Assessing multiple climate change impacts on water quality: a Bayesian Networks approach

Sperotto A., Molina J.L., Critto A., Torresan S.,
Pulido Velazquez M., Marcomini A.

cmcc Centro Euro-Mediterraneo sui Cambiamenti Climatici

Anna Sperotto
MSc

- **Master in Environmental Sciences**-Integrated Coastal Zone Management, Cà Foscari University, Venice;

- **PhD student in Science and Management of Climate Change program**, Department of Economics, Ca' Foscari University, Venice;

- **Environmental Chemistry and Environmental Risk Assessment (ECRA)** unit, Department of Environmental sciences, Informatic and Statistic, Cà Foscari Univeristy, Venice;

- Centro Euromediterraneo sui Cambiamenti Climatici **(CMCC**), **Risk Assessment and Adaptation Strategies (RAAS) division**.

Introduction

Explore alternative tools for the assessment of interactions between multiple climatic and non-climatic stressors on water resources:

→ To develop risk scenarios enabling to compare the effect of multiple climate change scenarios and available management and adaptation options;

→ To produce appropriate climate risk and adaptation services for the effective communication of climate-related risks and uncertainties.

Water quality as a multi-stressor problem

- **Water resources management** is characterized by **high complexity** due to the coexistence of **multiple uses**, agents and **conflicting goals**.
- **Climate change in combination with other** increasing **pressures is likely to affect water quantity and quality in multiple ways** (Jiménez-Cisneros et al., 2014) and the future management of freshwater resources requires predictions of plausible future conditions .
- Despite the effects of climate change on water availability have been widely studied, **the implications for water quality have been just poorly explored** (Vliet et al., 2007;).
- **Few studied consider the impact of climate change in combination with other stressors** (i.e. land use, urbanization, erosion) on water quality attributes alteration (Huttunen et al., 2015) while, most typically study each stressor in isolation (Bussi et al., 2016,Yushun Chen et al., 2016, Xia et al., 2016);
- A **multi-stressors perspective is required** to address an integrated water resources management and to set efficient adaptation measures as much as possible in synergy with other sectorial policy and legislation (i.e. WFD, Flood directive, IWRM).

Water quality as a multi- problem

TOP DOWN MODELLING:

- Focused on single stressors
- Oriented at reducing physical impacts
- Large uncertainty
- Quantitative information
- Large scales

INTEGRATIVE METHODS-BAYESIAN NETWORKS

- incorporate multiple stressors and objectives in the same framework;
- combine different information sources to improve stressors interaction assessment;
- deal with and communicate uncertainty in an understandable manner;
- assess the effects of adaptation/management on a range of possible futures.

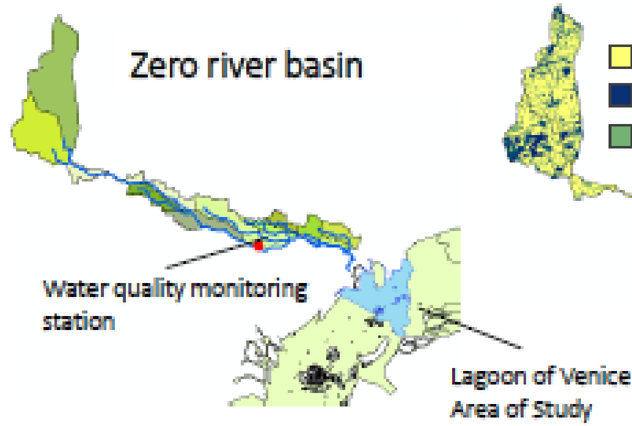
BOTTOM-UP MODELLING:

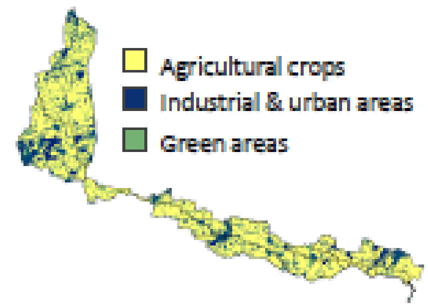
- Oriented at reducing vulnerability
- More focused on socio-economic issues
- Ignore uncertainty
- Semi-quantitative and qualitative information
- Local scales

Case-study and objectives

Use BN to assess the effect of interacting stressors on water quality attributes:

- Prioritize the effect of **climate change** and **land use** on **nutrients loading** in transitional waters;
- Provide **multiple risk scenarios** to estimate the **probability of not meeting a "Good water status"** under future conditions;
- **Testing** a set of **best practices for adaptation and management** according to the Water Framework Directive and the national legislations.





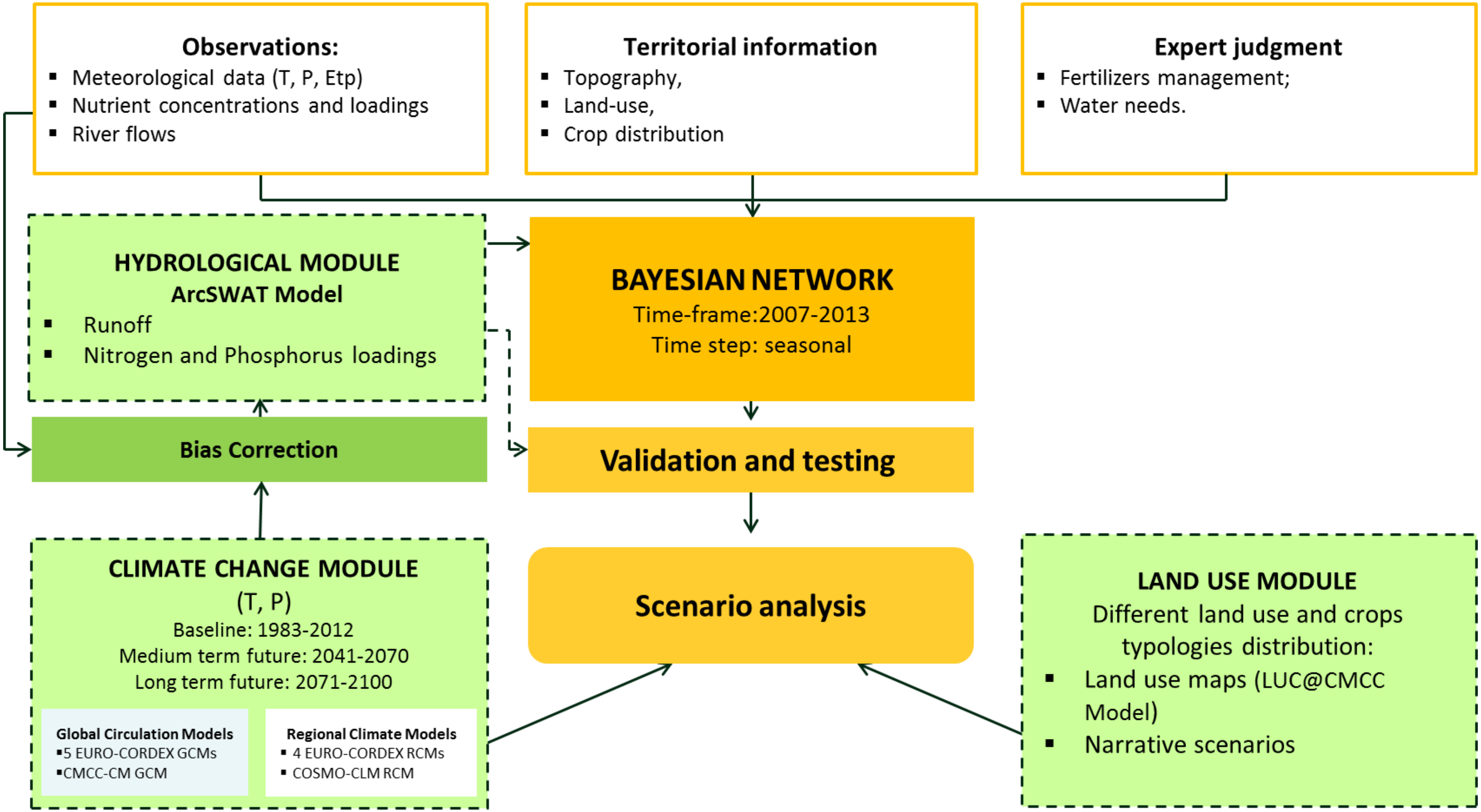
Pilot case study-The Dese-Zero basin and the Venice Lagoon:

Area: 140 km^2

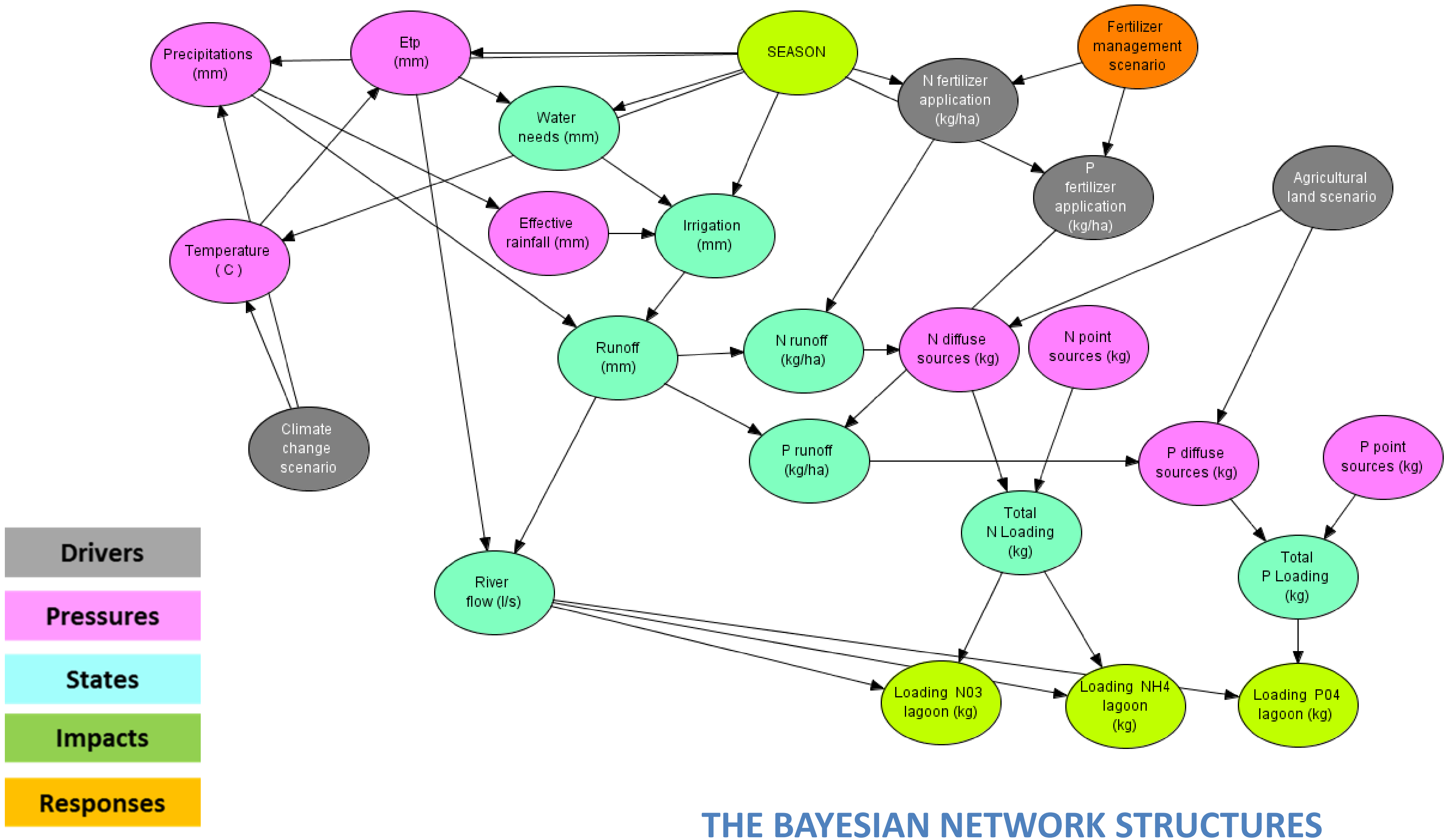
- Urban and industrial area: 24%
- Agricultural areas: 69% (corn, soy, wheat)
- Green & Pasture areas: 7%

One of the main tributaries of the Venice Lagoon

The methodological approach



1. BN-Model conceptualization



THE BAYESIAN NETWORK STRUCTURES

2. BN-Model training

Variable	Description	Unit	States	Source
Temperature	Seasonal average temperature	°C	Interval	Observations
Precipitation	Seasonal total precipitation	mm	Interval	Observations
Evaptranspiration	Seasonal total evapotranspiration	mm	Interval	Observation
River flow	Seasonal average river flow	L/s	Interval	Observations
Irrigation	Amount of water applied as irrigation for season	mm	Interval	Empirical Equation
Effective rainfall	Amount of effective rainfall for season	mm	Interval	SWAT output
Water demand	Seasonal water demand for different	mm	Interval	Empirical Equation
Runoff	Amount of water lost trough runoff	mm	Interval	SWAT output
N in runoff	Amount of total nitrogen loaded in the runoff	kgN/ha	Interval	SWAT output
P in runoff	Amount of total phosporous loaded in the runoff	KgP/ha	Interval	SWAT output
N from diffuse source	Amount of total nitrogen coming from diffuse source (i.e. agricolture)	Kg	Interval	Empirical Equation
N from point sources	Amount of nitrogen coming from point sources (i.e. civil and industrial activities)	kg	Interval	Observations
N fertilizer application	Nitrogen fertilizer applied for each season depending on crop typology	kg/ha	Interval	Experts
Loading NH4 lagoon	Loading of NH4 in transitional waters (i.e. lagoon)	kg	Interval	SWAT output
Loading PO4 lagoon	Loading of PO4 in transitional waters (i.e. lagoon)	kg/season	Interval	SWAT output
Loading N03 lagoon	Loading of N03 in transitional waters (i.e. lagoon)	kg/season	Interval	SWAT output
Agricoltural land scenario	% of change in agricoltural land extention respect the baseline	% increase	Labelled	Expert
Fertilizer management scenario	Alternative fertilizer applications (i.e. amount and timing)	---	Labelled	Expert/Normative

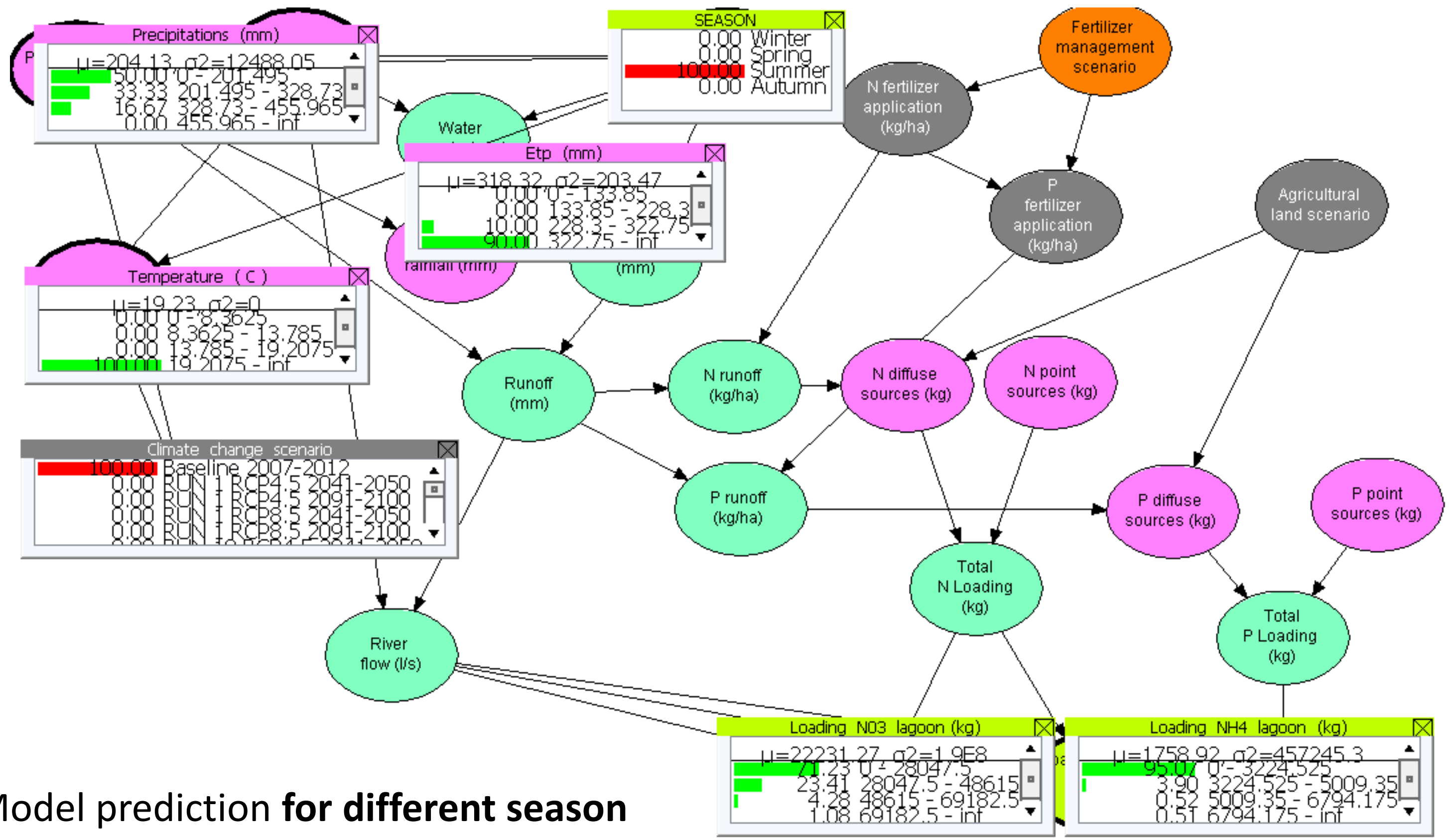
Expert elicitation

Models simulations

Observed data

Training period:
2004-2013
Time step:
Seasonal

3. Model evaluation and testing

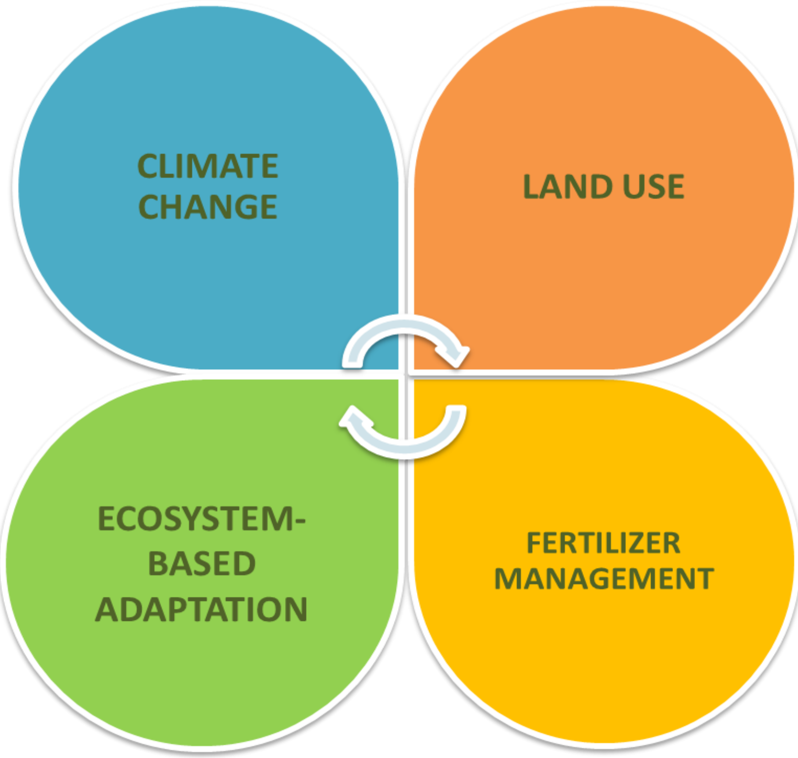


Model prediction **for different season baseline scenario 2007-2012** summer season under current land use

Evaluation of model performances for baseline scenario using an independent dataset 2007-2012.

4.Scenario Analysis-Alternative Scenarios

Precipitation and temperature variation according to an ENSEMBLE of regional climate models and different emission scenarios (RCP4.5-RCP8.5).

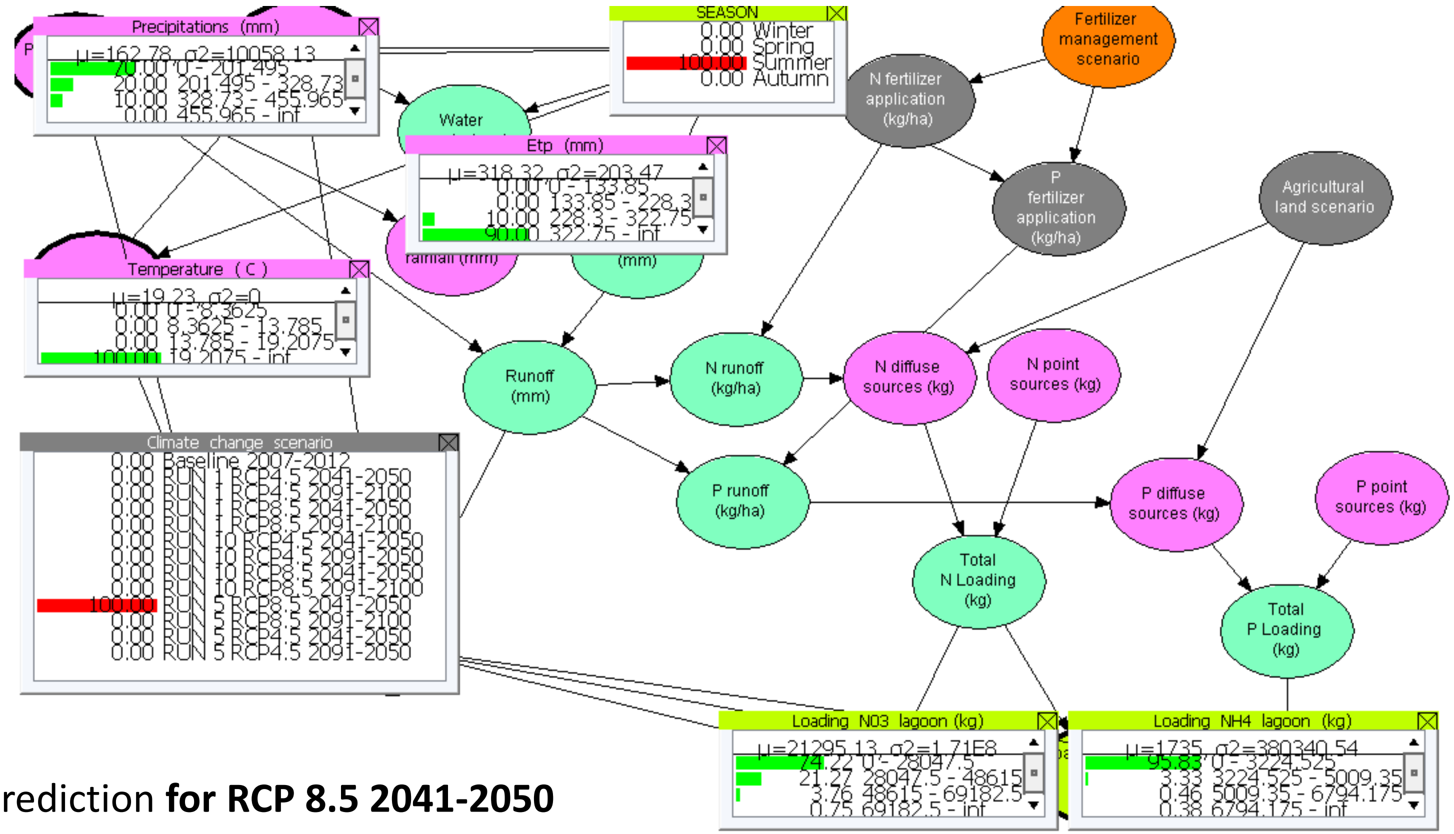


Variation in the spatial distribution of different land use typologies: i.e. % of agricultural land extension change respect to the baseline scenario.

Implementation of nature based-solutions to manage nutrients runoff: i.e. restoration of natural riparian vegetation and wetlands, creation of buffer zones.

Quantity and timing variation of the applied fertilizer for each crop type: i.e. improved management, Nitrate directive derogations.

4.Scenario Analysis-Climate change Projections



Model prediction **for RCP 8.5 2041-2050 scenario** summer season under current land use

Development of alternative scenarios considering different climate change projections according with different combination of GCM and RCM.

4.Scenario Analysis-Climate change Projections

Climate projections: obtained from regional climate models under different emission scenarios to describe future climate conditions

- Precipitation (mm)
- Temperature (°C)

Reference Period
2004 - 2013

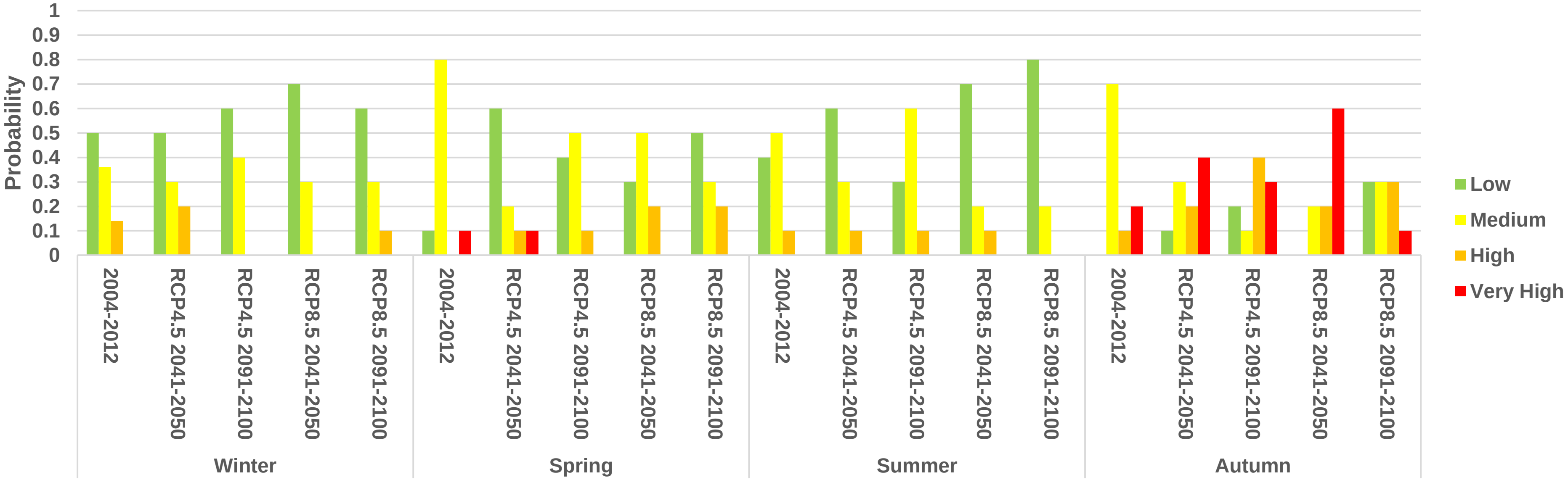
Medium-term Period
2041 - 2050

Long-term Period
2091-2100

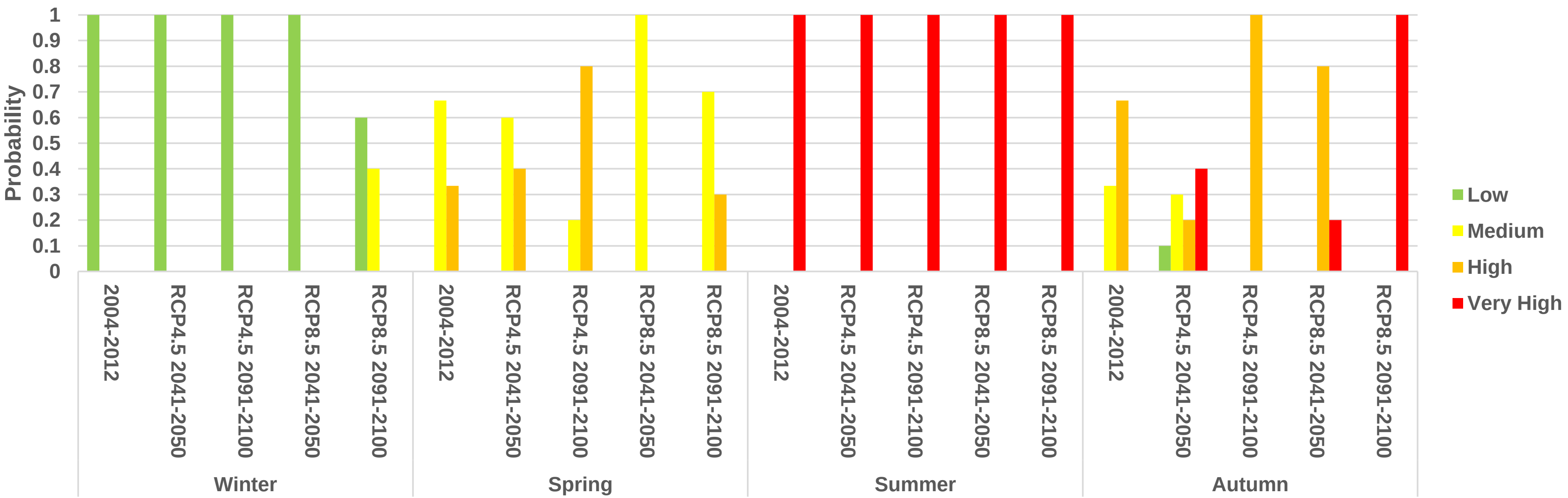
Run	Global Climate Model (GCM)	Regional Climate Model (RCM)	Resolution	Emission
1	ICHEC-EC-EARTH	RACMO22E	12.5 km	RCP 4.5 RCP8.5
2	IPSL-IPSL-CM5A-MR	RCA4	12.5 km	RCP 4.5 RCP8.5
3	MOHC-HadGEM2-ES	RCA4	12.5 km	RCP 4.5 RCP8.5
4	MPI-M-MPI-ESM-LR	RCA4	12.5 km	RCP 4.5 RCP8.5
5	ICHEC-EC-EARTH	RCA4	12.5 km	RCP 4.5 RCP8.5
6	ICHEC-EC-EARTH	HIRHAM5	12.5 km	RCP 4.5 RCP8.5
7	CMCC-CM	COSMO-CLM	8 km	RCP 4.5 RCP8.5
8	CNRM-CM5	CCLM4-8-17	12.5 km	RCP 4.5 RCP8.5
9	CNRM-CM5	RCA4	12,5 km	RCP 4.5 RCP8.5
10	MOHC-HadGEM2-ES	RCA4	12,5 km	RCP 4.5 RCP8.5

4.Scenario Analysis

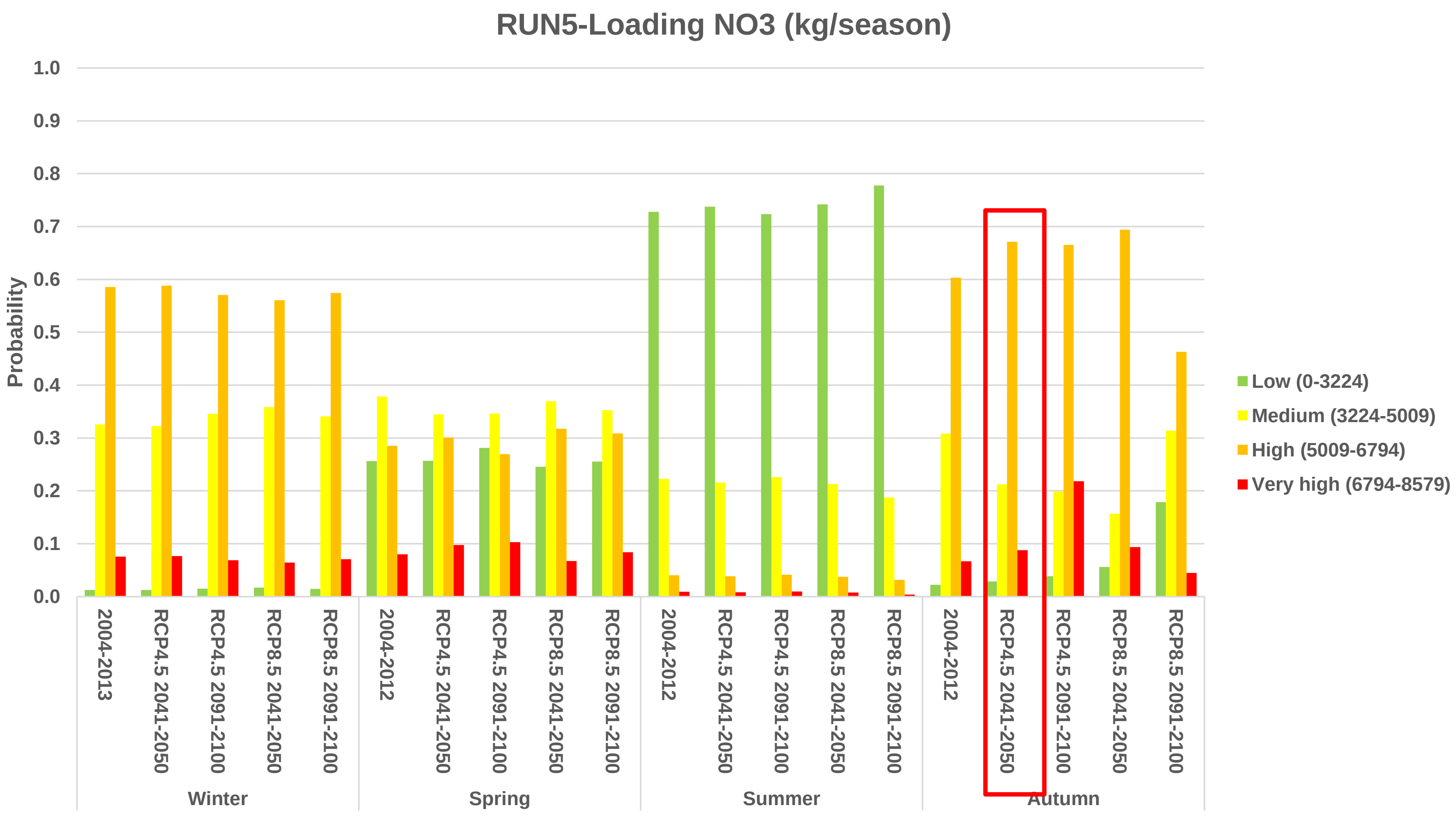
RUN5-Precipitation (mm)



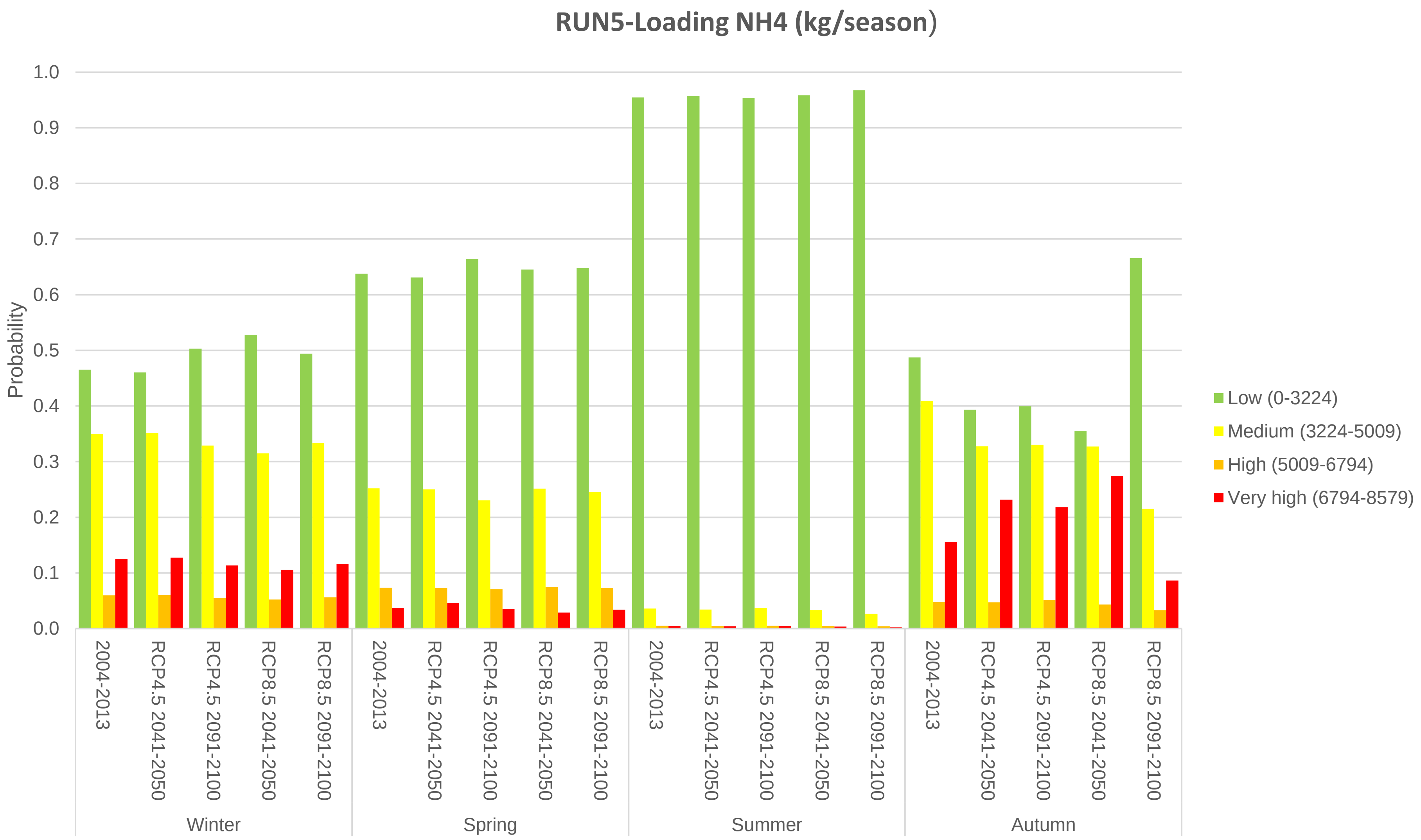
RUN5-Temperature (C)

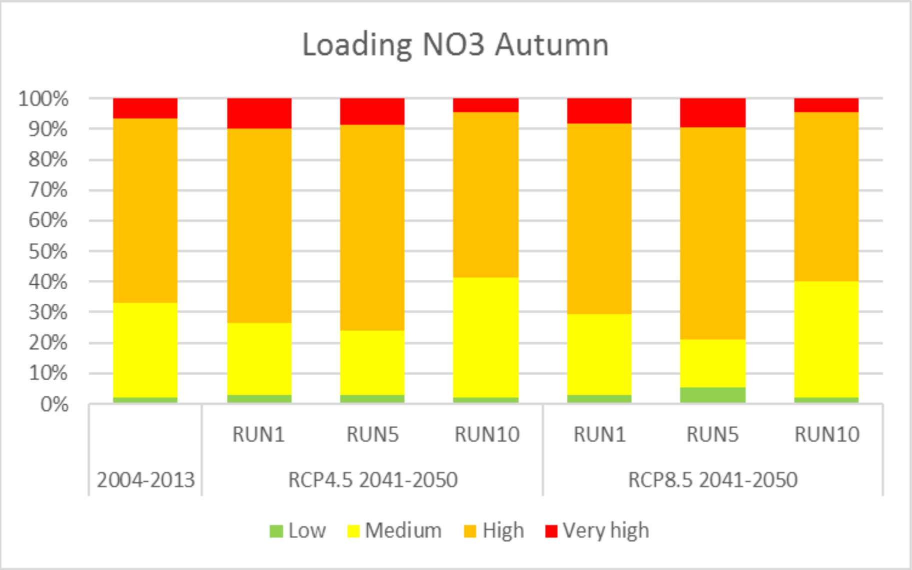


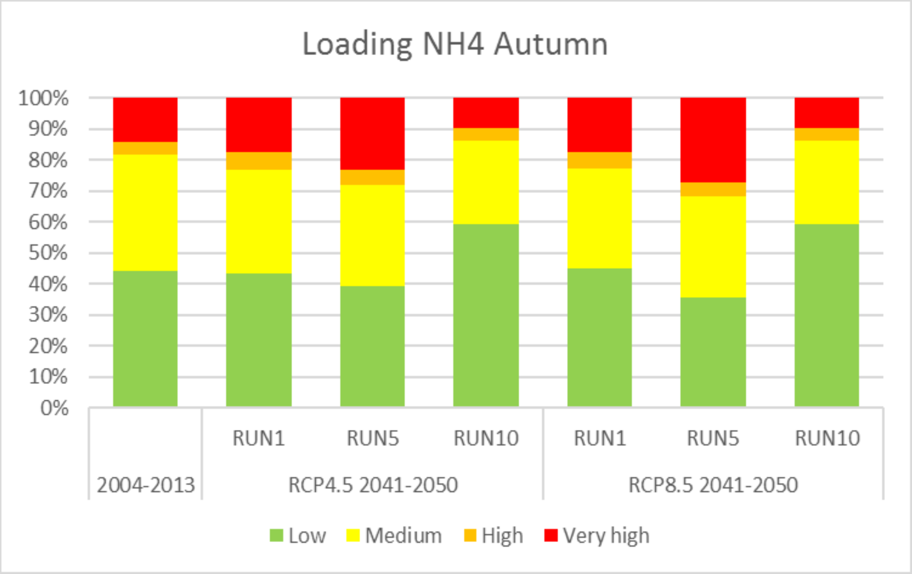
4.Scenario Analysis



4.Scenario Analysis







...the picture gets even more complicated if we look at multiple climate change model....

Future developments

- Development of scenarios for multiple climate change projections and analysis of uncertainty;
- Implementation of future land use scenarios;
- Analysis of interactions and prioritization of different stressors (i.e. climate change, land use);
- Evaluation of management practices and adaptation measures according with stakeholders needs;
- Link nutrients loading with ecological indicators as required by WFD.

Thanks for for your attention!

For more information:
Anna Sperotto

Environmental Risk Assessment Unit, Ca' Foscari University, Venice: http://venus.unive.it/eraunit/

Euro-Mediterranean Center on Climate Change (CMCC), RAAS - Risk assessment and adaptation strategies, Venice: www.cmcc.it/it/divisions/raas

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Some references:

Gallina V., Torresan S., Critto A., Sperotto A., Glade T., Marcomini A., 2016. ***A review of multi-risk methodologies for natural hazards: Consequences and challenges for a climate change impact assessment*** in JOURNAL OF ENVIRONMENTAL MANAGEMENT, vol. 168, pp. 123-32-132 (ISSN 0301-4797);

Sperotto A., Molina J.L., Torresan S., Critto A., Marcomini A**.,** 2017. ***Reviewing Bayesian Networks' potentials for climate change impacts assessment and management: a multi-risk perspective***. Journal of Environmental Modelling and Software (Submitted).