Economic impacts of ozone on crops & forests - 1990 to 2030

Conclusions from the APollO project

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TFIAM 49, 20-22 April 2020

Background to this work

- Research project APollO: Economic analysis of air pollution impacts from ozone on agricultural and forestry productivity
- Co-financed by the French Ministry for the Environment and the ADEME (Agency for the Ecologic Transition)
- November 2016 to June 2019
- Partners
  - INERIS: National Institute for the Industrial Environment and Risks
  - APCA: Permanent Assembly of the Chambers of Agriculture
- Objectives
  - Develop the modelling suite to quantify and monetize the effects of atmospheric ozone pollution on the productivity of crops and forests using the stomatal ozone flux indicator
  - Apply the modelling chain to different case studies in France and Europe

Schucht S., Tognet F., Colette A., Létinois L., Lenoble C., Agasse S., Mathieu Q. 2019. Coût économique pour l'agriculture des impacts de la pollution de l'air par l'ozone - APollO : Analyse économique des impacts de la pollution atmosphérique de l'ozone sur la productivité agricole et sylvicole en France. Rapport,160 pages.

Methods

- Implementation of the ozone flux concept as in the CLRTAP Modelling & Mapping Manual
  - Use of POD6SPEC for wheat, tomatoes, potatoes and POD1SPEC for grassland, beech, oak, spruce
- Development of an offline ozone module that can accommodate modelling results (CHIMERE) and observation data
- Case studies
  - EU28, 1990-2010, based on Eurodelta-Trends study (*), respective meteorological conditions
  - France, 1990-2010 with a specific focus on the 2003 heatwave (same data sources)
  - France 2010, 2020 & 2030, based on PREPA (**) study, meteorological conditions 2010
  - France, 1990-2010 & 2020 & 2030, integrated series, based on Eurodelta and PREPA study data
- Climate effects and changes in agricultural practices were not accounted for
- Survey to experts from agricultural chambers on economic impact and feasibility of adaptation strategies

(*) Colette, A., Andersson, C., Manders, A., et al. (2017): EURODELTA-Trends, a multi-model experiment of air quality hindcast in Europe over 1990–2010, Geosci. Model Dev. 10(2017), pp. 3255-3276.

(**) PREPA = NEC Air Pollution Emissions Reduction Plan, scenarios from the study Aide à la décision pour l'élaboration du PREPA, rapport principal, Le Plan national de réduction des émissions de polluants atmosphériques, 2016

Phytotoxic ozone dose (POD) calculation

- Central is the calculation of an instantaneous stomatal conductance (g_{sto}) proposed by Jarvis (1976) and modified by Emberson et al (2000) defined as:

$$g_{sto} = g_{max} * [\min(f_{phen}, f_{O3})] * f_{light} * \max\{f_{min}, (f_{temp} * f_{VPD} * f_{SW})\}$$

- g_{sto} and g_{max} (species -specific maximum value for the stomatal conductance) are measured in mmol O_3 $m^{-2}s^{-1}$ of Projected Leaf Area (PLA)
- Parameters f_{phen}, f_{O3}, f_{light}, f_{temp}, f_{VPD}, f_{SW} and f_{min} are expressed as relative proportions of g_{max}, taking values between 0 and 1
- They allow taking into account the influence on stomatal conductance of irradiance (f_{light}), temperature (f_{temp}), water vapor deficit at leaves level (f_{vpd}), soil moisture (f_{sw}), the phenology for the different growing stages (f_{phen}) and the influence of O_3 on the stomatal flux by promoting premature senescence (f_{O3}).
- f_{min} is the minimum relative value of stomatal conductance during daylight

Jarvis, P.G., 1976. The interpretation of the variations in leaf water potential and stomatal conductance found in canopies in the field, Philos. Trans. R. Soc. Lond., B 273, 593-610.
Emberson, L., Simpson, D., Tuovinen, J.-P., Ashmore, M. & Cambridge, H. M. (2000b) : Towards a model of ozone deposition and stomatal uptake over Europe, Rep. No. Note 6/2000. EMEP MSC-W.

Data

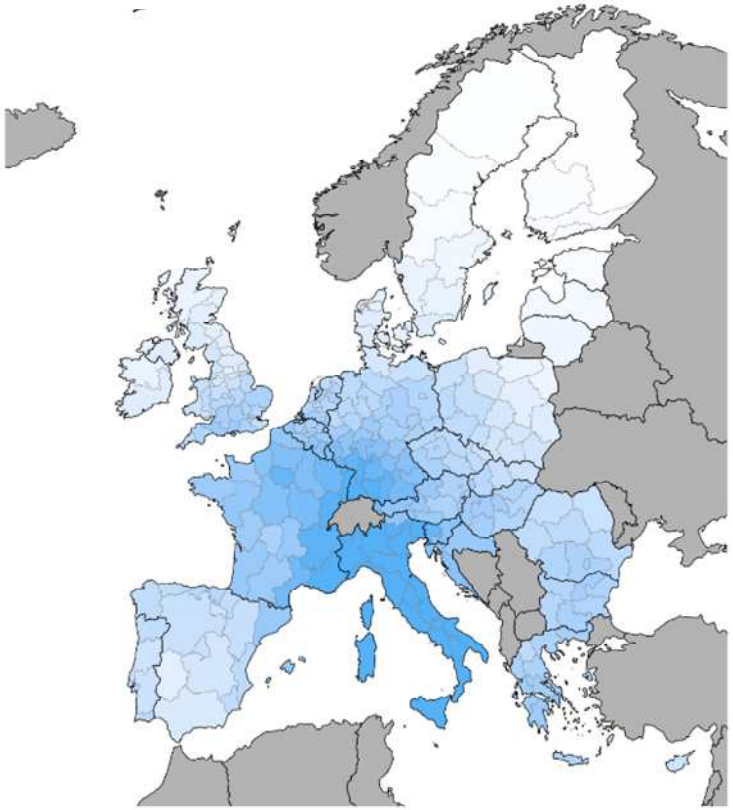
Input data	Land use		Production		Prices	
Species	**France**	**Europe**	**France**	**Europe**	**France**	**Europe**
Wheat	AGRESTE & Corine Land Cover	Corine Land Cover (NUTS 2)	AGRESTE	EUROSTAT	FranceAgriMer (quotations)	EUROSTAT (selling price)
Tomatoes cultivated outside greenhouses					FranceAgriMer-RNM (quotations)	
Potatoes					AGRESTE (quotations)	
Grassland				EUROSTAT; Huygue et al. (2014)	Cabinet d'experts comptables CGOCEAN (average fodder price)	-
Beech	BD FORET® v2 from IGN	-	IGN	-	ONF-DCBS (average prices for standing timber)	-
Oak		-		-		-
Spruce		-		-		-

- A single reference year for production and prices (2010)

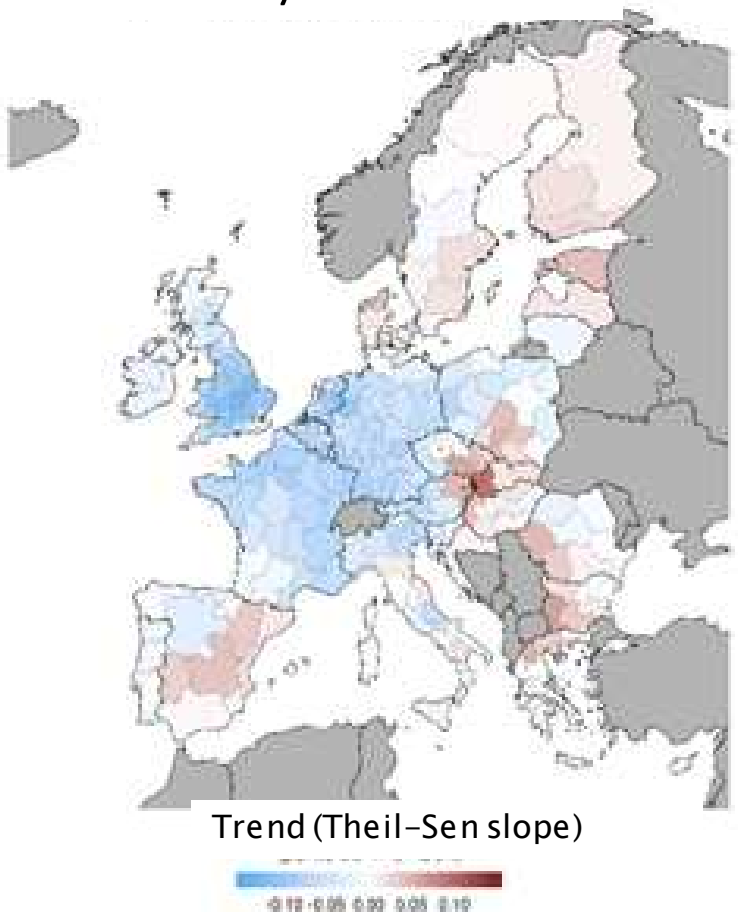
  => to isolate the ozone impact on yield losses (otherwise need for decomposition analysis)

AOT40 vs. POD for wheat in Europe, trend 1990-2010

Trend AOT40 1990–2010



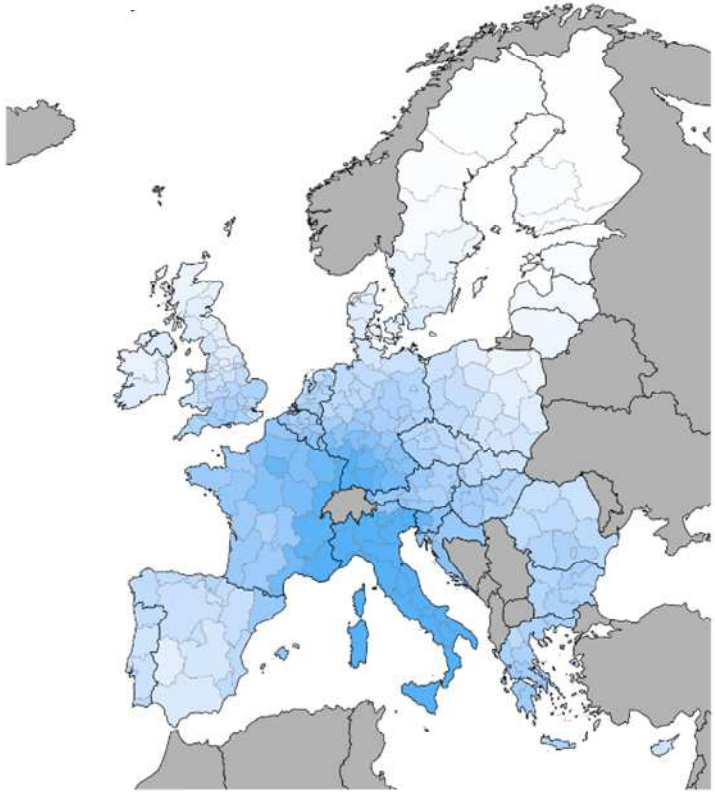
Trend PODy wheat 1990–2010



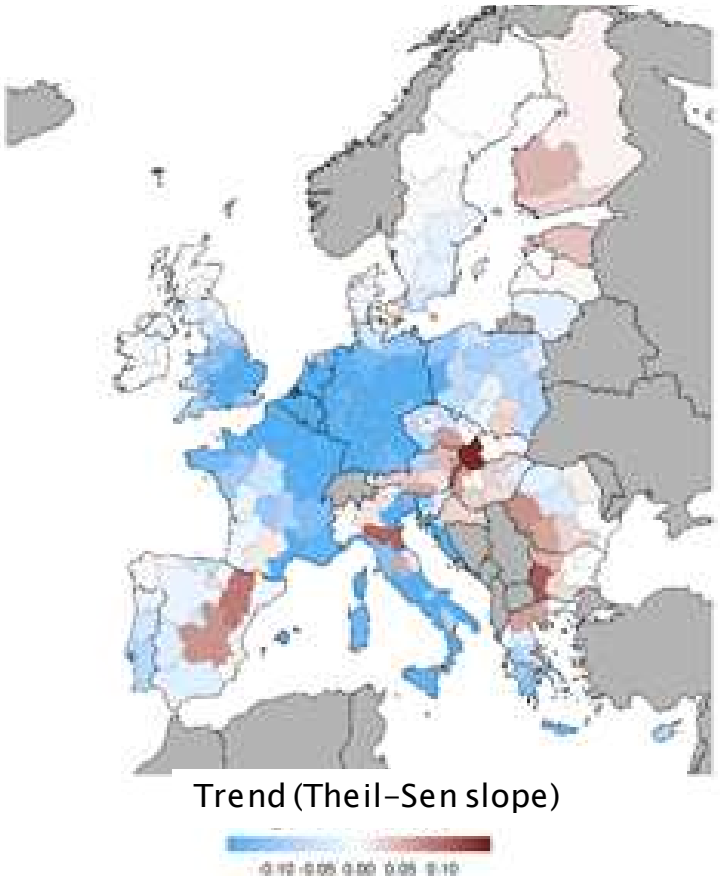
- AOT40: decreasing trend between 1990 and 2010 all over Europe
- For POD results vary between species and regions
- POD wheat - increasing trend in certain geographic areas (Central and Eastern Europe)

AOT40 vs. POD for potatoes in Europe, trend 1990-2010

Trend AOT40 1990-2010



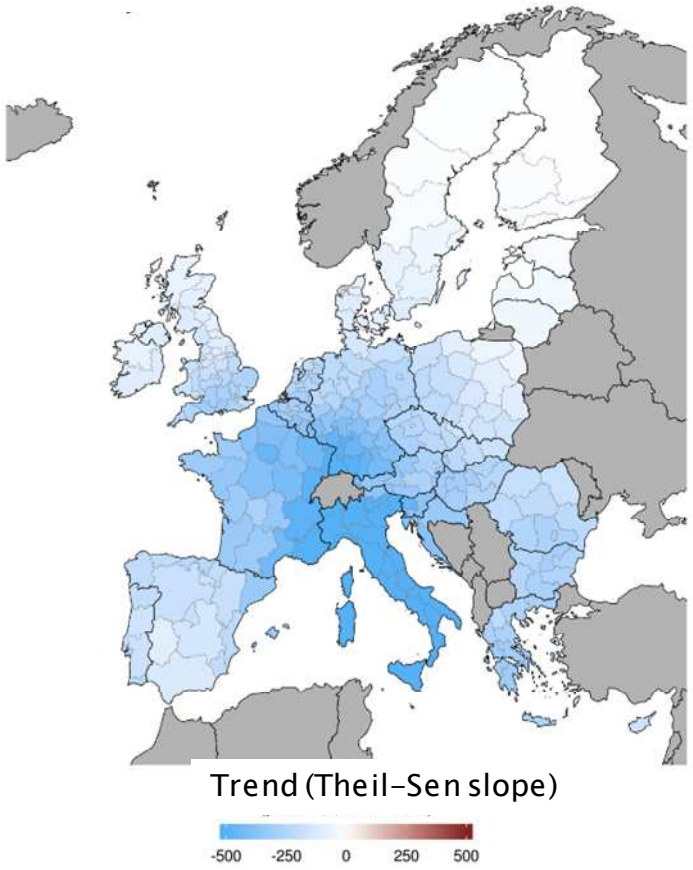
Trend PODy potatoes 1990-2010



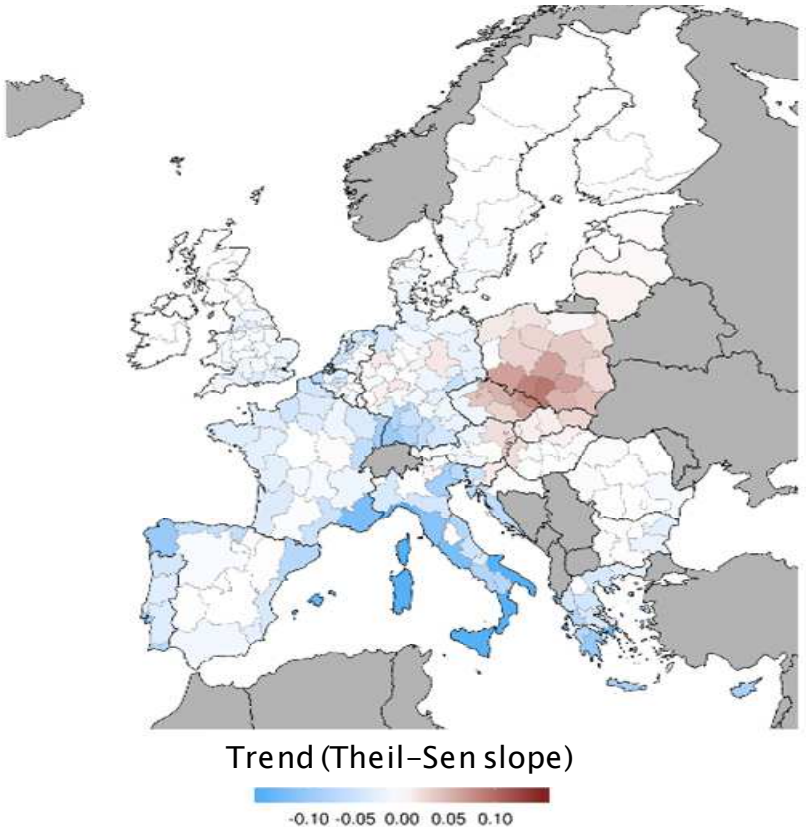
- POD for potatoes – differences between regions more marked than for wheat

AOT40 vs. POD for tomatoes in Europe, trend 1990-2010

Trend AOT40 1990–2010

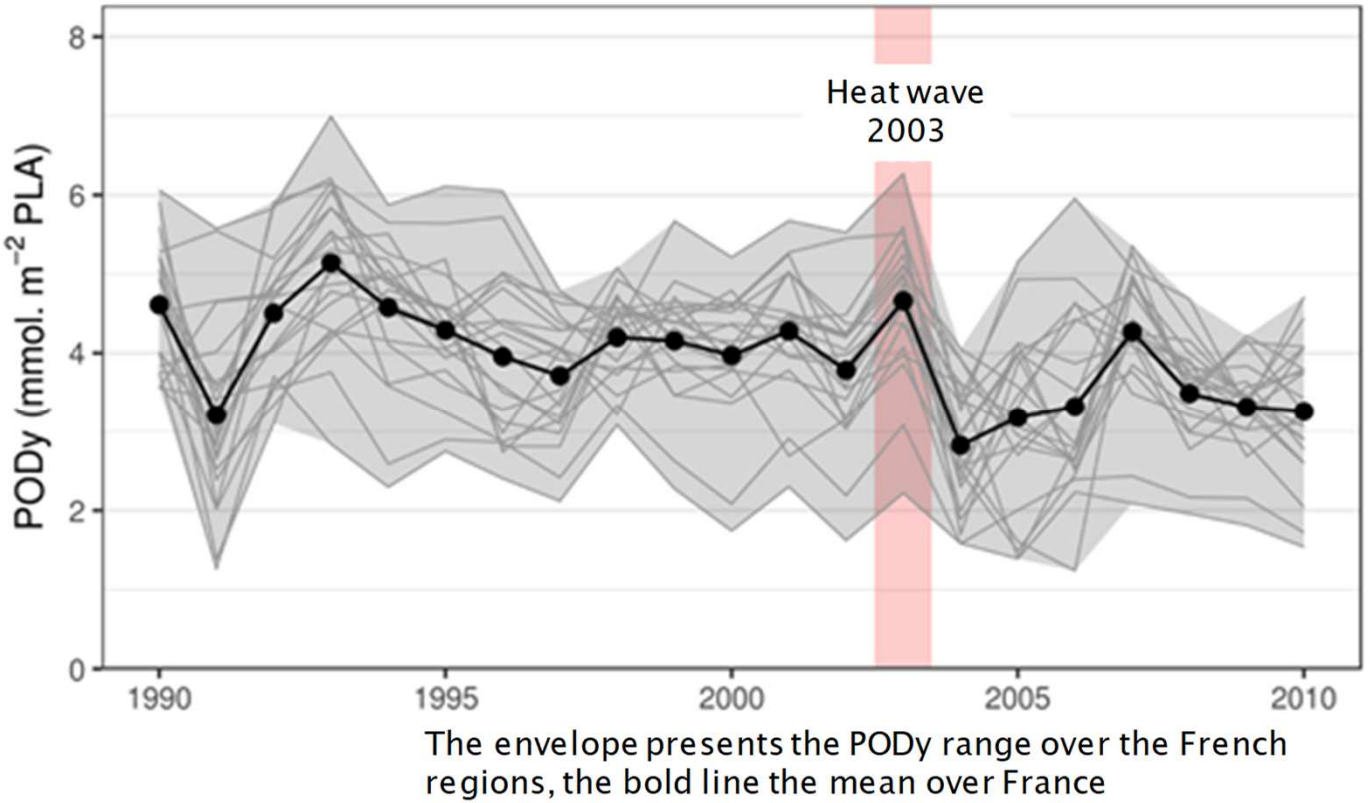


Trend PODy tomatoes 1990–2010



- POD for tomatoes (open field production only) – most neutral trend amongst the species studied for Western Europe

Heatwave impact on POD for wheat in French regions, trend 1990-2010



The envelope presents the PODy range over the French regions, the bold line the mean over France

- Marked decreasing trend for POD for wheat in France
- Identifiable peak in 2003, moderate in the light of the trend and the interannual variability
- Limited impact of the heatwave in 2003 on crops and forests (in line with other studies)
- Low POD for 1991 (fresh spring) and 2004 (summer without anticyclonic conditions)

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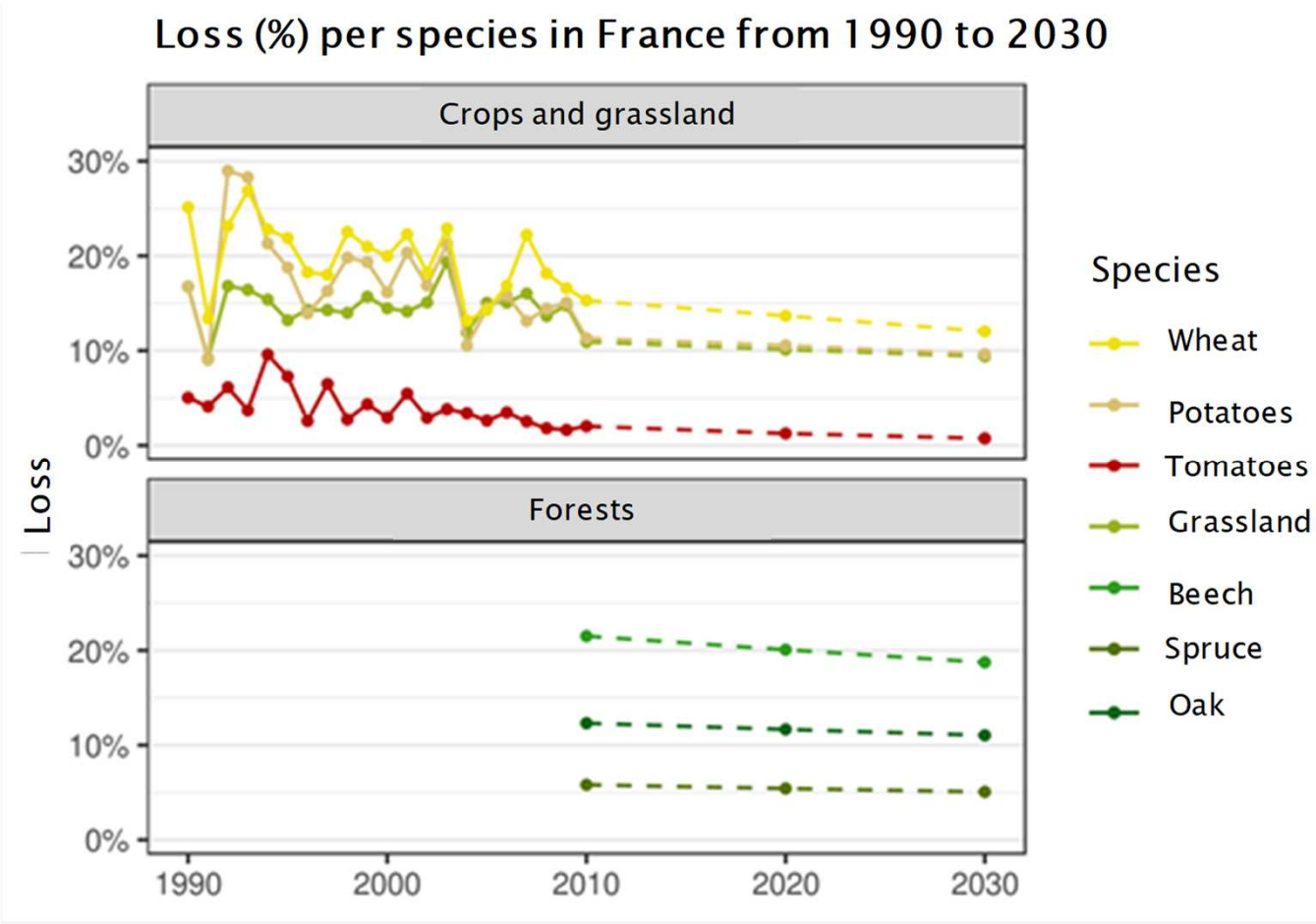
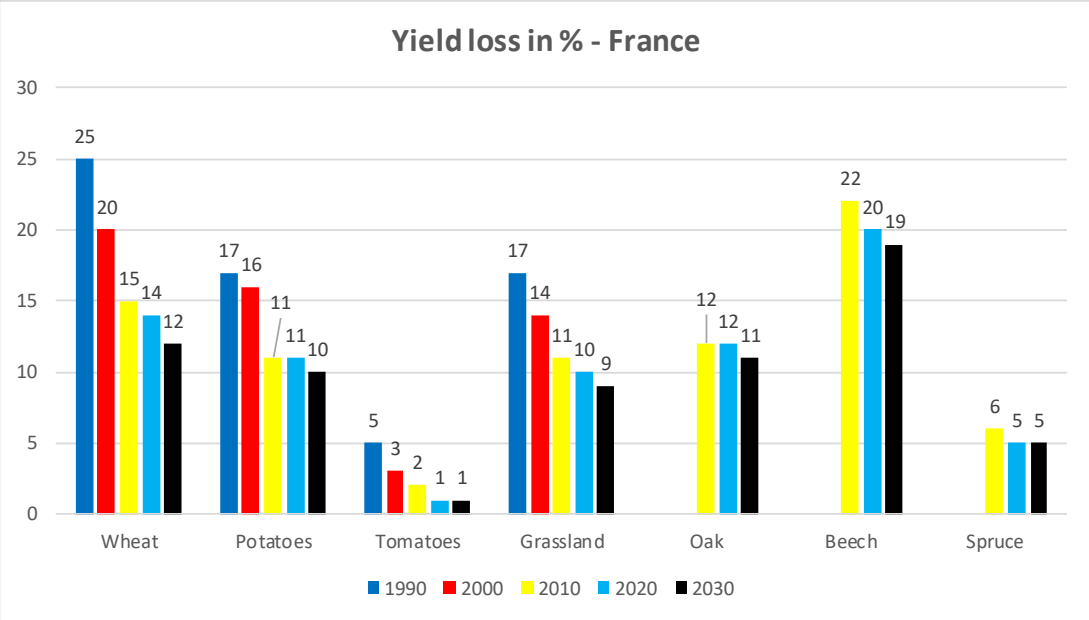
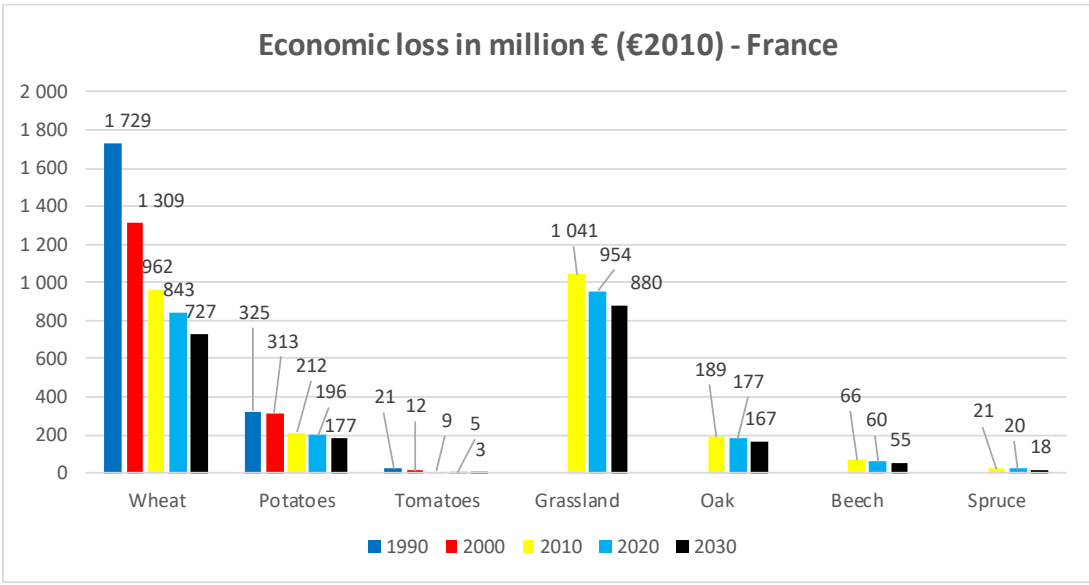
Yield loss for POD for crops and forests in France, 1990-2030



- Correction applied over the time series based on analysed data available for 2010
- Slight decrease in trend for all species
- Relatively less pronounced for tomatoes (and spruce)
- Lower conductance, later accumulation period for tomatoes => lower ozone absorption in Western Europe than for other species
- Decreases less pronounced between 2010 and 2030

Yield and economic losses in France





- Despite the decreases in POD levels aggregated yield losses in France remain important
- Expected reductions between 2010 and 2030 appear lower than those between 1990 and 2010
  - Climate penalty not accounted for => source of additional uncertainty for the results
- Economic losses most pronounced for wheat and grassland
- For tomatoes only open field production considered (1/3 of overall production in France)
- LRTAP manual emits reservations for quantification of yield loss (and economic damage associated) for trees

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Economic losses in France – crops vs. health

Costs in million € (€$_{2010}$)	2030
Health damage of $PM_{2.5}$, O_3, NO_2	22 239
amongst which health damage of O_3	502
Damage on crops and grassland of O_3 – corrected values	1 786

- Economic loss for crops and grassland compared to health damage (PREPA project scenario for 2030)
  - In 2030 the estimated economic impacts of ozone on crops and grassland correspond to approximately 8 % of the health costs from O_3, $PM_{2.5}$ & NO_2
  - The estimated economic impacts of ozone on crops and grassland are three times higher than the ozone impacts on health
  - The indicators are not directly comparable: turnover versus societal impact

Uncertainties

- Cumulating over the modelling steps
- Examples specific to this study
  - estimation of ozone accumulation periods undifferentiated between different varieties of a given crop
  - application of identical hypothesis over the whole region (stomatal conductance, response functions)
  - quantification of production (open field production of tomatoes, grassland)
  - spatialization of production
  - price assumptions for some species and regions
  - disregard of long growing periods for trees
  - use of production and price data for one reference year only
  - disregard of climate effects

=> But: results consistent with other available (comparable) studies

Limited results from the survey

- Limited knowledge of ozone impact by experts from agricultural chambers
- Huge spread in estimates of perceived loss in income and profit
- Adaptation strategies discussed in literature perceived as non applicable
  - Plant growth regulators & fungicides counter to phytosanitary policy
  - Irrigation strategies not relevant in many regions
  - Replacement by other crops or tree species limited by market demand or habitat requirements
  - …

  ⇒ Strategies to reduce ozone precursor emissions appear more appropriate than adaptation strategies by the sector

Conclusions

- A module calculating stomatal ozone fluxes was developed
  - able to use data from observations and from CTMs
  - furthermore quantifying the impact of ozone in terms of yield and economic loss
- It was applied to case studies for EU28 and France spanning 4 decades
- Results show a trend towards reduced ozone impacts when aggregated over France and EU28
- Localized increases in ozone impacts appear in certain regions, depending on the species
- Results overall consistent with those of comparable studies
- Economic loss in France remains high
  - 2010: ≈ 1 billion € for wheat, > 1 billion € for grassland, > 200 million € for potatoes
- Inclusion of ozone impacts on crops significantly increases overall ozone damage estimated, even though the share in overall health damage remains limited
- Strategies to reduce ozone precursor emissions appear more appropriate than adaptation strategies

Thank you for your attention