lombardia region showing the 14 meteorological stations. The yellow points indicate the stations used, whereas red points indicate those in which radiation data are not available.

However, only 9 stations provide measured data of solar radiation for the period 2004-2008 (Table 2.1). The data reliability was firstly tested, and then the global radiation was estimated for all the 14 stations by using the model proposed by Bristow and Campbell [1994]. The model was first calibrated on the basis of 4 sites/20 years where global radiation was measured.

In detail the procedure used was the follow:

- Analysis of data reliability: for the stations where radiation data were available it was first check the number of missing data (Table 2.1).

Table 2.1 - Number of missing data of the solar radiation measured in the period 2004-2008 among the 9 selected stations.

Station	N° of missing radiation data
Bergamo	77
Castello	293
Ispra	902
Mantova C	305
Minoprio	293
Ostiglia Palidano	180
S. Angelo Lodigiano	202
Soresina Capalbra	80
Treviglio	1264

- Further data elaboration: considering that theoretically the clear sky transmissivity, τ is almost 0.72-0.75 in a sunny summer day we found values of transmissivity not accurate for central period of the year. Then for each station was counted the number of data over 0.70 and averaged the five highest atmospheric transmissivities between day of year 120 and day of year 240. Among the 9 stations were finally selected 5 stations characterized by the highest number of transmissivity data over 0.70 and by the mean of the five greatest transmissivity data over 0.71 (Table 2.2) for the calibration and validation of the models (Bechini et al., 2000) of solar radiation (Hargreaves, Bristow-Campbell and Donatelli-Campbell) and to choose the best one. Values of clear sky transmissivity over 0.85 were not never detected.

Table 2.2 - Number of transmissivity data over 0.70 and mean values of the five greatest transmissivity data between the 120° e 240° day of the year 2004.

Station	tt > 0.70	Mean value of the five greatest tt
Bergamo	0	0.67
Castello	0	0.68
Ispra	17	0.73
Mantova C	0	0.57
Minoprio	47	0.73
Ostiglia Palidano	38	0.71
S. Angelo Lodigiano	26	0.71
Soresina Capalbra	0	0.67
Treviglio	31	0.75

- Calibration of the models: the calibration of the parameters of each model was done for the year 2004 on trimonthly basis using the non-linear regression method of SPSS (first quarter: January-March; second quarter: April-June; third quarter: July-September; fourth quarter: October- December). The model proposed by Hargreaves and Samani (1982)estimate the daily actual radiation (*Rad*$_i$):

$$Rad_i = Kr \times RadP_i \times (Tmax_i + Tmin_i)^{0.5}$$

where $RadP_i$ as daily extraterrestrial radiation and *Kr* as empirical parameter calibrated by using measured data.

In Bristow-Campbell and Donatelli- Campbell the daily actual radiation is obtained by multiplying daily extraterrestrial radiation for a given day and latitude by the atmospheric transmissivity tt_i.

Bristow-Campbell (Bristow e Campbell, 1984) model estimates the actual atmospheric transmissivity (tt_i) using the clear sky transmissivity (τ) and daily maximum ($Tmax_i$) and minimum ($Tmin_i$) temperatures:

$$tt_i = \tau \cdot \left[1 - \exp\left(\frac{-B\Delta T_i^{\,C}}{\Delta T_m}\right)\right]$$

where $\Delta T_i = Tmax_i - (Tmax_i + Tmin_{i+1})$ and ΔT_m as average monthly temperatures and *B* and c are empirical parameters calibrated using measured data.

The model proposed by Donatelli and Campbell (1998) estimates the actual atmospheric transmissivity(tt_i) for the *ith* day of the year as a function of clear sky transmissivity (τ) and daily maximum ($Tmax_i$) and minimum ($Tmin_i$) temperatures:

$$tt_i = \tau \cdot [1 - \exp(-b \cdot f(Tavg) \cdot \Delta T_i^2 \cdot f(Tmin))]$$

where $Tavg = ½(Tmax_i + Tmin_i)$ and $\Delta T_i = Tmax_i - (Tmax_i + Tmin_{i+1})$. The functions $f(Tavg) = 0.017 \exp(\exp(-0.053 \times Tavg))$ and $f(Tmin_i) = \exp(Tmin_i / Tnc)$ are empirical, whereas *b* and *Tnc* are two location-specific parameters, which are calibrated by using measured data.

The estimates of the parameters are reported in Table 2.3.

Table 2.3 - Parameters calibrated for 2004 in four stations and for the three models used

	Model	Hargreaves	Bristow-Campbell		Campbell-Donatelli	
Station	Parameters	kr	B	c	b	Tnc
	1° quarter	0.144	0.032	2.460	0.693	28.588
Minoprio	2° quarter	0.140	0.026	2.484	0.672	29.181
	3° quarter	0.144	0.014	2.754	1.008	58.966
	4° quarter	0.109	0.302	1.282	0.429	14.258
	1° quarter	0.141	0.336	1.468	0.753	19.565
Ostiglia	2° quarter	0.151	0.050	2.327	0.775	23.214
	3° quarter	0.150	0.093	2.078	0.821	26.346
	4° quarter	0.140	0.344	1.378	0.980	35.930
	1° quarter	0.143	0.178	1.750	0.847	56.857
S. Angelo	2° quarter	0.155	0.091	2.111	0.955	29.275
Lodigiano	3° quarter	0.157	0.082	2.168	1.044	28.704
	4° quarter	0.127	0.302	1.364	0.802	35.131
	1° quarter	0.154	0.220	1.705	0.949	39.056
Treviglio	2° quarter	0.157	0.066	2.257	0.793	19.191
	3° quarter	0.161	0.027	2.628	1.300	41.271
	4° quarter	0.142	0.209	1.601	0.854	27.397

- Validation of the models: the validation was performed using data of three-year period (2005-2008) and the parameters previously selected. The simulated radiation was compared with that measured.
- Model evaluation: the results of statistical indexes (Table 2.4) used to evaluate the models performances indicate the Bristow Campbell model as the best one. Always for all the stations and for the six indices used in this evaluation, Bristow-Campell over performed respect to the other methods
- Use of the metereological information: a spatial interpolation was performed on the basis of the measured data to extend the meteorological information throughout the entire plain of the region by employing Thiessen polygon method.

Table 2.4 - Statistical indexes calculated in the validation procedure.

	Indexes	**R^2**	**Slope**	**RSME**	**RRMSE**	**MAE**	**EF**
	Optimal value	1	1	0	0	0	1
Station	Model						
	Hargreaves	0.829	0.768	3.505	25.383	2.793	0.823
Minoprio	**Bristow-Campbell**	**0.882**	**0.902**	**2.972**	**21.521**	**2.279**	**0.873**
	Donatelli-Campbell	0.869	0.824	3.120	22.592	2.450	0.860
	Hargreaves	0.885	0.829	2.882	19.780	2.280	0.881
Ostiglia	**Bristow-Campbell**	**0.907**	**0.915**	**2.587**	**17.760**	**1.939**	**0.904**
	Donatelli-Campbell	0.904	0.881	2.612	17.929	1.965	0.903
	Hargreaves	0.869	0.855	3.120	21.422	2.326	0.866
S. Angelo	**Bristow-Campbell**	**0.904**	**0.943**	**2.665**	**18.301**	**1.941**	**0.902**
Lodigiano	Donatelli-Campbell	0.899	0.910	2.729	18.738	1.932	0.897
	Hargreaves	0.844	0.792	3.494	23.362	2.531	0.826
Treviglio	**Bristow-Campbell**	**0.888**	**0.916**	**2.827**	**18.905**	**2.076**	**0.886**
	Donatelli-ampbell	0.873	0.838	3.156	21.107	2.295	0.858

2.2.3 Soil data

A digital soil map at scale 1:50000 is available, where 1038 soilscapes are defined and characterized by at least one soil profile. Soil physical and chemical properties, such as texture, structure, organic matter, pH, soil cation exchange capacity, derived from field and laboratory analysis are available for each horizon of the soil profiles down to 1.5 m depth. The soils are classified according to the WRB classification [FAO, 1998].

Soil data have been successively elaborated to manage the simulation within the agronomic module. To limit the number of simulation of the cropping system model and at the same time to maintain a clear representation of the results, all the regional soil types have been grouped.

A cluster analysis using the TWOSTEP CLUSTER procedure of SPSS which allows to use both qualitative and quantitative variables was carried out to identify homogeneous groups of soils. Also the number of groups is automatically determined by the procedure, using a index derived from the Akaike one (Akaike, 1974). The variables used for cluster analysis were considered for two layers (0-40 and 40-200 cm depth):

- D50 (mm): median particle diameter;
- Skeleton (%);
- Organic carbon content (%);
- saturated hydraulic conductivity (mm/h) estimated with Hypress (Wosten et a., 1998)

The characteristics of the three groups of soil individuated are presented in Table 2.5.

Table 2.5 – Main characteristics of the three groups of soil individuated from cluster analysis

Cluster		Clay (%)	Silt (%)	Sand (%)	Organic carbon (%)	Skeleton (%)	D50 (mm)	Bulk density (g/cm3)	Ks (mm/h)	Clay (%)	Silt (%)	Sand (%)	Organic carbon (%)	Skeleton (%)	D50 (mm)	Bulk density (g/cm3)	Ks (mm/h)
		1° layer (0-40 cm depth)								2° layer (40-200 cm depth)							
1	Mean	24.56	51.14	24.30	1.22	0.79	0.03	1.36	9.24	25.46	47.90	26.64	0.32	5.40	0.039	1.37	12.08
	Std. deviation	10.60	7.68	7.13	0.24	1.19	0.01	0.07	2.98	10.06	7.45	11.59	0.13	9.21	0.03	0.09	3.12
2	Mean	11.30	32.88	55.81	1.17	2.81	0.17	1.54	12.11	10.91	20.50	68.59	0.23	9.94	0.26	1.61	22.31
	Std. deviation	6.95	7.72	12.15	0.26	4.13	0.10	0.09	3.11	5.34	10.11	12.04	0.11	13.61	0.16	0.11	8.83
3	Mean	16.28	36.92	46.80	1.63	13.18	0.09	1.47	11.52	8.97	14.18	76.85	0.18	48.13	0.38	1.65	18.63
	Std. deviation	7.11	9.46	9.72	0.44	10.31	0.04	0.08	5.27	7.04	5.30	11.22	0.13	18.17	0.17	0.11	6.34

2.2.4 Technical and agronomic management data

Only a part of the information needed to run the DSS is directly available from the SIARL database, so that another database containing five reference tables of default data was filled. Default data derived from existing literature and farmers interviews are:

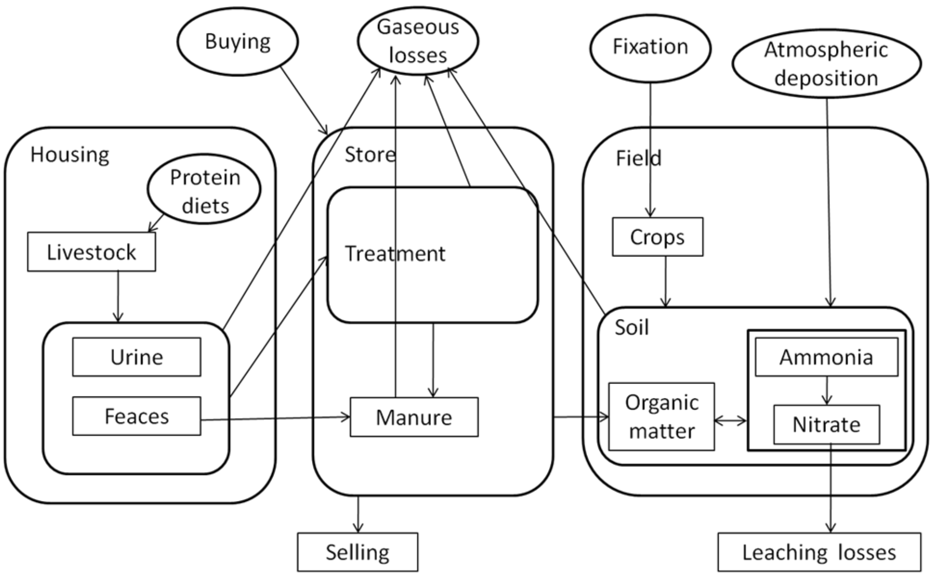
- techniques, functional and economic features of the available technologies used for the manure treatment;
- animals ration in terms of protein content on the basis of data reported by the Italian Breeders Association (AIA, 2010);
- prevalent crops of the regional arable land and related agronomic management such as sowing and harvest time, organic and mineral N supply (Regione Lombardia, 2010);
- irrigation techniques, frequency and water volume typical of the different area of the region;
- the current regulation on the matter of (i) NVZs definition, (ii) allowed timing of manure application, (iii) restriction of manure fertilization in particular areas such as riparian zones, protected areas, (iv) prescription for manure incorporation [Regione Lombardia, 2007]

2.3 Software development

The software has to meet a series of requirements in order to be helpful to stakeholders and easy to be updated. The main are both to be web based and installed and run on any computer avoiding specific hardware requirement, to be very simple to use (no more than 5 clicks to get to a complete analysis in agreement with the "three click rule" for user friendly and more impactful web disegn) and finally, to report simulation results both in maps and tabular form.

The intended purpose of the software is to simulate at farm scale each stage of livestock excreta cycle from excretion by the herd to the crop N uptake as well as the N cycle and losses occurring via leaching, and gaseous emission (volatilization and denitrification). Figure 2.3 shows the simulated N flows at farm level: flows related to (i) purchased animals, fertilizer, feed and bedding materials, and (ii) sold animals, milk, crops and fertilizer are not shown.

Figure 2.3 – Schema showing the simulated nitrogen flows at farm level (modified from Bertnsen et al., 2003)



The software consists of different modular components relating a specific stage of the manure production process and developed following the object-oriented programming (OOP) paradigm proposed by (Donatelli and Rizzoli, 2008; Donatelli et al., 2012). Each component allows for selection of strategies to simulate a specific process and each module results represent the input data the subsequent one (Figure 2.4).

The farm represents the simulation unit and the aggregation of farms allows the assessment of the potential risk for the environment at territorial scale under a specific scenario. In order to carry out such territorial analysis, a WebGis application was developed to elaborate a tabular and map based summary, at different aggregation scale (e.g. farm, hydrologic basin, municipality, county, region, NVZs, etc).

The software allows for different application under actual and alternative scenarios, taking into account eventual update of new technologies, crops or agricultural practices and future scenarios of meteorological data. Different scenarios can be evaluated and compared by synthetic indexes which take into account environmental, economic, technical, multifunctional and normative aspects.

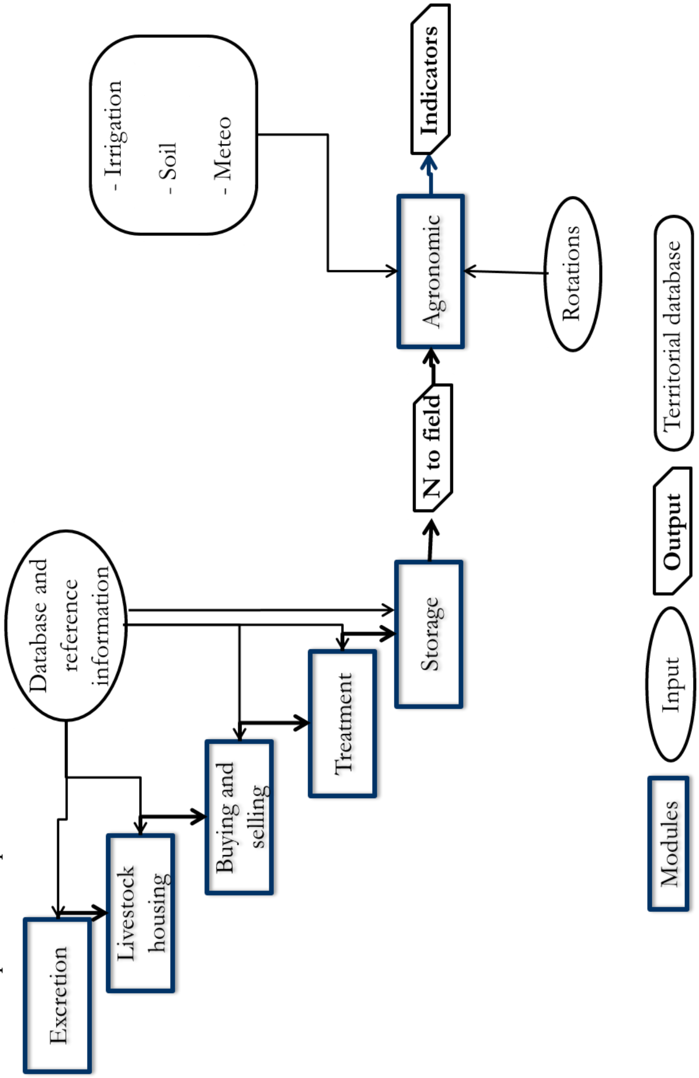


Figure 2.4 – Modular components of the DSS relating to each specific stage of the manure production process. Each module implements its specific simulation model.

2.3.1 Excretion module

In order to evaluate the impact of the different livestock rations on urine and faeces excreted by cattle and swine the dynamic of N and P content was simulated as a function of feed intake. In the analysis, the dairy cattle, beef and pigs breeding were considered as the main source of production of slurry in the Lombardia.

With regard to cattle, the model allows to estimate separately for urine and faeces the amount of N and P excreted by quantifying first the amount of manure. For dairy cattle, the excretion is computed by a sub-model from the following input variables: (i) the body weight of lactating dairy cows, dry cows, heifers and calves (ii) the milk production level, (iii) milk fat and protein content, (iv) the dry matter intake, (v) and the protein content of feed. In particular, the dry matter intake is calculated by using the equation proposed by the National Research Council of USA (2001). The model produces the following outputs data: (i) the excreted products as fresh matter (kg FM d^{-1}), calculated according to Nennich et al. (2005), (ii) urine and its N content (kg d^{-1}), calculated according to Fox et al. (2004), (iii) the amount of faeces, calculated as difference between the total excreted products and urine (kg d^{-1}), (iv) the N faeces content, computed as difference between N intake and urine and, v) the milk N content (kg d^{-1}). The model developed for the pigs simulation estimates the excreted amount of N, P and K according to van Milgen et al., 2003; Le Bellego at al., 2001; Pomar et al., 1991a; Pomar et al., 1991b; Pomar et al., 1991c. Such amounts are divided in solid and liquid fraction as a function of the body weight, the daily rate of body weight increase (kg d^{-1}), the feed, protein and P intake (kg d^{-1}), the protein and P digestibility (%) and the feed-to-grain conversion index.

For other animal species such as, poultry, sheep, goats and horses, the excretion was estimated as a fixed percentage of live weight, as recommended by existing legislation (Regione Lombardia D.g.r. November 21st 2007 n. 5868).

2.3.2 Manure storage and treatment module

Slurry is subjected to chemical and physical modification with relative gaseous losses to the atmosphere. For each stage of the storage and treatment process the slurry module simulates the amount of slurry mass and its N and P content. Moreover, it allows for the assessment of the feasibility of alternative techniques in plant management.

The input data of the slurry storage and treatment module are: (i) chemical and physical composition of the excreted products expressed as (kg DM (Dry matter), kg FM, faeces TKN (Total Kjeldhal nitrogen) content, urine TKN and P_2O_5 content in faeces and urine), (ii) the litter fraction of the manure, and (iii) the rainfall. The effect of the typology of livestock housing is simulated according to Fulhage and Pfost, (1993), Kroodsma et al.(1993) and Ogink and Kroodsma, (1996). The effect of different types of slurry storage is simulated according to Amon et al. (2006), Espagnol et al. (2008), Ni et al., (2009) and Vanderzaag et al. (2009). Both conventional and non- conventional treatments are considered in the module: solid-liquid separation [Christenesen et al., 2009; Hjorth et al., 2009; Jørgensen and Jensen, 2009; Dinuccio, et al., 2008; Fangueiro et al., 2008a; Fangueiro et al., 2008b; Sørensen and Møller, 2006], anaerobic digestion with biogas and energy production [Amon et al., 2007; Biswas et al 2007; Lubken et al., 2007; Karim et al., 2005], ammonia stripping [Lei at al., 2007; Bonmatì and Flotats, 2003], nitrification and denitrification [Castrillon et al., 2009; Rousseau et al., 2008; Waki et al., 2007; Obaja et al., 2003], aerobic stabilization [Beline et al., 2007; Loyon et al., 2006] and composting [Fukumoto and Inubushi 2009; Szanto et al., 2007; Paillat et al., 2005].

The slurry module calculates: (i) the final volume of the stored slurry, (ii) the final chemical and physical composition, (iii) the solid and liquid fraction, (iv) gaseous losses to the atmosphere, and (v) the eventual production of biogas for the anaerobic digestion plants.

2.4.3 Agronomic module

The agronomic module is based on the crop simulation model, ARMOSA (Acutis et al., 2007). However, due to the long computational times required the efficacy of process-based models in a large scale is questionable. Therefore, we used a meta-model that can provide almost the same results as the original model at a lower computational cost.

2.4.3.1 The cropping systems simulation model ARMOSA

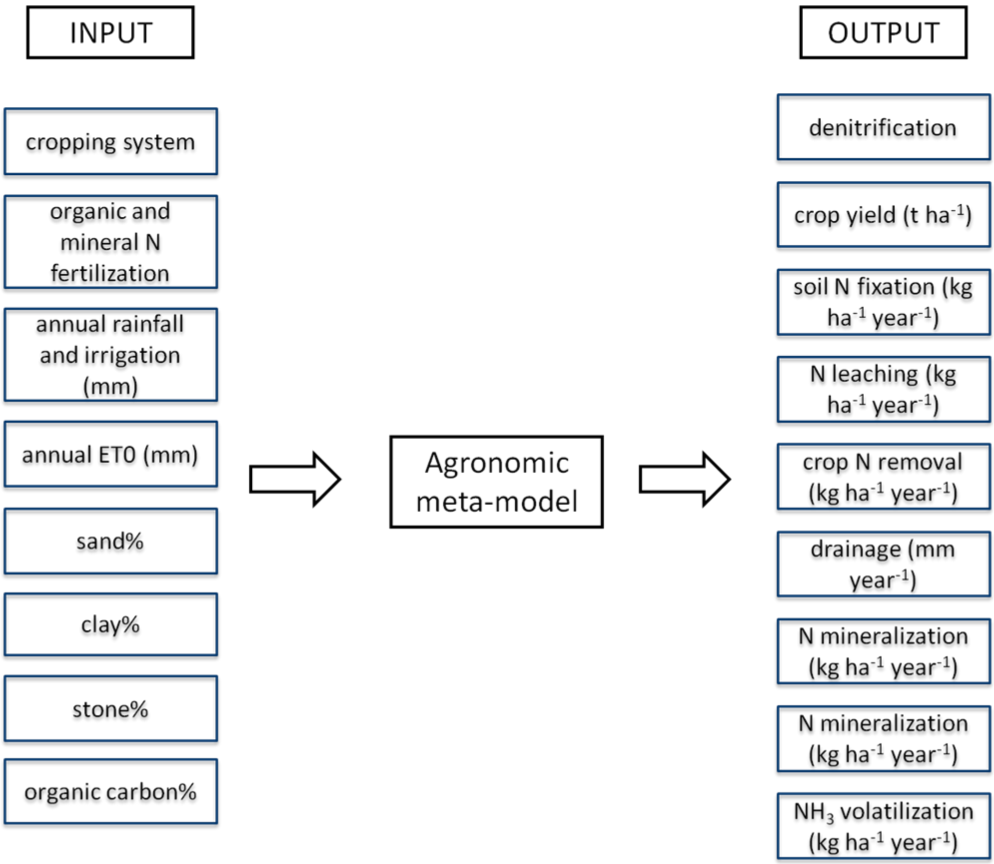
ARMOSA model simulates crop growth, water and nitrogen dynamics in arable land, under different climatic conditions, crops and management practices. It is a simulation model specifically developed on the basis of field data and implements approaches largely validated in the scientific literature and used for practical application. Crop growth model development was based on SUCROS – WOFOST (a photosynthesis-based model from Wageningen school, used, among others application, at European scale for the Bulletin of yield prediction for wheat, maize and other important crops (Supit et al., 1994; van Ittersum et l., 2003). Water dynamics can be simulated using the cascading approach, or the Richards' equation, solved as in the SWAP model (Van Dam et al., 1997; Van Dam and Feddes, 2000). The SWAP appeared to be the best performing one with very detailed soil moisture data set in 6 typical soils in Lombardia (Bonfante et al.; 2010, Perego et al., 2012). Nitrogen dynamics is simulated according to the SOILN approach (Johnsson et al., 1987; Eckersten et al., 1996), but with some improvements. In SOILN only three pools of organic and mineral nitrogen are simulated: humus, litter, manure, while in ARMOSA each type of organic matter has been differentiated with reference to mineralisation rates, respiration losses and C/N ratio, allowing for separate calculations for the different types of organic fertilisers or crop residuals incorporated into the soil. Depth of incorporation is also taken in account. As in SOILN, NH_4^+ and NO_3^- pools are considered; NH_4^+ pool can be up taken by plants, oxidised to NO_3^-, fixed by the clay component of the soil, and immobilised in the organic matter; losses due to ammonia volatilisation are also simulated. NO_3^- pool is subject to plant uptake, leaching and denitrification. Several options to use for medium-long time simulation are included: it is possible to define sowing and harvest DOY (day of the year), crop rotation, automatic irrigation, set of fertilization. Another improvement respect to SOILN model deals with plant nitrogen uptake; in SOILN this process is based just on the amount of transpiration mass flow of NH_4^+ and NO_3^-, whereas in ARMOSA crop uptake is also calculated on the basis of minimum, critical and maximum N dilution curve. Soil temperature is also simulated, according to the Campbell (1985) approach. ARMOSA model was calibrated and validated using a large dataset consisting of 3500 SWC daily data of soil profile from 0.8 to 1.3 m depth (Bonfante et al. 2010), soil solution N concentrations, N leaching and crop growth and N uptake data (Perego et al., 2012).

2.4.3.2 The agronomic meta-model

The need to operate on a territorial scale involves the use of the meta-model, once developed on the basis of the ARMOSA model. Such procedure represents an easy approach, quick in generating results of N losses and crop yields under different cropping systems, management and pedo-climatic conditions. The meta-model was developed on the basis of the examples provided by the literature (Forsman et la., 2003; Gandolfi et al., 2010). It was performed starting from the results of 70.000 simulation under different scenarios of cropping systems in Lombardia. In particular, the agricultural management was defined in function of the farm type and the pedoclimatic conditions of the region. The different pedological conditions, for example, resulted by using a cluster analysis previously described (paragraph 2.3.4) as function of D50 value, stone and organic carbon content along soil profile of 2 m depth. The meta-model development started with the sensitivity analysis

(Morris, 1991; Saltelli et al., 2005) of the input variables on the ARMOSA output in order to finally reduce the input data. The input meta-model are: crop yield (t ha^{-1}), N leaching (kg ha^{-1} $year^{-1}$), crop N uptake and removal (kg ha^{-1} $year^{-1}$), drainage (mm $year^{-1}$), N mineralization (kg ha^{-1} $year^{-1}$), ammonia N volatilization (kg ha^{-1} $year^{-1}$), denitrification (kg ha^{-1} $year^{-1}$), soil N fixation (kg ha^{-1} $year^{-1}$). For different crops, such as silage and grain maize (Zea mayze L.), winter wheat (Triticum aestivum L.), alfalfa (Medicago sativa L.), permanent meadow, foxtail millet (Setaria italica L.), and Italian ryegrass (Lolium multiflorum L.), a multiple linear regression was calculated by applying the stepwise method in order to identify the significant factors in determining N leaching, volatilization, crop N uptake, and crop yield, with average R^2 of 0.52. The meta-model input and output variables are reported in Figure 2.5.

Figure 2.5 – Input and output variables of the agronomic meta-model.



2.4 Tasks of the DSS

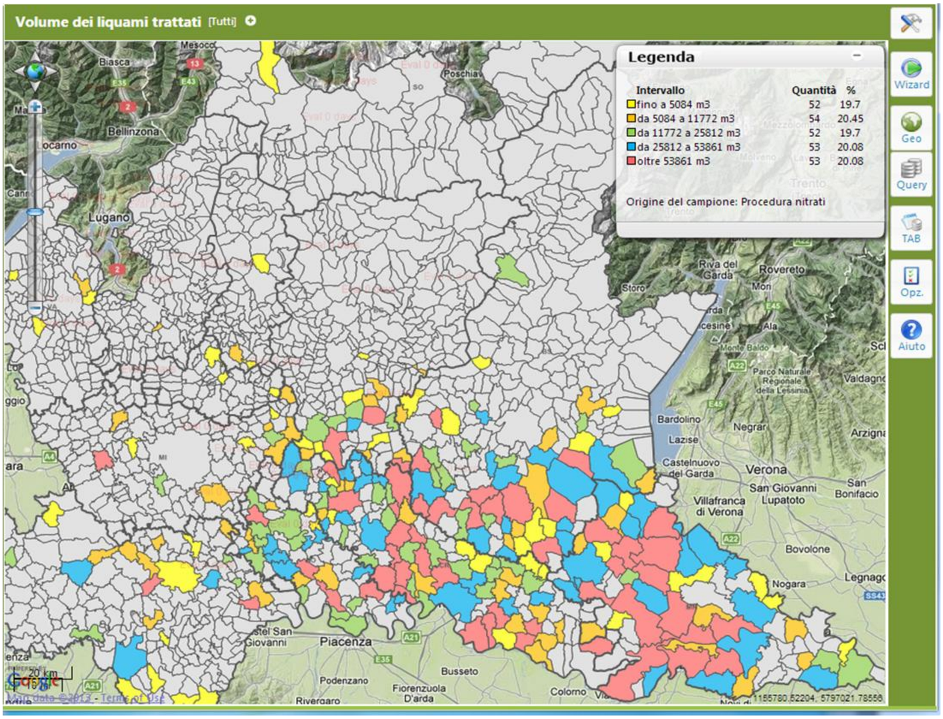
The ValorE DSS allows to evaluate the effects of the livestock manure management at farm scale and the possible consequences in the spatial domain. First, its offers a possibility to know the current perspective in terms of manure management system and related aspects at farm or territorial scale by interrogating the available databases through a query function. Then it is possible to enhance the N management generating different alternative scenarios both at farm and territorial scale, thanks to an extensive choice of management options. Changes can be focused on manure management system and on cropping system characteristics. Actual and alternative scenario sustainability can be evaluated and compared by using indicators. Moreover a specific tool of the DSS makes possible to investigate the effect of policy measures.

2.4.1 Query task

The software offers a possibility to get an instrument for an easy interrogation of the regional databases. Both predefined and free queries can be done and the results are available in exportable reports (Excel or PDF format).

The query system is based on a WebGis interface, to help the users to obtain aggregated information for specific geographic areas (e.g. whole region, provinces, municipality, farms etc..). Thus, it makes possible to obtain a general perspective of the farming systems characteristics including the potential and critical environmental issues related to the manure management. The query procedure involves, first, the selection of the aggregation level to finally present the results (i.e. farm, municipality and provinces) and, second, the selection of the geographic area of interest (e.g. one or more municipality). Both free and predefined queries are related to several domains: animals herd, animal housing, manure storage, manure treatments, cropping systems, economical and mechanization aspects, policies aspects (e.g. normative compliance of slurry storages) and pedo-climatic characteristics. The predefined query option provides a set of about 40 queries previously selected as relevant by a group of experts and stockholders: in this case the user has the possibility to change the parameterization of the query itself (e.g. selection criteria of several queries could be farm area, the number of the livestock units, the typology of housing, the soil type etc.). A free query can be written using a query generator developed ad hoc to simplify the access to the database, or directly using SQL. An example of free query is reported in figure 2.6.

Figure 2.6 – Example of free query operated on regional database using ValorE software: annual volume (m^3) of treated liquid manure on regional farms. Results are aggregated at municipality scale.



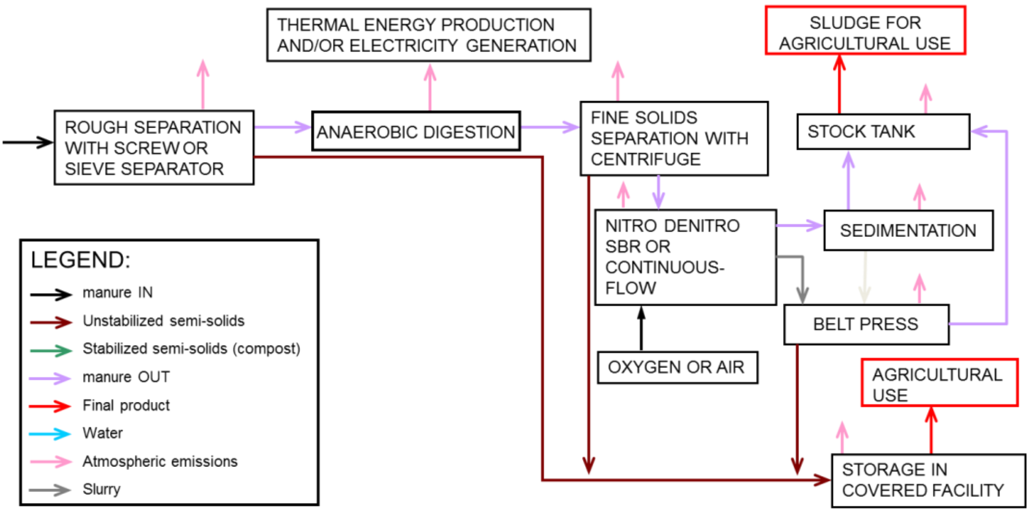
2.4.2 Alternative scenarios generator

The user can quickly generate many different alternative scenarios by choosing options related to manure collection systems, manure treatments, storage facilities and manure land application methods. Moreover to enhance the manure and relative N management changes at cropping system level can be done. As example a list of the available solutions in term of livestock manure treatment with their specific objective is reported in Table 2.6 for each manure type. To simplify the choice of the users each alternative is detailed through a flow chart as reported in Figure 2.7.

Table 2.6– List of the manure treatment options and relative objective.

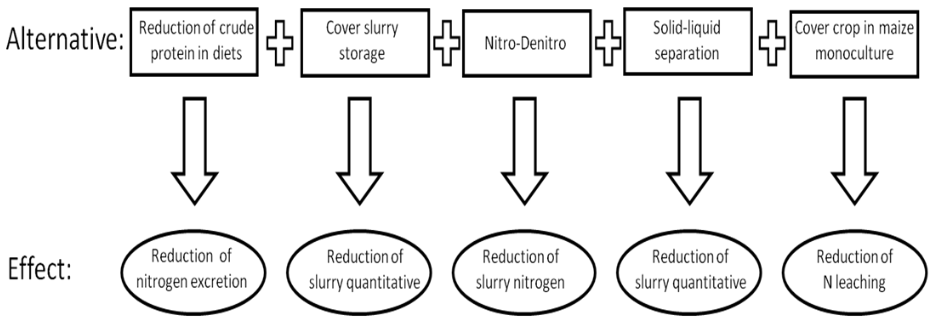
Liquid manure treatment	
Option	Objective
1	Reduction of the volume of liquid manure
2	Composting and export of the solid fraction from the farm
3	Biogas production
4	Biogas production and composting of the digestate
5	Biogas production and nitrogen removal
6	Biogas production and high-strength nitrogen removal
7	Biogas production and mineral nitrogen recovery
8	Nitrogen removal
9	High-strength nitrogen removal
10	Reduction of the odour emission
Solid manure treatment	
Option	Objective
1	Composting
2	Biogas production
3	Biogas production and composting
4	Biogas production and nitrogen removal
5	Biogas production and high-strength nitrogen removal
6	Biogas production and mineral nitrogen recovery
Solid and liquid manure treatment	
Option	Objective
1	Reduction of the volume of liquid manure and composting of the solid fraction
2	Biogas production
3	Biogas production and composting of the digestate
4	Biogas production and nitrogen removal
5	Biogas production and high-strength nitrogen removal (forced)
6	Biogas production and mineral nitrogen recovery

Figure 2.7 – Liquid manure tretament - Option 6: decrease of storage volumes, reduction of time and costs for transportation to the fields, thermal energy production and/or electricity generation, high-strength nitrogen removal.



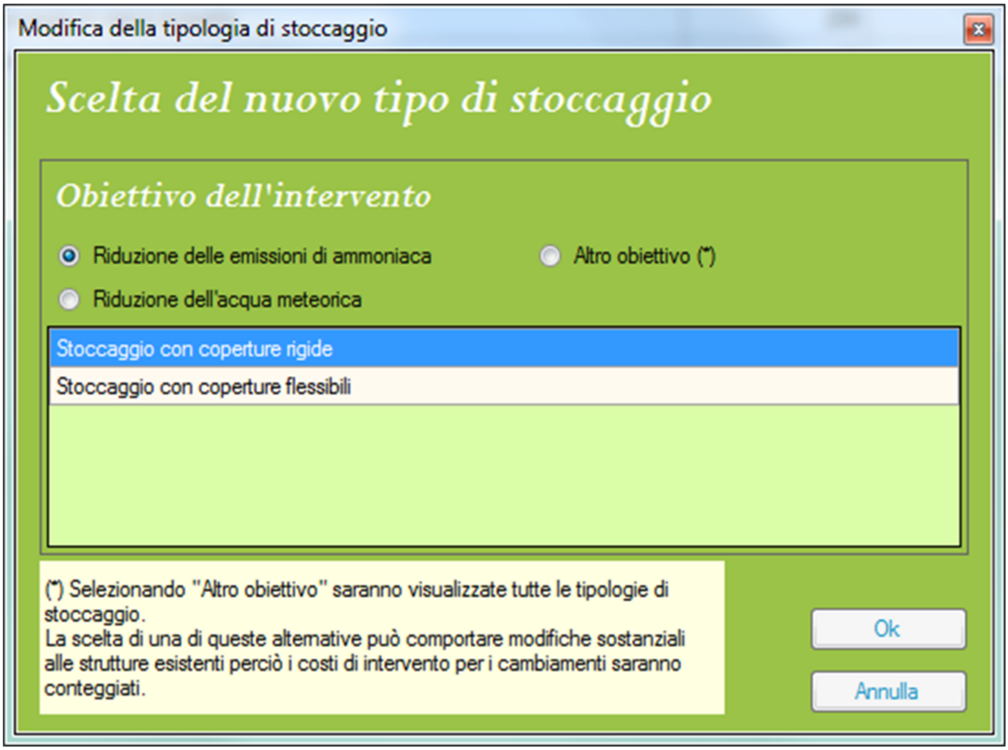
The farm simulator allows to create management options at farm scale by modifying several inputs, such as i) number of LSU, protein content in animal ration and the daily weight increase rate (kg d^{-1}), ii) livestock housing (e.g. straw based or slurry based tying stalls), iii) manure treatment (solid-liquid separation, anaerobic digestion with biogas and energy production, ammonia stripping, nitro-denitro process, aerobic stabilization and composting), iv) manure storage features (i.e storage and covering types), v) type and timing of manure application on the basis of calculated fertilisation plan, vi) cropping systems (e.g. changes in the crops rotation by introducing new crops and cover crops and vii) fertiliser management scheme. An example of alternative scenario in which a combination of 5 alternative managements is adopted in order to improve N management at farm scale is shown in Figure 2.8.

Figure 2.8 – Possible combination of 5 alternative management options and their effect on the improvement of the N management at farm scale.



Through the webGis interface new scenarios at territorial scale can be generated by introducing alternative agricultural management in a selected sample of farms. The range of options available for the users is not wide as at farm scale. The territorial simulator allows to define alternative management only related to four domains such as animal housing, manure treatment, storage facilities and cropping systems. In the case of cropping system and manure treatment domains the users can select directly the management options. For example, the method of manure distribution or the introduction of a cover crop and several manure treatments types (e.g. the solid-liquid separation, the biogas production). On the opposite, in the case of animal housing and manure storage domains the DSS provides different management options on the basis of the final aim selected by the users, namely the reduction of manure amount excluding rainfall water or the reduction of ammonia emission (Fig. 2.9). However, the software controls ensure that adopted management is in agreement with current regulation and farm characteristics. For example a particular type of treatment requires a minimum volume of manure to be functional. Either the crude protein content of the animal diet has to be included in a default range of values. Scenarios evaluation at regional scale is obtained by aggregating farms sample results. In fact, the software application at regional or municipality scale allows stakeholders to simulate the environmental impact of possible normative intervention and technical innovations as for example the implementation of plants cooperative for slurry storage and/or treatments (e.g. biogas production, solid/liquid separation and composting) that could be used by different farms of the same area.

Figure 2.9 – Software screen relatively the selection of the objective to reach through the covering of livestock manure tanks and the type of cover. Objective: ammonia emission reduction (riduzione delle emissioni di ammoniaca) or reduction of the manure volume excluding rainfall water (riduzione acqua meteorica). Cover type: storage with rigid cover (stoccaggio con coperture rigide) of storage with flexible cover (stoccaggio con coperture flessibili).



2.4.3 Indicators

The evaluation of actual and alternative scenarios and their comparison is computed with the software through the calculation of a wide set of indicators. They are a synthetic representation of the implications on technical, agronomic, environmental, energetic, and economic aspects due to the adoption of a particular management. The major part of indicators are quantitative, however, some of them, are expressed with a qualitative scale as bad, fair, good, excellent. The complete list of indicators is reported in Table 2.7.

Table 2.7 – Indicators calculated and used for the evaluation of sustainability of the manure management options.

Agro-ecological indicators	Units	Reference
NH_3-N volatilization	kg N year^{-1}	EEA Report N° 6/2006
N_2O-N emission	kg N year^{-1}	EEA Report N° 6/2006
CO_2 emission	kg N year^{-1}	EEA Report N° 6/2006
CH_4 emission	kg N year^{-1}	EEA Report N° 6/2006
NO_3-N leaching	kg N year^{-1}	
P_2O_5 erosion	kg P year^{-1}	Renard et al. (1997)
Soil surface N balance	kg N year^{-1}	Oenema et al. (2003)
IPNOA	Score from 1 (low risk) to 6 (high risk)	Padovani and Trevisan (2002); Capri et al. (2009)
Crop diversity indicator	Score from 0 (worst case) to 10 (best case)	Bockstaller and Girardin (2000)
Technical indicators		
Power installed	kW	EEA, Renewable gross final energy consumption
Energy requirement	kWh year^{-1}	(ENER 028) - Assessment published Jan 2011
Multi-functional indicators		
Odour emission		
Visual impact		
Territorial accessability	Score from -5 (worst case) to +5 (best case)	Environmental Resources Management (1998). A Handbook on Environmental Assessment of Regional Development Plans and EU Structural Funds, Programmes, European Commission, Bruxelles
Citizenship feedback		
Normative indicators		
Compliance of slurry storage	kg N year^{-1}	Regione Lombardia (2007)
Compliance of N-manure applied	kg N year^{-1}	EEC (1991)
Calculated N balance	kg N year^{-1}	Regione Lombardia (2007)
Economic indicators		
Variable costs	€ ha^{-1}	Castoldi and Bechini (2009)
Gross income	€ ha^{-1}	Castoldi and Bechini (2009)
Gross margin	€ ha^{-1}	Castoldi and Bechini (2009)

Several indicators are related to agro-environmental aspects such as (i) CO_2, CH_4, NH_4^+, N_2O gaseous emissions to atmosphere, (ii) the crop prevalence at farm or regional scale (Crop Diversity Indicator, CDI, Bockstaller, 2000), which estimates cropping systems impact on biodiversity and landscape in terms of crops allocation and field size, (iii) the soil surface N balance (Oenema et al., 2003) that compares the difference between ingoing and outgoing N fluxes through the soil surface N balance indicating the potential N surplus at field scale and, (iv) the agricultural nitrate hazard index (IPNOA, Padovani and

Trevisan 2002, Capri et al., 2009) which summarizes the results of N supply, soil nitrogen content, meteorological condition, agricultural practices and irrigation adopted.

Multi-functional, normative, and technical indicators, such as power required and energetic consumption of slurry treatments, assess the compliance of farm and/or region of mandatory standards related to nitrate leaching towards groundwater.

Economic indicators show the benefit of the adoption of new management and technologies, at farm and regional scale.

For the actual scenario, all indicators are already calculated for the entire regional area and stored in a database to reduce computational time in what-if analysis.

2.4.4 Multi-criteria analysis

To identify the optimal or compromise solutions that take into account the farming system characteristics, the agronomical, social, environmental and economic objectives as well as the expectations of the stakeholders involved, a subsequent multi-criteria analysis has to be performed on the basis of weighted sum of a subset of the indicators. Relevant indicators and their weights can be obtained by expert elicitation. An on-going work is the implementation of a multi-criteria analysis module based on the Meacros software (Mazzetto et al., 2003). This software performs concordance analysis providing preference rankings for the alternatives based on computed indices and allowing sensitivity analysis of weighted values as well as displaying the results in the graphic form.

2.4.5 Model validation, updating procedures and stakeholders interaction

The model validation step is an on-going procedure carried out by a group of potential users such as, agronomists and technicians of the Italian farmers organizations. Twenty farms have been identified as representative of the entire regional area by applying selection criteria (e.g. farm belonging the nitrate vulnerable area, minimum agricultural area equal to 35/40 ha, number of animals over 150 and 2000 for cattle and swine, respectively) to get real data through farmer's interviews. This let us to estimate the reliability of the model, to detect weaknesses of the system and to do a general improvement of the application usability.

Databases are updated to acquire the latest reference data available for a state. The SIARL database is annually updated with the new information provided by the farmers as well as meteorological and soil databases could be refreshed if new information is available. The knowledge base could be modified with changes in regulations and/or new scientific achievements (e.g. parameters for crop modelling). Variations of the raw materials price such as energy, fertilisers and crop products are also taken into account.

Following the indications provided by the literature that reports the importance of the participatory processes on DSS' success (Van Meensel et al., 2012) we are currently involving stakeholders that actively collaborate to test it on real cases, to debug and propose new software features and improvement.

Chapter 3

APPLICATION OF VALORE IN LOMBARDIA REGION: CASE STUDIES AT FARM AND REGIONAL SCALE

3.1 Introduction

As described in the chapter 2 ValorE was developed to face with livestock (mainly cattle and swine) manure management that is becoming crucial in our regional agricultural domain due to the strict environmental regulations. Being a software that consists of different modular components each specific stage of the waste production process is simulated. It starts considering the manure production as a function of animal diet, to its final distribution on field and their productive and environmental consequences. The software allows simulation both at farm and territorial scale. The farm scale simulator lets to individuate the more sustainable farm management to reduce environmental impact (mainly nitrogen feature) and to valorise livestock manure. The territorial scale simulator allows, starting from the current state, to analyse the effects of the hypothetical implementation of alternative managements following a multidisciplinary approach. The actual farm configuration was labelled as "actual scenario" (ACT) while the hypothetical farm configuration is labelled as "alternative scenario" (ALT). In the present chapter are presented and discussed some examples of application of ValorE both at farm and regional scale. A variety of alternative management options are theoretically implemented and consequences on nitrogen management are highlighted. At farm scale are analysed two example of interventions and two scenarios in which a combination of alternative managements is adopted. At regional scale are first presented some examples of queries with which users can interrogate the database available, then alternative managements in a selected sample of farms are discussed.

3.2 Application of ValorE at farm scale

3.2.1 Selection of the farms

Each intended decision on farm management or structures requires a specific objective other than to know the potential implications on technical, agronomic, environmental, energetic, and economic aspects. To provide some examples of application of the tool at farm level four farms have been identified on the basis of technical and production characteristics and of pedo-climatic features. The farms represent four typologies of livestock farms such as dairy farm, beef cattle farm, swine farm and a mixed farm with dairy cows and pigs. All the farms belong to an intensively cultivated area of four different Provinces and their dimension is large enough to guarantee an interesting assessment. Moreover all the farms are located on nitrate vulnerable zone and the high amount of livestock manure produced do not allow to respect the limit of 170 kg per year/hectare of nitrogen from organic fertilisers. The selection of the characteristics of the farms was carried out using the "query" function.

The simulation of the actual farm configuration was done using input data from the regional databases updated at 2011 and from reference information obtained from literature and regional regulations. The principal characteristics of the farms and the results of simulation about N flows highlighted as indicators mainly related to nitrogen managements are summarized in Table 3.1.

Table 3.1 – Characteristics of current management of the selected farms

	Units	Swine Farm	Dairy farm	Beef Cattle farm	Dairy and swine farm
Number of cattle	N.		565	2,133	255
Number of pigs	N.	8,200			1,332
Utilisable agricultural area	ha	177	130	169	88
Area vulnerable to nitrates	ha	177	130	169	88
Cropping systems					
Grain maize	ha	177	=	169	=
Silage maize	ha	=	72	=	11
Permanent meadows	ha	=	45	=	28
Alfalfa / grain maize	ha	=	13	=	=
Winter wheat/grain maize	ha	=	=	=	49
N excreted by herd	kg N	89,784	56,829	83,220	42,361
N purchased	kg N	0	0	0	0
N sold	kg N	0	5,432	0	5,824
N volatilised from stable	kg N	14,747	5,390	12,944	5,254
N volatilised from treatment	kg N	0	0	0	0
N volatilised from storage	kg N	11,805	6,532	10,429	5,241
N volatilised from spreading	kg N	3,797	2,586	2,788	1,601
Total N volatilised	kg N	30,349	14,508	26,161	12,096
N distributed on field	kg N	63,232	39,475	59,847	26,042
N distributed on field	kg N/ha	357	305	355	294
Mineral N applied	kg N	14,000	11,850	0	7,550
N leaching	kg N	20,397	32,664	23,473	15,684
N uptake	kg N	48,453	31,157	37,167	21,848
Maximum N applicable on field	kg N	30,090	22,015	28,662	15,037
Compliance with N limits	kg N	NO	NO	NO	NO
Storage capacity	m3	12,546	4,454	12,112	4,642
Minimum storage required	m3	10,552	4,228	8,679	4,196
Compliance with storage limits		YES	YES	YES	YES
Storage capacity	days	172	120	165	144
Minimum storage required	days	122	122	122	122
Compliance with storage limits		YES	NO	YES	YES

In all of the farms maize both for silage and grain is currently cultivated. The forage crops such as silage maize, meadows and alfalfa are cropped in the farm with dairy cows to sustain milk production. None of the farms had a manure treatment plant and two farms usually sold N outside. The software simulated for the actual scenario that ammonia volatilisation occurring along all the manure chain, ranged from 26% to 34 % of the total N excreted by herd. N leaching varied from 26% to 63 % of the N applied on field from mineral and organic fertilisers. All the farms were not in compliance with N limits: the N from organic fertilisers usually distributed per hectare on field was on average almost the double of that allowed. It ranged from 294 to 357 kg N ha^{-1}, However storage limitations were quite always respected.

3.2.2 Examples of alternative management options

3.2.2.1 Management option 1: reduction of the crude protein content of the animal diets

Objective: to reduce the N content of the livestock manure.

Description: for each animal category the default data of crude protein content of the diet were reduced. The chosen value is the minimum of the default range for which are not expected relevant variations in terms of meat and milk production. This is consistent with experimental findings: Olmos Colmenero and Broderick (2006) found that diets containing 16.5% of crude protein supported maximal production of dairy cows with minimal N excretion compared with diets with 19.4% of crude protein.

Results and discussion: The results of the simulation are reported in Table 3.2. The alternative scenario involved limited effects on N distributed on field. Its reduction was by 5% in swine farm and by 12% in dairy farm but was not enough to be under the amount of 170 kg ha^{-1}. However from an environmental point of view resulted a relevant reduction of ammonia volatilisation from stable and storage facilities. In dairy farm the reduction was by 22%.

Table 3.2 – Main effects of the reduction of crude protein content of the animal diet

	Units	Swine Farm			Dairy farm			Beef Cattle farm			Dairy and swine farm		
		ACT	ALT	INCR (+) DECR (-) %	ACT	ALT	INCR (+) DECR (-) %	ACT	ALT	INCR (+) DECR (-) %	ACT	ALT	INCR (+) DECR (-) %
Protein content*	%	18.5	17.5		17.7	15.3		14.0	13.0		17.6	15.90	
N excreted by herd	kg N	89,784	83,542	**-7**	56,829	48,992	**-14**	83,220	75,875	**-9**	42,361	38,277	**-10**
N volatilised from stable	kg N	14,747	13,704		5,390	4,657		12,944	11,801		5,254	4,818	
N volatilised from storage	kg N	11,805	9,481		6,532	4,594		10,429	7,809		5,241	4,010	
Total N volatilised	kg N	26,552	23,185	**-13**	11,922	9,251	**-22**	23,373	19,610	**-16**	10,495	8,828	**-16**
N distributed on field	kg N	63,232	60,357	**-5**	44,907	39,741	**-12**	59,847	56,265	**-6**	31,866	29,449	**-7**

*For dairy farm the value is related to dairy cows group, for swine farm is related to the most numerous age categories, for dairy and swine farm is a mean of the previous categories explained, for beef cattle farm is related to male from1 to 2 years for slaughtering

ACT= actual scenario; ALT=alternative scenario

3.2.2.2 Management option 2: covering of liquid manure stores

Objective: to reduce ammonia emission during manure storage

Description: Given that a relevant part of the ammonia emission occurred during manure storage the construction of a rigid cover represents the suitable way to get the final objective. For all of the stores available on farm it was simulated the cover.

Results and discussion: The results of the simulation are reported in Table 3.3. The cover of the tanks involved a relevant reduction of the ammonia volatilization from 27% to 32% based on livestock type. This determined an increase of available N to apply on field from 10% to 14%. Then a more accurate nitrogen management during field practices to avoid ammonia volatilization and leaching is needed. From an economic point of view the direct construction costs are relevant. However, the reduction of the total manure volume (almost by 24% in beef cattle farm) because rainfall water has been excluded from the system, involves to reduce the transport costs to move manure from farm to fields. Moreover, considering the aids provided by the measure 121 of the current Rural Development Programme applied in the Lombardia region the economic investment could offset by 35-40%.

Table 3.3 – Main effects of covering liquid manure stores.

	Units	Swine Farm			Dairy Farm			Beef cattle farm			Dairy and swine farm		
		ACT	ALT	INCR(+) DECR(-) %	ACT	ALT	INCR(+) DECR(-) %	ACT	ALT	INCR(+) DECR(-) %	ACT	ALT	INCR(+) DECR(-) %
N excreted by herd	kg N	89,784	89,784		56,829	56,829		83,220	83,220		42,361	42,361	
N sold	kg N	0	0	**0**	5,432	6,090	**12**	0	0	**0**	5,824	6,479	**11**
N volatilised from stable	kg N	14,747	14,747		5,390	5,390		12,944	12,944		5,254	5,254	
N volatilised from treatment	kg N	0	0		0	0		0	0		0	0	
N volatilised from storage	kg N	11,805	3,221		6,532	1,649		10,429	1,884		5,241	1,862	
N volatilised from spreading	kg N	3,797	4,170		2,586	2,773		2,788	3,164		1,601	1,728	
Total N volatilised	kg N	30,349	22,138	**-27**	14,508	9,812	**-32**	26,161	17,992	**-31**	12,096	8,844	**-27**
N distributed on field	kg N	63,157	71,741	**14**	39,331	43,556	**11**	59,771	68,316	**14**	25,971	28,696	**10**
Maximum N applicable on field	kg N	30,090	30,090		22,015	22,015		28,662	28,662		15,037	15,037	
Conformità effluenti	kg N	-33,067	-41,651		-17,316	-21,541		-31,109	-39,654		-10,935	-13,660	
Compliance with N limits		NO	NO		NO	NO		NO	NO		NO	NO	
Storage capacity	m^3	12,546	12,546		4,454	4,454		12,112	12,112		4,642	4,642	
Minumum storage required	m^3	10,552	8,871	**-16**	4,228	3,992	**-6**	8,679	6,619	**-24**	4,196	3,940	**-6**
Compliance with storage limits		YES	YES		YES	YES		YES	YES		YES	YES	
Storage capacity	gg	172	244		120	120		165	165		144	144	
Minumum storage required	gg	122	122		122	122		122	122		122	122	
Compliance with storage limits		YES	YES		NO	NO		YES	YES		YES	YES	
Liquid manure to distribute	m^3	22,354	18,793	**-16**	11,068	10,349	**-6**	19,200	14,642	**-24**	8,611	7,963	**-8**
Investment	€		65,000			34,900			79,000			25,000	

ACT= actual scenario; ALT= alternative scenrio

3.2.2.3 Management option 3: reduction of the crude protein content of the animal diets + construction of solid-liquid separator and selling of the solid fraction+ request of adoption of the limit of 250 kg N ha^{-1} as provided by nitrate derogation

Objective: to reduce the amount of N to distribute on fields to get compliancy with nitrate directive

Description: The alternative scenario involved the combination of three types of intervention along the manure management chain. It was selected i) the reduction of crude protein content of the diet as done previously, ii) the installation of a liquid-solid separation treatment plant to finally export the solid fraction that is mandatory under nitrate derogation for swine farms and, iii) the request of adoption of the prescription of the nitrate derogation regarding the maximum amount permitted of 250 kg nitrogen per hectare per year from cattle manure and treated pig manure.

Results and discussion: The results of the simulation are reported in Table 3.4. The combination of the three management options involved a relevant reduction of the N available on farms that ranged from 20% to 36%. This was due to the lesser amount of N excreted of which the 20% was exported. This resulted in a lower environmental impact as ammonia volatilization and leaching. However, being the amount of organic N available to distribute on fields equal at 230 kg ha^{-1}, to get compliancy with nitrate directive the farmers have to require the adoption of the nitrate derogation.

Table 3.4 – Main effects of the adoption of 3 alternative management options: low protein content of the diet, solid-liquid separation, nitrate derogation.

	Units	Swine farm			Dairy farm			Beef cattle farm			Dairy and swine farm		
		ACT	ALT	INCR(+) DECR(-) %	ACT	ALT	INCR(+) DECR(-) %	ACT	ALT	INCR(+) DECR(-) %	ACT	ALT	INCR(+) DECR(-) %
Number of cattle	N.				565	565		2133	2133		255	255	
Number of pigs	N.	8,200	8,200								1332	1332	
Utilisable agricultural area	ha	177	177		130	130		169	169		88	88	
Area vulnerable to nitrates	ha	177	177		130	130		169	169		88	88	
Cropping systems													
Grain maize	ha	177	177		=	=		169	169		=	=	
Silage maize	ha	=	=		72	72		=	=		11	11	
Permanent meadows	ha	=	=		45	45		=	=		28	28	
Alfalfa / grain maize	ha	=	=		13	13		=	=		=	=	
Winter wheat / grain maize	ha	=	=		=	=		=	=		49	49	
N excreted by herd	kg N	89,784	83,542	**-7**	56,829	48,992	**-14**	83,220	75,875	**-9**	42,361	38,277	**-10**
N purchased	kg N	0	0		0	0		0	0		0	0	
N sold	kg N	0	16,509		5,432	9,919		0	15,932		5,824	7,499	
Manure sold	m^3		1904		1,793	4,311			5,788		2,202	2,238	
N volatilised from stable	kg N	14,747	13,704		5,390	4,657		12,944	11,801		5,254	4,818	
N volatilised from treatment	kg N	0	2,674		0	956		0	1,656		0	998	
N volatilised from storage	kg N	11,805	9,481		6,532	4,594		10,429	7,809		5,241	4,010	
N volatilised from spreading	kg N	3,797	2,786		2,586	1,963		2,788	1,796		1,601	1,346	
Total N volatilised	kg N	30,349	28,645	**-6**	14,508	12,170	**-16**	26,161	23,062	**-12**	12,096	11,172	**-8**
N ditributed on field	kg N	63,232	40,777		39,475	28,866		59,847	38,677		26,042	20,953	
N distributed on field	kg N ha^{-1}	357	230	**-36**	305	223	**-27**	355	229	**-35**	294	237	**-20**
Mineral N applied	kg N	14,000	14,000		11,850	11,850		0	0		7,550	7,550	
N leaching	kg N	20,397	9,317	**-54**	32,664	26,743	**-18**	23,473	12,498	**-47**	15,684	12,095	**-23**
N uptake by crop	kg N	48,453	42,306		31,157	28,132		37,167	31,798		21,848	19,282	
Maximum N applicable on field	kg N	30,090	44,250		22,015	32,375		28,662	42,150		15,037	22,113	
Compliance with N limits		NO	YES		NO	YES		NO	YES		NO	YES	
Storage capacity	m^3	12,546	12,546		4,454	4,454		12,112	12,112		4,642	4,642	
Minimum storage required	m^3	10,552	9,990		4,228	2,811		8,679	6,063		4,196	3,299	
Compliance with storage limits		YES	YES		YES	YES		YES	YES		YES	YES	
Storage capacity	days	172	172		120	120		165	165		144	144	
Minimun storage required	days	122	122		122	122		122	122		122	122	
Compliance with storage limits		YES	YES		NO	NO		YES	YES		YES	YES	

ACT= actual scenario; ALT= alternative scenario.

3.2.2.4 Management option 4: changes in crop rotations + changes of manure distribution across time + redistribution of organic N among crops + immediate incorporation of manure

Objective: to reduce the amount of N leaching and the ammonia emission from manure distribution.

Description: The scenario regarded the adoption of management options at cropping systems level. The first change involved the increases of the area devoted to autumn-winter crops in a double cropping system (two crops harvested in 12 months) with maize, in order to increase N uptake during the period when most leaching occurs. Italian Ryegrass was selected in cattle farms whereas barley was considered in swine farms being more compatible with pigs' diet. To increase the apparent N recovery of organic fertilisers applied was simulated the distribution of 66% of manure in the firsts six months and a better redistribution among crops. The last change was the immediate incorporation of manure after spreading to mainly reduce ammonia losses.

Results and discussion: The results of the simulation are reported in Table 3.5. The increase of soil cover together with a more efficient use of the N from manure, reduced N leaching (from 23% to 64%). Also ammonia volatilization was substantially reduced. The reduction ranged from 50% to 70%. These advantages from an environmental point of view were obtained maintaining a comparable biomass production per hectare as well as the crop N uptake.

Table 3.5– Main effects of the adoption of 4 alternative mangement options at cropping system level

Farm Type	Scenario	Rotation	UUA (ha)	Organic N (kg N ha^{-1})	Mineral N (kg N ha^{-1})	AGB (kg DM ha^{-1})	N uptake (kg N ha^{-1})	N leaching (kg N ha^{-1})	N volatilization (kg N ha^{-1})
Swine farm	ACT	**GM**	**177**	**357**	**80**	**25,467**	**286**	**116**	**40**
	ALT	GM	105	333	80	25,536	302	106	25
		GM 500-GB	72	391	80	23,647	467	65	15
		Annual Mean	**177**	**357**	**80**	**24,767**	**369**	**89**	**21**
Dairy farm	ACT	SM	72	302	150	25,547	290	141	27
		MG	45	353	0	17,827	85	39	19
		AG - GM	13	155	60	17,639	171	40	13
		Annual Mean	**129**	**305**	**89**	**22,102**	**207**	**95**	**22**
	ALT	SM - IR	72	302	100	27,381	303	44	7
		MG	45	353	0	17,827	85	39	19
		AG - GM	13	160	28	17,869	168	25	11
		Annual Mean	**129**	**305**	**58**	**23,181**	**214**	**40**	**11**
Beef cattle farm	ACT	**GM**	**169**	**354**	**100**	**25,291**	**264**	**64**	**31**
	ALT	**GM - IR**	**169**	**355**	**100**	**27,558**	**293**	**23**	**9**
Dairy and swine farm	ACT	SM	11	331	125	21,665	262	141	21
		MG	28	259	0	15,892	66	29	12
		WW - GM 600	49	307	120	16,518	235	117	22
		Annual Mean	**88**	**294**	**82**	**16,961**	**184**	**92**	**18**
	ALT	SM - IR	11	567	0	24,311	344	42	7
		MG	28	259	0	15,885	68	9	3
		WW - GM 600	49	254	60	16,151	232	64	6
		Annual Mean	**88**	**294**	**33**	**17,084**	**193**	**43**	**5**

GM = Grain maize; GB = Grain barley; SM = Silage maize; MG = Meadows grass; IR = Italian ryegrass; WW = Winter wheat
ACT= actual scenario, ALT= alternative scenario

3.3 Application of ValorE at regional scale

3.3.1 Examples of databases interrogation

As described in paragraph 4.2.1 it is possible to interrogate the regional databases using a "query" function and through a WebGIS interface to visualize a picture of the current state of a specific area. Results are also available into spreadsheets that can be exported in Excel format. The query procedure involves, first, the selection of the aggregation level to finally present the results (i.e. farm, municipality and provinces) and, second, the selection of the geographic areas of interest. These could be municipality, provinces, protected area such as natural parks, hydrologic basin and agrarian regions. The latter derived from the subdivision of the national territory in homogeneous zones deriving from the aggregation of neighboring municipalities, normally built on the base of altimetric threshold values.

The first example of free query shows the organic N load aggregated at municipality scale for the Province of Cremona (Figure 3.1). The same parameter is represented in Figure 3.2 for the agrarian region of the province of Cremona named "Plain Crema Area" while in Figure 3.3 the organic N load is visualized at level of the hydrologic basin of the Adda river.

Figure 3.1 – Mean organic N load (kg ha^{-1}) [carico medio di azoto organico] aggregated at municipality scale for the Province of Cremona.

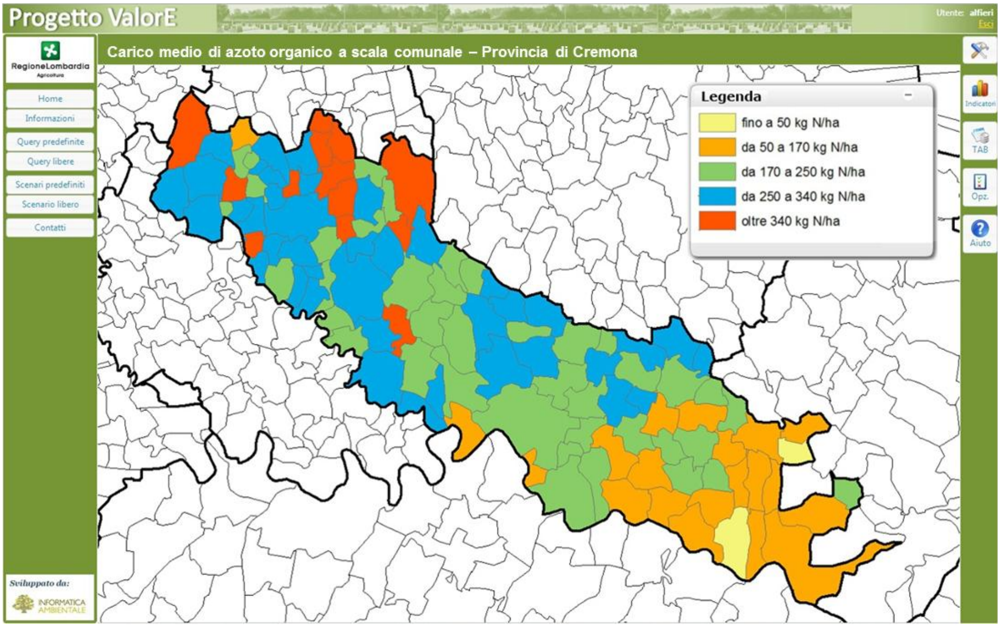


Figure 3.2 – Mean organic N load (kg ha^{-1}) [carico medio di azoto organico] aggregated at municipality scale for the agrarian region "Plain Crema area".

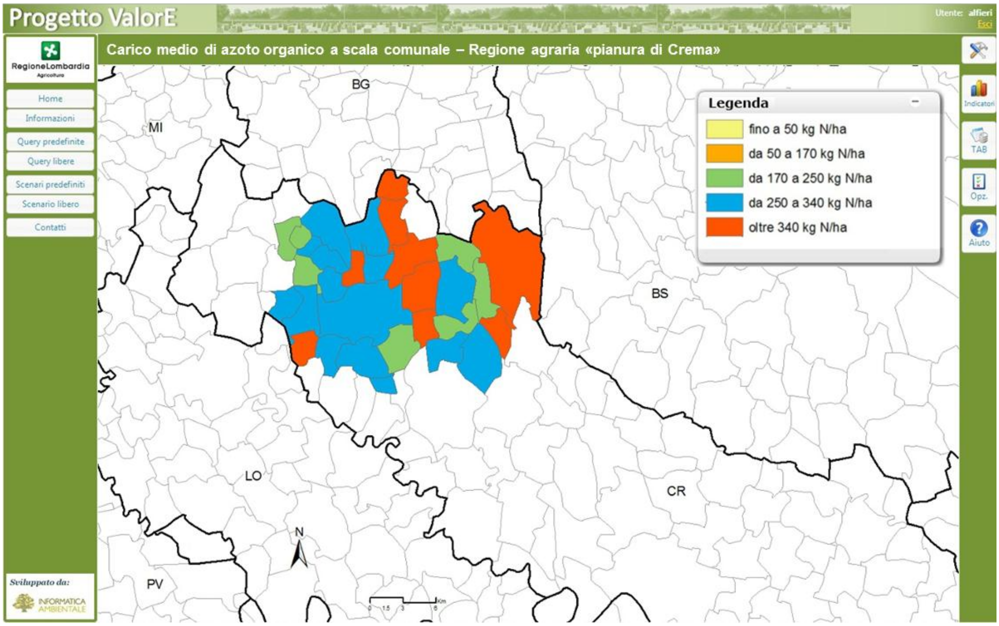
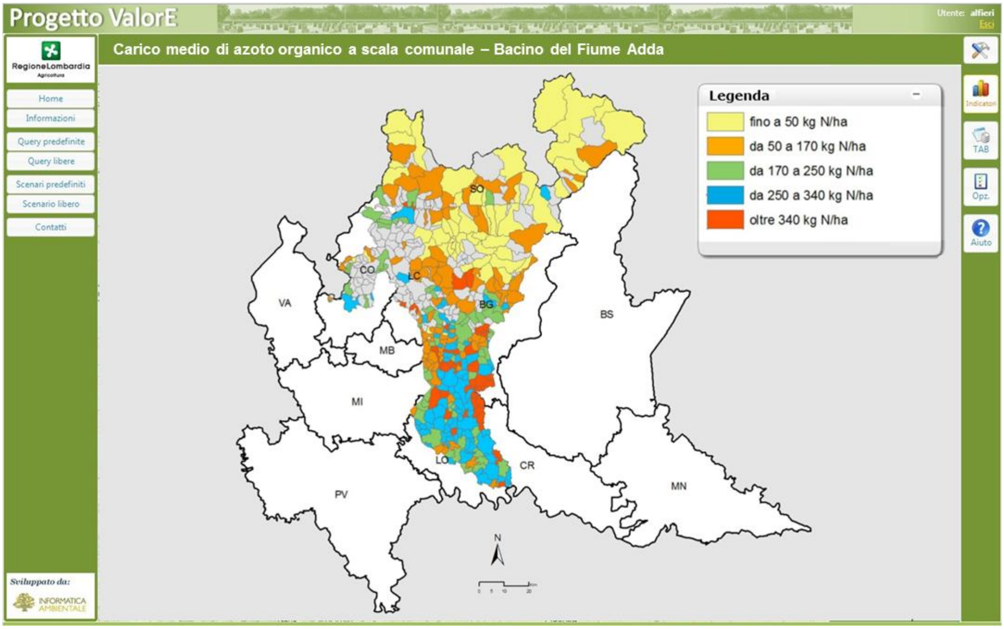


Figure 3.3 – Mean organic N load (kg ha^{-1}) [carico medio di azoto organico] aggregated at municipality scale for the hydrologic basin of the Adda river.



3.3.2 Examples of alternative management options

3.3.2.1 Management option 1: nitro-denitro treatment plant with removal of nitrogen

Objective: to reduce the amount of N to distribute on fields to get compliancy with nitrate directive

Sample area: the area is represented by nine neighbouring municipality localized in the south part of the province of Bergamo. It was chosen because is a nitrates vulnerable area with high organic N load. Within the area, through a "query" function, were selected only livestock farms, over 50 ha of agricultural utilizable area and that do not respect the limit of 170 kg per year/hectare of nitrogen from organic fertilisers. The sample is composed by 28 farms that could sustain the management and construction costs of the plant also aggregating in a consortium. The organic N load aggregated at municipality level is very high and ranged from 325 to 605 kg ha-1 of UUA (Figure 3.4a)

Description: The alternative scenario hypothesized involved the implementation of the nitro-denitro treatment plant with removal of nitrogen. The livestock manure is first separated in a liquid and solid fraction. The liquid fraction enters in the nitro-denitro plant and successively stored in a tank for the final agronomic use. The remaining part is moved to a belt press and stored in covered facility together with the solid fraction obtained from the first separation. This final product could be applied on fields or sold outside farm (Figure 3.5).

Figure 3.4 – Mean organic N load (kg ha^{-1}) [carico medio di azoto organico] aggregated at municipality scale for the ACT scenario (a) and after the implementation of the nitro-denitro plants (ALT scenario) (b).

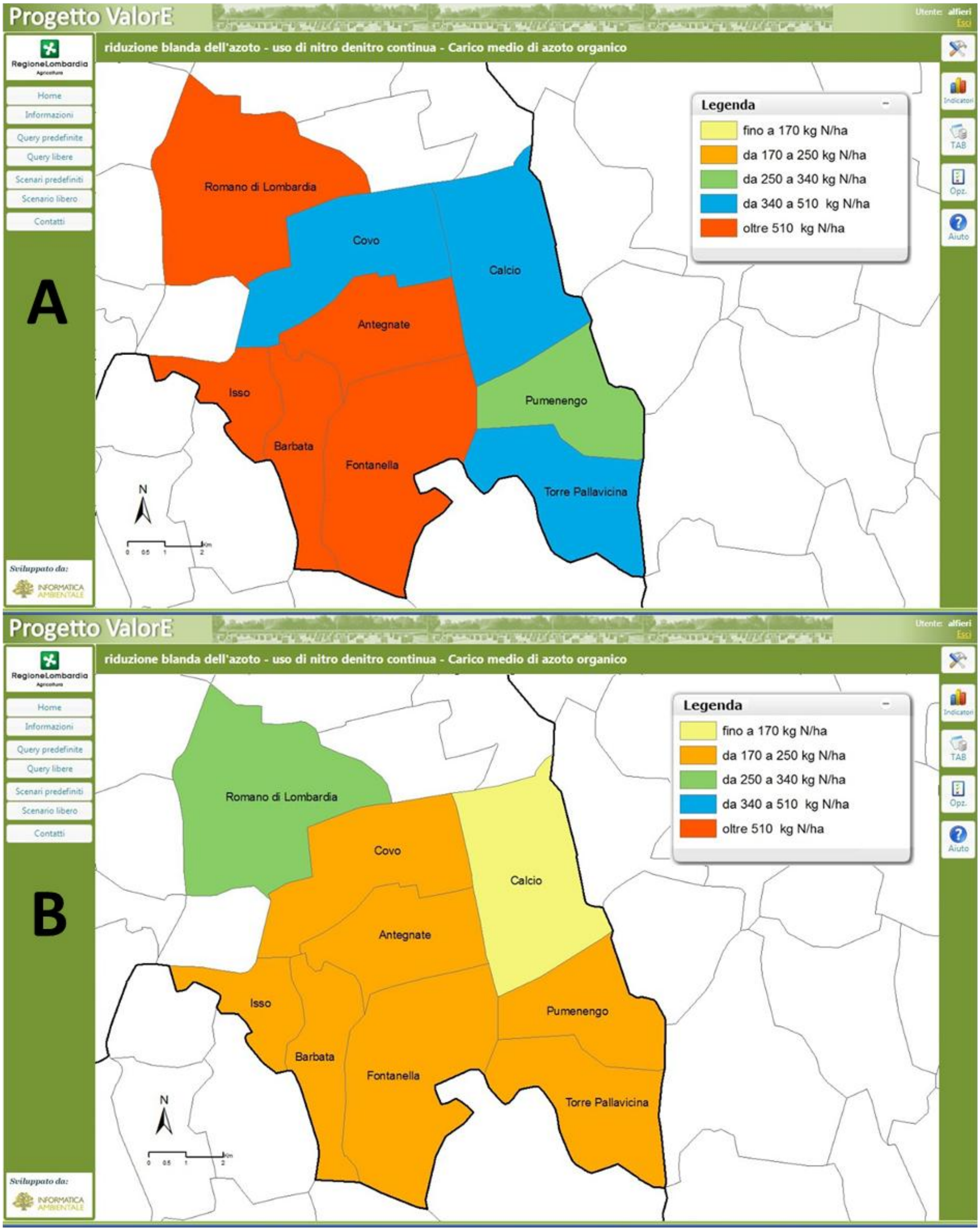
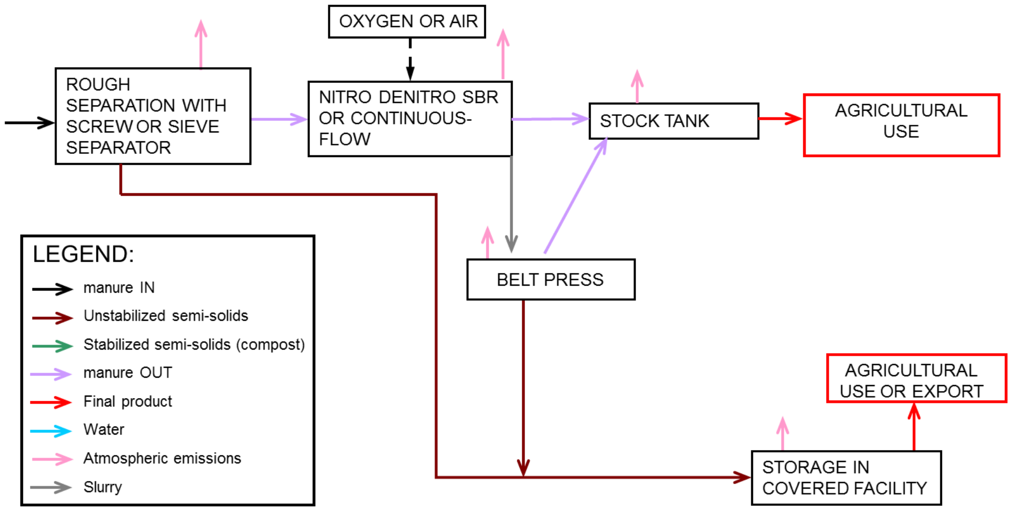


Figure 3.5 – Liquid manure treatment - Option 8: nitrogen removal with nitro-denitro process.



Results and discussion: The first positive effect due to the implementation of this management option was the strong reduction of the organic N available to be distributed on fields (Fig. 3.4b). As reported in Table 3.6 the reduction ranged from 39% to 66% demonstrating that nitro-denitro process is a reliable solution to get compliancy with nitrate directive under derogation limits. Moreover as reported, relevant advantages from an environmental point of view can be obtained. N leaching and ammonia volatilisation were reduced from 38% to 75% and from 24% to 34%, respectively (Table 3.6, Figure 3.6 and Figure 3.7). The negative consequence is that the fertilisation value of manure is halved because of the 50% of N is lost as N_2. This implies the reviewing of the nitrogen fertilisation plans. From an economic point of view the direct costs of construction are relevant: for a dairy farm of 130 ha with 55 lactating cows and an annual volume of liquid manure produced of 12000 m^3, the expected investment (estimated by the software) is around 380.000 Euro. However, considering the aids provided by the measure 121 of the current Rural Development Programme applied in the Lombardia region the economic investment could offset by 35-40%.

Table 3.6 – Main effects of the implementation of nitro-denitro treatment plant.

Municipality	N distributed on field (Kg ha^{-1})			N leaching (Kg ha^{-1})			Ammonia volatilized (Kg LSU^{-1})		
	ACT	ALT	INCR(+) DECR(-) %	ACT	ALT	INCR(+) DECR(-) %	ACT	ALT	INCR(+) DECR(-) %
Antegnate (BG)	544	206	-62	219	77	-65	68	50	-26
Barbata (BG)	537	182	-66	197	77	-61	96	68	-29
Calcio (BG)	488	168	-66	135	52	-61	51	37	-26
Covo (BG)	503	201	-60	223	69	-69	44	29	-34
Fontanella (BG)	606	249	-59	231	89	-61	81	59	-27
Isso (BG)	538	239	-56	159	40	-75	45	34	-26
Pumenengo (BG)	326	199	-39	135	84	-38	42	32	-24
Romano di Lombardia (BG)	587	254	-57	109	50	-55	47	36	-24
Torre Pallavicina (BG)	419	200	-52	131	62	-53	47	35	-25

LSU: livestock standard units; ACT= actual scenario; ALT= alternative scenario

Figure 3.6 – Mean ammonia volatilisation (kg LSU^{-1}) [emissioni ammoniacali medie - kg UBA^{-1}] aggregated at municipality scale for the ACT scenario (a) and after the implementation of the nitro-denitro plants (ALT scenario) (b).

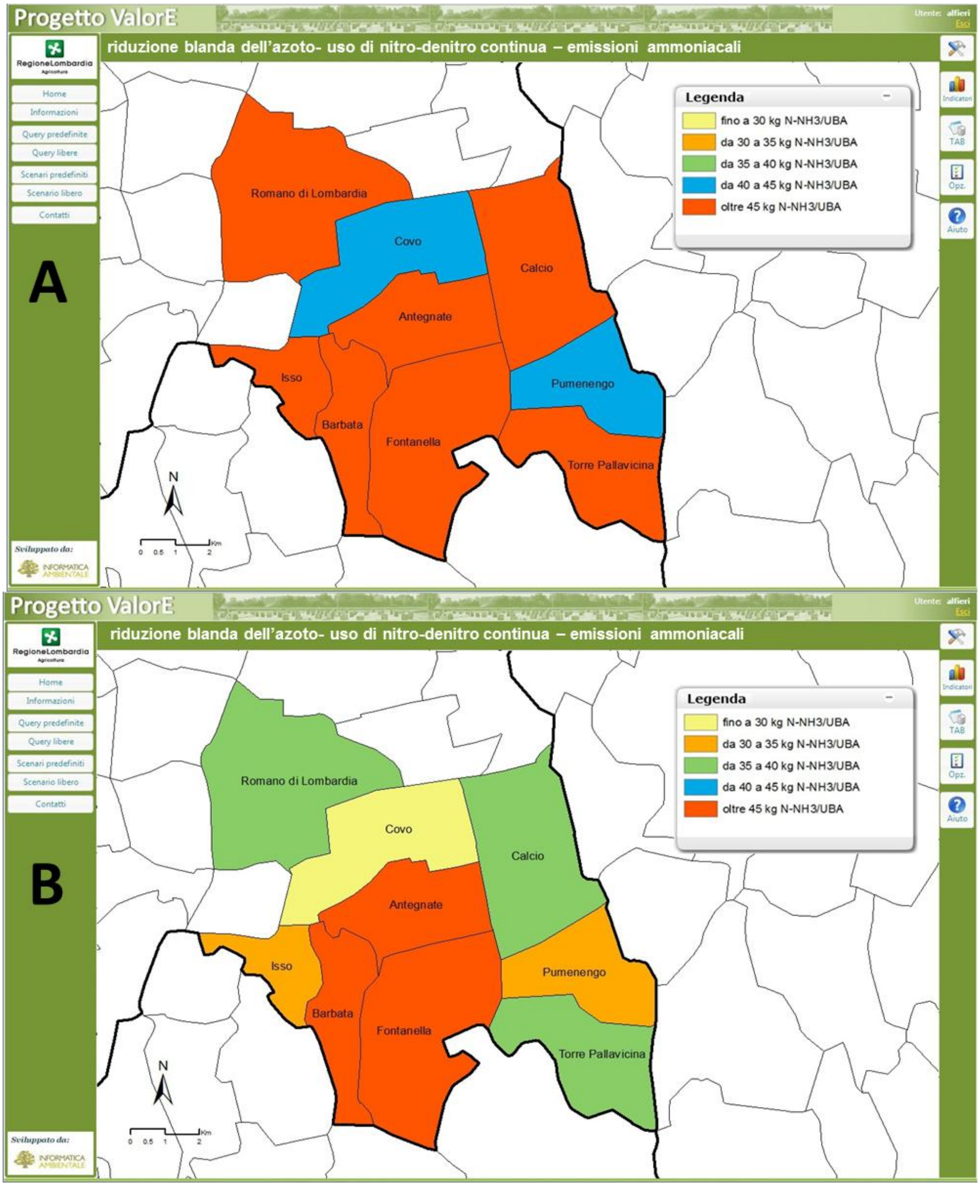
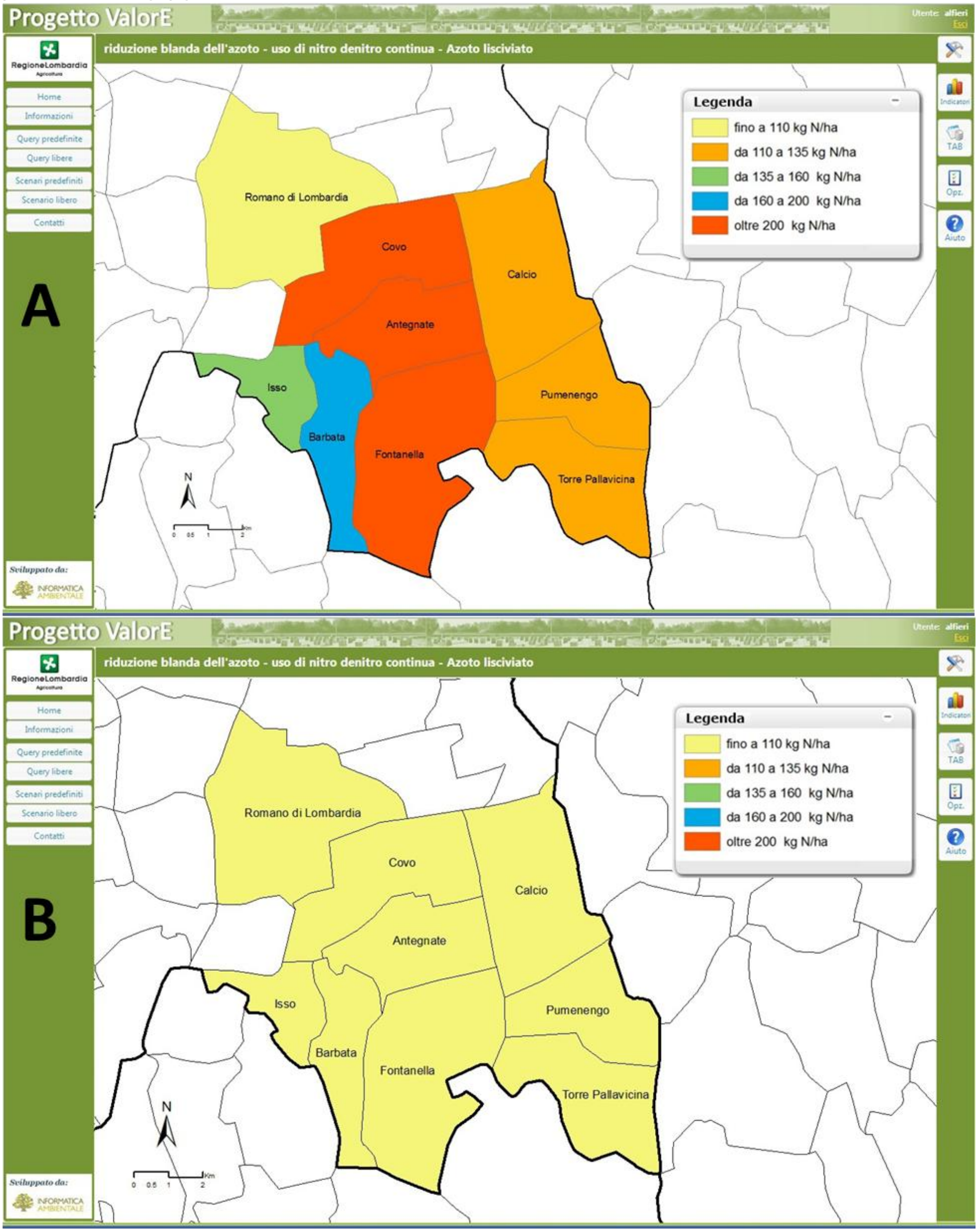


Figure 3.7 – Mean N leaching (kg ha^{-1}) [azoto lisciviato medio] aggregated at municipality scale for the ACT scenario (a) and after the implementation of the nitro-denitro plants (ALT scenario) (b).



3.3.2.2 Management option 2: covering of liquid manure stores.

Objective: to reduce ammonia emission and livestock manure volumes during manure storage

Sample area: the sample is composed by 58 livestock farms localised in the province of Cremona having an agricultural utilizable area over 50 ha and that do not respect the limit of storage capacity.

Description: the alternative scenario involved the construction of a rigid cover for all of the stores available on farm to mainly reduce a part of the ammonia emission occurring during manure storage.

Results and discussion: The effect of covering of manure stores was the strong reduction of ammonia volatilisation that ranged from 8% to 46%. (Table 3.7 and Figure 3.8). At the same time a mean reduction of the total manure volume by 4% (Figure 3.9) occurred due to the exclusion of rainfall water from the system. This could reduce the transport costs to move manure from farm to fields. However, this management option determined a mean increase of available N to applied on field by 7%, then a more accurate nitrogen management during field practices to avoid ammonia volatilization and leaching is needed. As reported in Table 3.7 the required investment could be relevant in some cases.

Table 3.7 – Mean effects of covering liquid manure stores.

Municipality	Ammonia volatilised (Kg)			N distributed on field (Kg ha^{-1})			Manure stored (m^3)			Investment (€)
	ACT	ALT	INCR(+) DECR(-) %	ACT	ALT	INCR(+) DECR(-) %	ACT	ALT	INCR(+) DECR(-) %	
Agnadello (CR)	21,831	17,178	-21	453	477	5	4,649	4,337	-7	61,322
Annicco (CR)	21,394	12,926	-40	-	-	-	92	92	0	1,957
Ca, d'Andrea (CR)	10,671	8,606	-19	317	332	5	2,238	2,171	-3	16,375
Cappella Cantone (CR)	7,169	6,192	-14	499	519	4	1,342	1,309	-2	5,787
Casalmorano (CR)	5,749	4,828	-16	357	374	5	1,191	1,161	-3	5,208
Castel Gabbiano (CR)	4,259	3,726	-13	285	295	4	532	522	-2	3,474
Castelleone (CR)	69,983	44,580	-36	207	226	9	21,482	21,020	-2	102,911
Castelverde (CR)	11,155	9,722	-13	242	252	4	2,760	2,673	-3	13,208
Corte de, Frati (CR)	9,897	8,146	-18	352	375	6	2,050	1,881	-8	28,345
Credera Rubbiano (CR)	5,221	4,214	-19	255	270	6	1,224	1,200	-2	9,345
Crema (CR)	2,035	2,028	0	155	155	0	12	12	0	418
Cumignano sul Naviglio (CR)	25,368	20,268	-2	320	347	8	5,241	5,002	-5	70,538
Fiesco (CR)	41,162	24,878	-40	60	62	3	14,012	13,633	-3	58,775
Formigara (CR)	16,407	12,647	-23	120	122	2	5,208	4,308	-17	32,395
Gerre de, Caprioli (CR)	3,918	2,721	-31	231	256	1	1,256	1,184	-6	5,139
Grontardo (CR)	6,335	5,328	-16	390	406	4	868	864	0	4,638
Grumello Cremonese ed Uniti (CR)	9,521	8,290	-13	393	410	4	2,039	1,992	-2	5,661
Gussola (CR)	4,719	4,149	-12	347	355	2	539	526	-2	6,332
Isola Dovarese (CR)	5,618	4,635	-18	281	297	6	948	910	-4	6,511
Malagnino (CR)	16,567	13,371	-19	328	355	8	1,757	1,709	-3	19,630
Olmeneta (CR)	5,904	4,164	-29	266	298	12	2,005	2,005	0	12,757
Ostiano (CR)	5,655	4,296	-24	327	350	7	1,239	1,180	-5	14,532
Pandino (CR)	55,919	40,049	-28	377	409	9	14,071	13,487	-4	96,424
Persico Dosimo (CR)	19,994	14,184	-29	40	40	0	7,294	7,236	-1	45,044
Pizzighettone (CR)	72,790	50,824	-30	673	762	13	16,143	15,019	-7	73,068
Pozzaglio ed Uniti (CR)	14,650	10,642	-27	180	197	10	3,291	3,107	-6	13,778
Ripalta Cremasca (CR)	13,167	8,493	-35	729	814	12	3,887	3,711	-5	38,381
Rivolta d,Adda (CR)	17,258	12,317	-29	393	424	8	5,399	5,302	-2	26,805
Robecco d,Oglio (CR)	32,446	23,771	-27	456	497	9	8,444	8,162	-3	69,732
Romanengo (CR)	6,910	5,536	-20	442	461	4	2,125	2,063	-3	13,732
San Giovanni in Croce (CR)	2,750	2,538	-8	130	134	3	185	185	0	2,923
Sesto ed Uniti (CR)	40,170	25,838	-36	423	476	12	14,808	13,136	-11	96,825
Soncino (CR)	32,409	21,070	-35	597	676	13	10,691	10,092	-6	89,444
Soresina (CR)	25,230	18,924	-25	401	436	9	6,626	6,490	-2	39,966
Spineda (CR)	6,481	5,699	-12	342	358	5	884	884	0	12,169
Spino d,Adda (CR)	6,892	5,229	-24	405	428	6	2,126	2,012	-5	15,118
Ticengo (CR)	12,005	9,361	-22	397	439	11	3,362	3,089	-8	44,850
Torlino Vimercati (CR)	9,261	6,761	-27	247	270	9	3,815	3,605	-6	19,018
Vescovato (CR)	8,876	6,130	-31	444	495	11	2,560	2,543	-1	10,421

ACT= actual scenario; ALT= alternative scenario

Figure 3.8 – Mean percent reduction of ammonia volatilisation at municipality scale as effect of covering liquid manure stores.

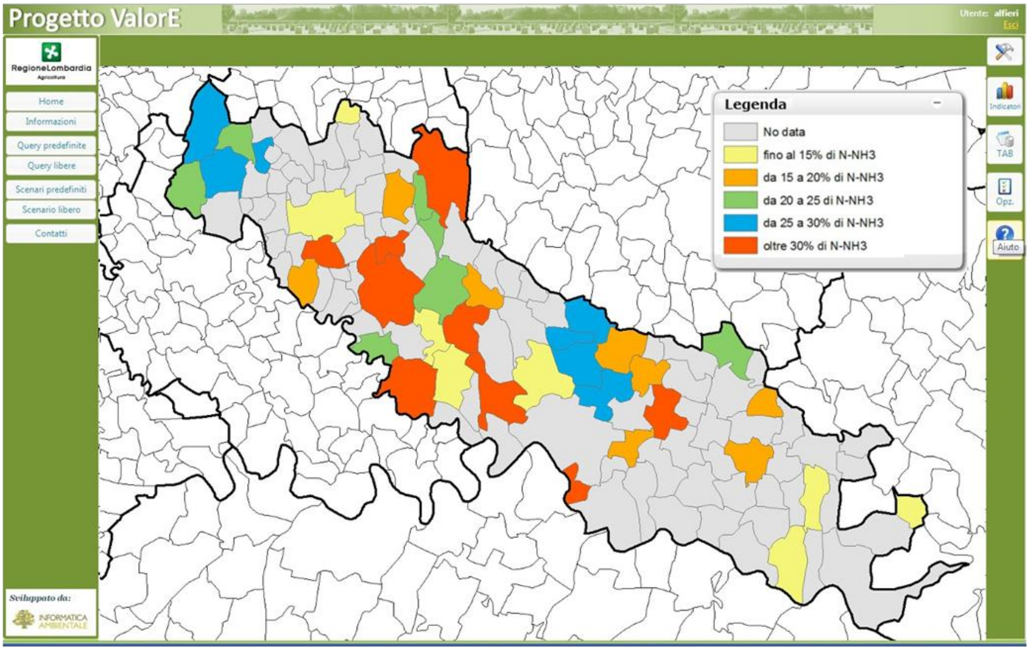
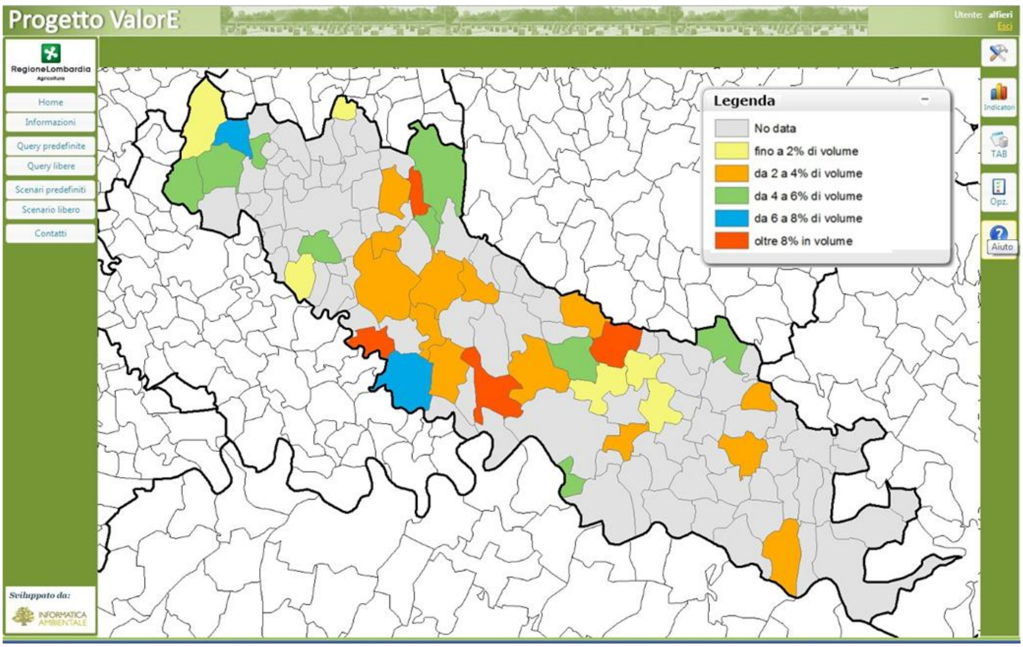


Figure 3.9 – Mean percent reduction of the volume of manure stored at municipality scale as effect of covering liquid manure stores.



Chapter 4

GENERAL DISCUSSION

5.1 Characteristics of the ValorE DSS

The DSS developed in the ValorE Project, founded by Regione Lombardia for 1,100,000 € (about 1,500,000 USD) is an attempt to create an instrument for environmental protection in a very intensive agricultural area with one of the livestock density higher in the World. Through the ValorE software the analysis can be carried out for all the farm in the region, and alternative management scenarios and hypothesis of policies can be tested in all the farms that have specific characteristics. The spatial and integrated approach involved to deal with conflicting objectives, interests and expectation of the stakeholders involved.

The advantages of the DSS ValorE over other similar systems are that it was designed to manage different livestock manure types and to be not region-specific. From the software structure point of view, several benefit can be highlighted. The OOP targeting at modularity and reusability allows a more intuitive and strong separation among data, models and interfaces. The architecture of the software and the OOP offered an easy updating of the application and of the model algorithms as well as the possibility to maximize the ease of maintenance. The software is adaptable to work with different databases provided that they contain the same information. This feature could offer a possibility to further share and synchronize the different databases of the other Regions of the north Italy, such as Emilia Romagna, Piemonte and Veneto in order to get and unique evaluation and decision making tool for a similar agricultural area. This opportunity is emphasized by the fact that the four Regions for which it was granted the nitrate derogation (EC, 2011), account for more than 70 % of livestock in Italy: in particular, 67,1% of dairy cattle, 60,6 % of other cattle, 81% of pigs and 79,4 % of poultry.

The multidisciplinary of the project together with the need to provide an operative and functional tool, required the participation of numerous partners.

Each partner provided its scientific background. The University of Milano offered agronomic, technical and animal breeding competences, the University of Piacenza provided skills on animal breeding and environmental assessment, whereas CRPA of Reggio Emilia was involved for technical and normative knowledge. Informatica Ambientale offered competences from an informatics point of view developing the software while other partners such as ARAL, FLA and Agrimercati were mainly involved on the software validation procedure.

The first prototypes of the software was appreciated by the public administration, producers organizations and farmer's consultant. Since it was first released to the public the number of users had reached more than 200 of which 60% are agronomists.

5.2 Application of the ValorE DSS

The examples of application of ValorE both at farm and regional scales highlighted its potentiality as a tool to support stockholders. In fact several options of the manure and of cropping systems management are available for the users. The farm simulator could help farmers and their consultant such as agronomists and technicians of the Italian farmers organizations to find better solution to valorise the organic manure in environmental, technical, agronomic and economic terms. Whereas, the territorial simulator represents a tool to support policy makers under the decision process, i.e. for example the planning of the Rural Development Programme interventions.

The results of applications at farm scale showed how a specific intervention is addressed to solve a definite environmental or technical issue, but could involve some implications. For example the cover of the tanks for the liquid manure storages reduced the ammonia volatilisation and the volume of organic materials that farmers have to handle. However, the amount of N available to distribute on field increased involving the adoption of a more accurate nitrogen management at cropping system level. Therefore, the combination of management options represents a solution to better handle the complexity of the system.

The two examples at territorial scale, referred to areas intensively managed, demonstrated how an intervention planned at district level could be a useful solution for livestock manure management. However, this requires a strong collaboration between farmers and industry, with the monitoring and coordination of the institutions which should provide regulations and economic helps. ValorE could be the key tool to test the potential effects of the hypothetical adoption of alternative managements to help policy makers.

5.3 Future research

Based on the results of this study, we propose that further research should have the following objectives:

i. continuous interaction with stakeholders in the debug activities;
ii. improvement of the software to satisfy the further request of the users;
iii. implementation of the software to simulate the rules, constraints and limits of the nitrate derogation;
iv. to make the software able to assists farmers in the preparation and submission of the Agronomic Utilisation Plans for livestock manure.

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