FROM WATER TO BIOETHANOL: THE IMPACT OF CLIMATE VARIABILITY ON THE WATER FOOTPRINT

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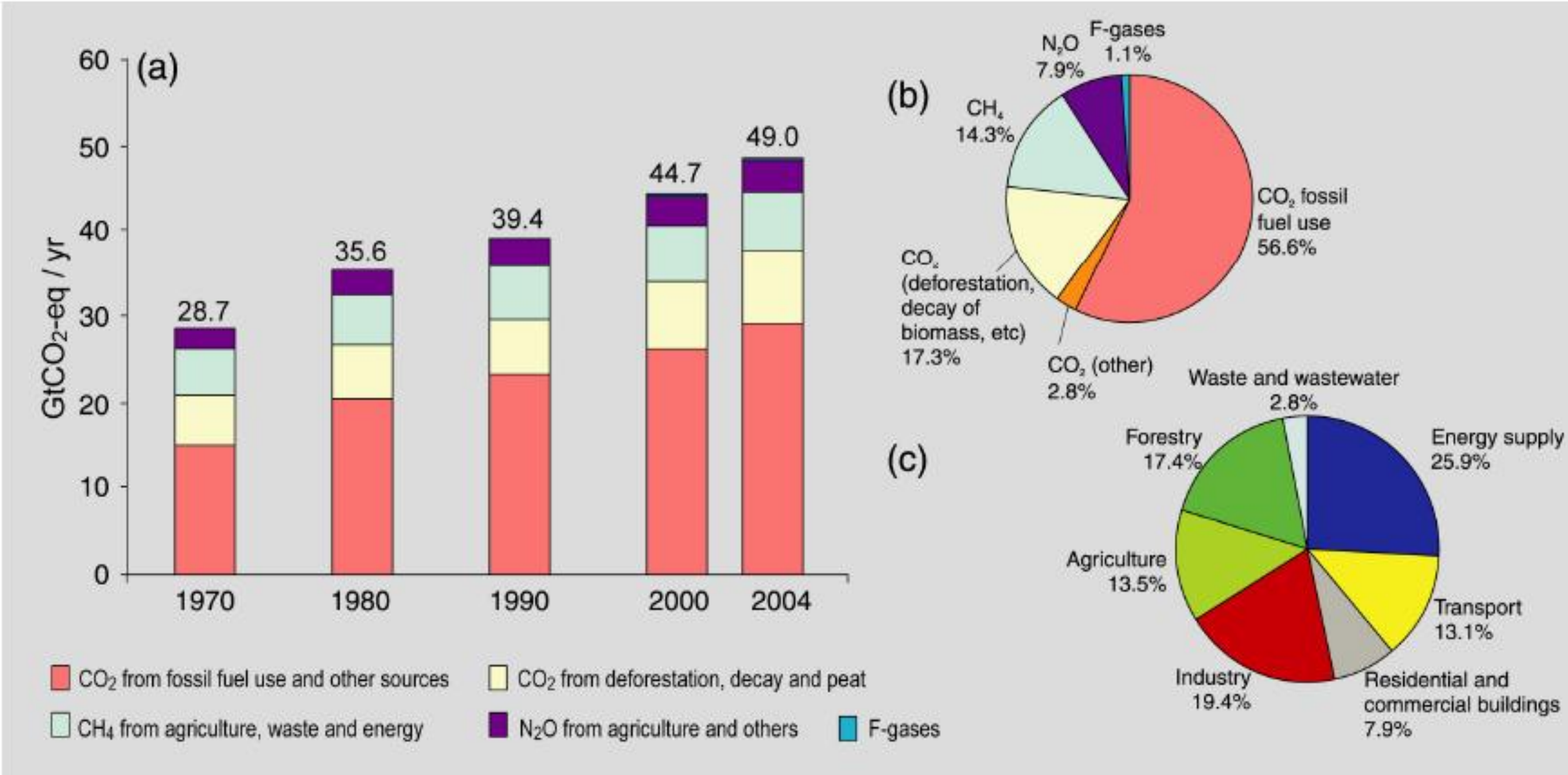
Global anthropogenic GHG emissions



(a) Global annual emissions of anthropogenic GHGs from 1970 to 2004.[5] (b) Share of different anthropogenic GHGs in total emissions in 2004 in terms of CO_2-eq. (c) Share of different sectors in total anthropogenic GHG emissions in 2004 in terms of CO_2-eq. (Forestry includes deforestation).

SUPPORT PROVIDED AT DIFFERENT POINTS IN THE BIOFUEL SUPPLY CHAIN

SUPPORT TO INPUTS

- Fertilizer, irrigation and other inputs support
- General energy and water-pricing policies
- Land-tenure policies

SUPPORT TO PRODUCTION

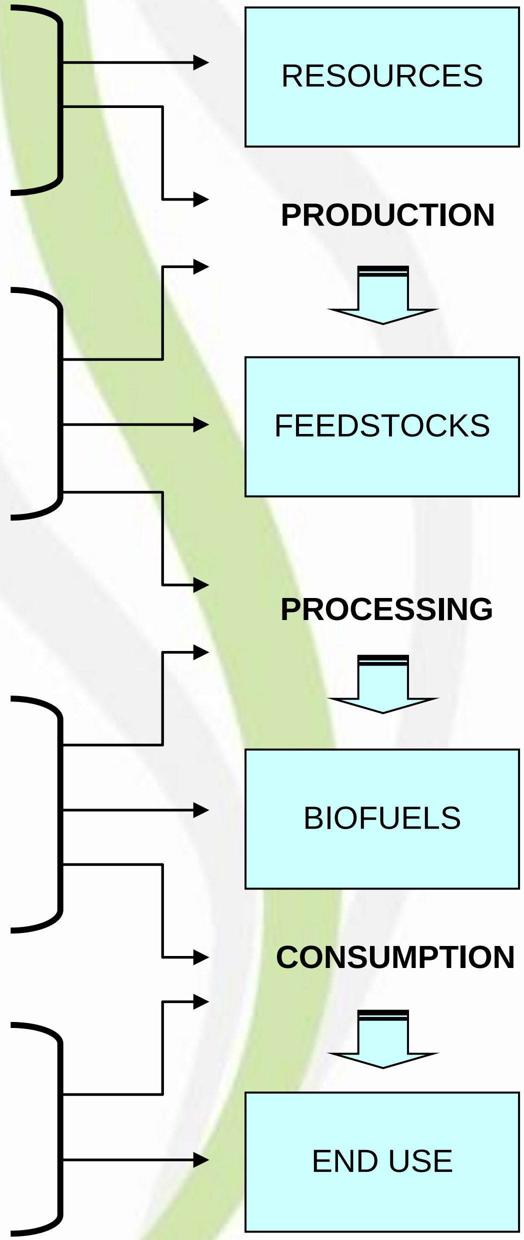
- Domestic agricultural subsidies
- Farm income support
- Trade policies
- General support to agriculture

PROCESSES AND MARKETING SUPPORT

- Production-linked payments
- Tax credits, incentives and exemptions
- Trade policies
- Subsidies for capital investments

SUPPORT TO CONSUMPTION

- Subsidies for purchase of biofuels
- Tax exemptions
- Subsidies for flex-fuel vehicle purchase



Source: FAO, 2008 adapted from Steenblink, 2007

ENVIRONMENTAL IMPACTS

SOIL

Reduction of soil organic matter
Soil erosion and compaction
Reduction of soil nutrients
Losses of soil carbon

BIODIVERSITY

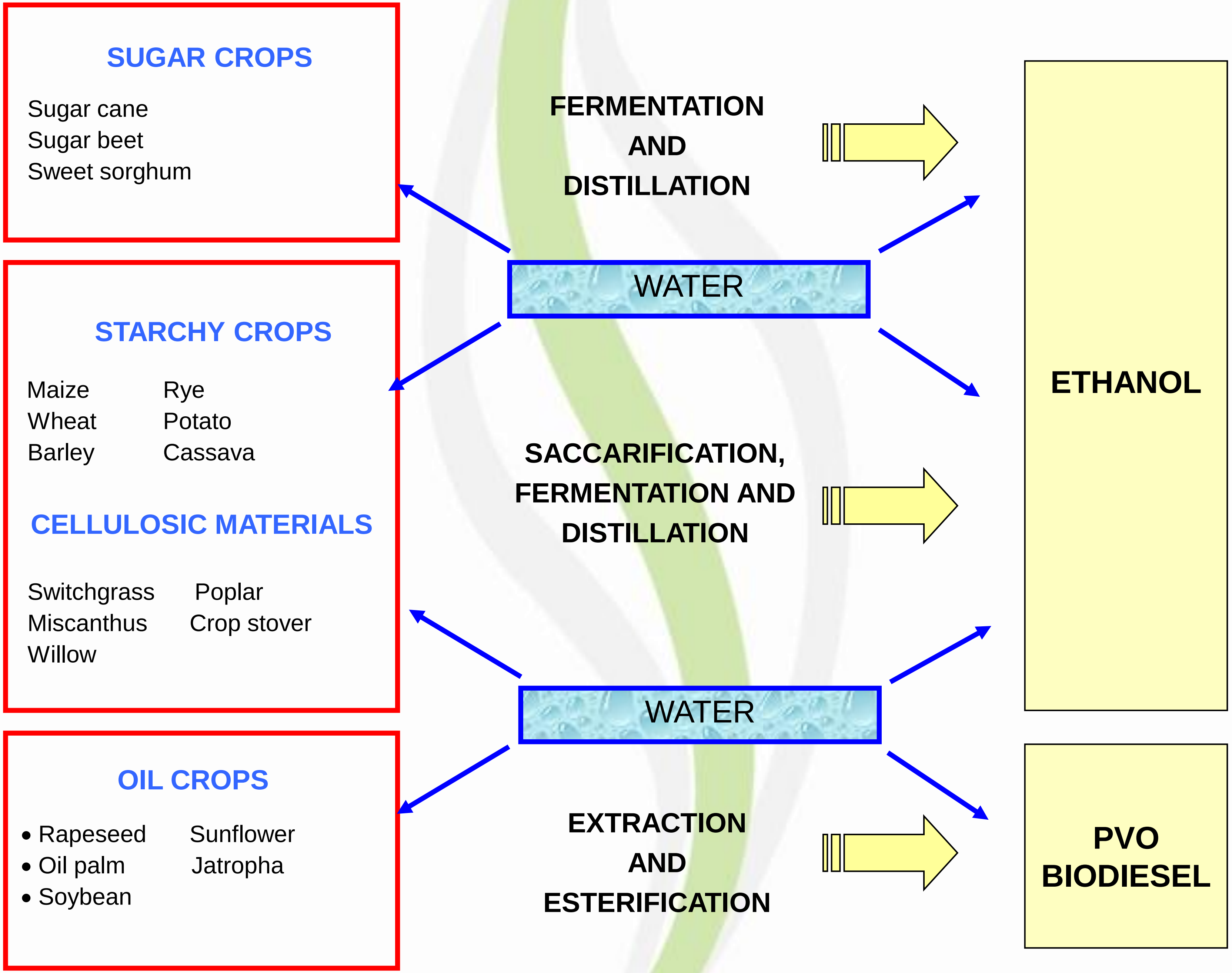
Expansion of crop production area: loss of habitat
Large-scale mono-cropping: system vulnerability

ATMOSPHERE

Land-use change, production intensification on existing croplands, use of pesticides, fertilizers and machinery can have adverse impact on atmosphere through an increased emission of GHG such as CO_2, CH_4 and N_2O

WATER

Many of the crops currently used for biofuel production (sugar cane, oil palm and maize) have high water requirements at commercial yield levels.
The processing of feedstock into biofuels can use large quantities of water
Biofuels production will affect also water quality due to soil erosion, sedimentation and nutrient runoff into surface waters and infiltration into groundwater from increased fertilizer applications



Source: FAO, 2008

CASE STUDY

Because the Regional Energetic Plan (PIER) of Tuscany indicates that for 2020 the production of energy from biofuels for transportation should reach 108 ktoe, (Kyoto Protocol) a careful investigation on the sustainability concerning the water-energy nexus is required, also considering the possible impacts of climate change and variability.

On these bases, the aims of this research are:

a) To estimate the productivity of irrigated maize in Tuscany and its trend for the last 55 years

b) To calculate the **water footprint** of bioethanol potentially produced

c) To analyze the impact of climate change on the use of water for bioethanol production from maize

MATERIALS AND METHODS

SOFTWARE

DSSAT – Ceres - Maize

CLIMATIC DATA

TEMPERATURE and *RAINFALL* from a historical series of homogenized daily data, from 1955 to 2009, coming from 10 weather stations

SOLAR GLOBAL RADIATION calculated by means of ETo Calculator (FAO)

SOIL DATA

The soil was 1.50 m deep with a standard texture (sand 42%, clay 22%, silt 36%)

Organic carbon 0.8%

Total nitrogen 0.08%

IRRIGATION

When AWC < 35%

NITROGEN FERTILIZATION

90 kg/ha at sowing

90 kg/ha at beginning of stem elongation

THE WATER FOOTPRINT OF MAIZE

The water footprint of bioethanol, defined as the ratio of the total volume of water used (m^3/ha) to the quantity of the production (ton/year) (Hoekstra et al., 2011).

The WF of an agricultural product is the volume of water used during the crop growing period for producing a unit of product, and it has three components:

- **GREEN:** the ratio of effective rainfall (R_{eff}) to the crop yield
- **BLUE:** the ratio of effective irrigation (R_{eff}) to the crop yield
- **GRAY:** volume of water that is required to dilute pollutants to restore the quality standards of water. In this study, the water pollution was associated to the leaching of nitrogen (N_{lea}) caused by the use of inorganic fertilizers and the dilution factor (DF) used was 10 mg/l

$$WF_{maize} = WF_g + WF_b + WF_{gray}$$

THE WATER FOOTPRINT OF ETHANOL

The WF of bioethanol was finally obtained considering:

a) **An yield coefficient of 30%**

b) **A volume of water of 15 m^3/t (computed as blue water) for processing maize**

The WF was then expressed as liters of water needed per MJ of energy obtained, in order to better highlight the water-energy nexus.

We fully allocated the WF of the crop to the biofuels derived, assuming that the value of the residues of production is much lower than the value of the biofuel.

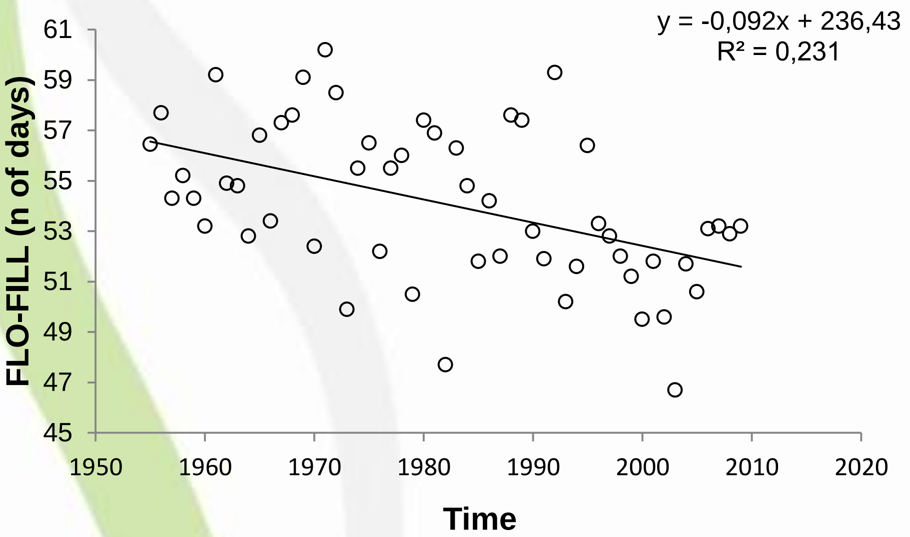
TREND OF MAIZE PRODUCTIVITY

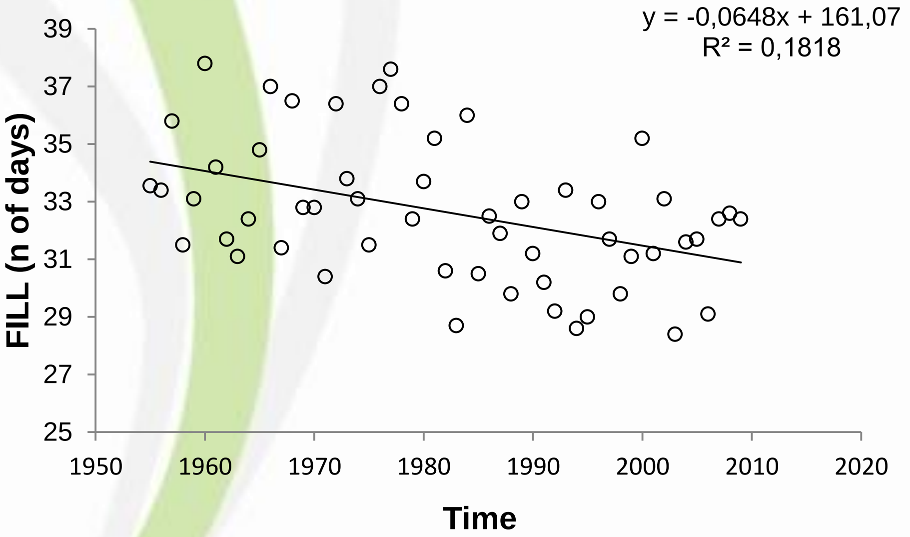
YIELD

Site	R^2	slope	sig
Are	0.681	-36.95	***
Cdp	0.394	-24.15	***
Cng	0.402	-17.34	***
Gro	0.592	-13.55	***
Liv	0.843	-12.06	***
Mama	0.406	-14.82	***
Per	0.556	-14.68	***
Pis	0.762	-19.62	***
Sie	0.421	-4.76	***
Volt	0.500	-13.82	***

Yield reduction over the last 55 years

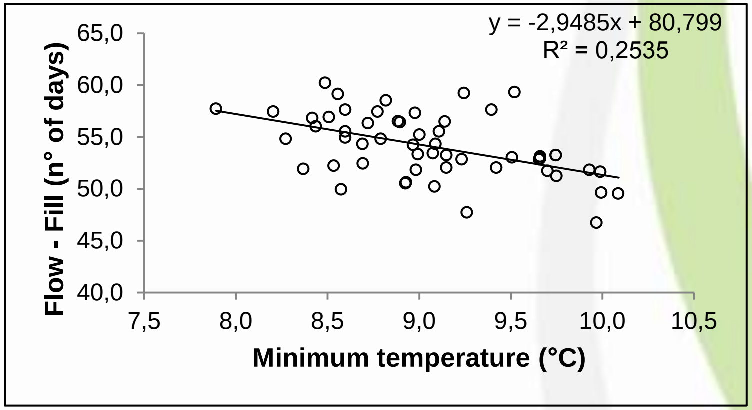
This effect is mainly due to temperature through its role in determining the duration of phenological phases.

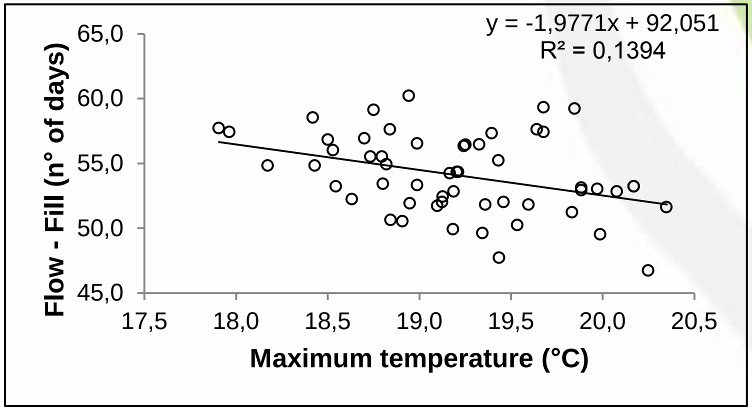


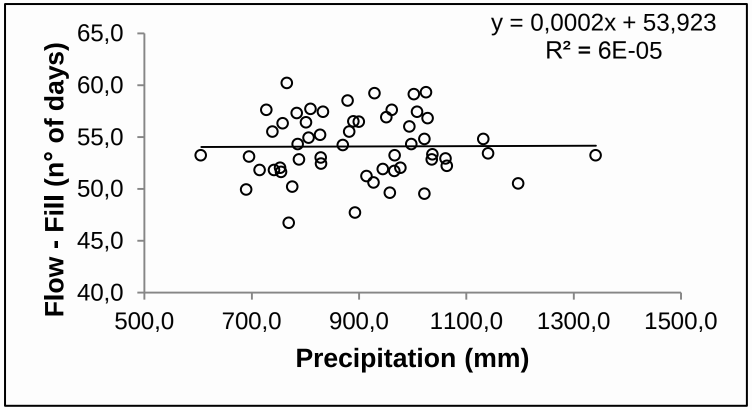


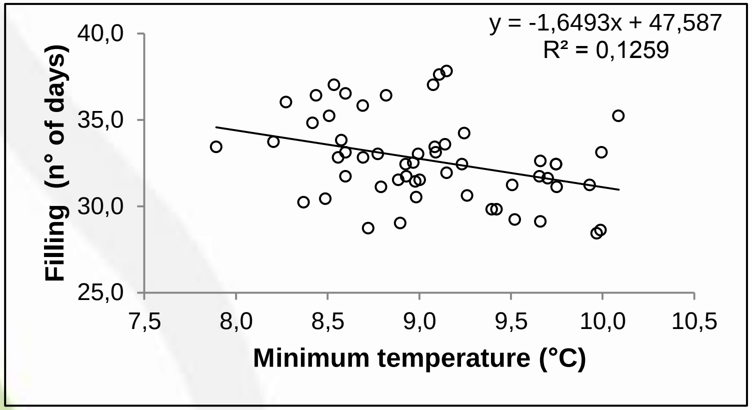
FLOWERING-FILLING

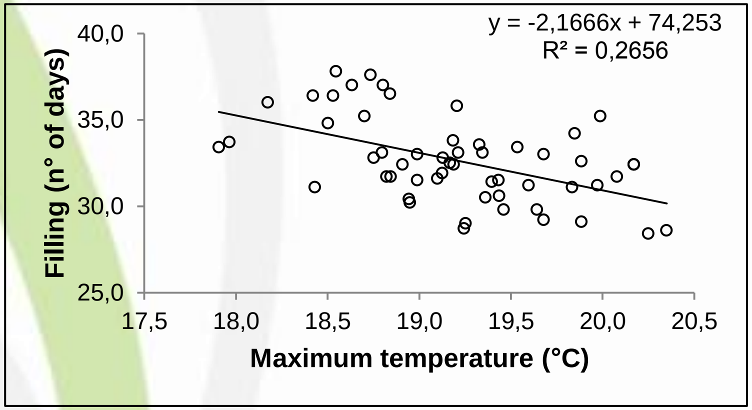
FILLING DURATION

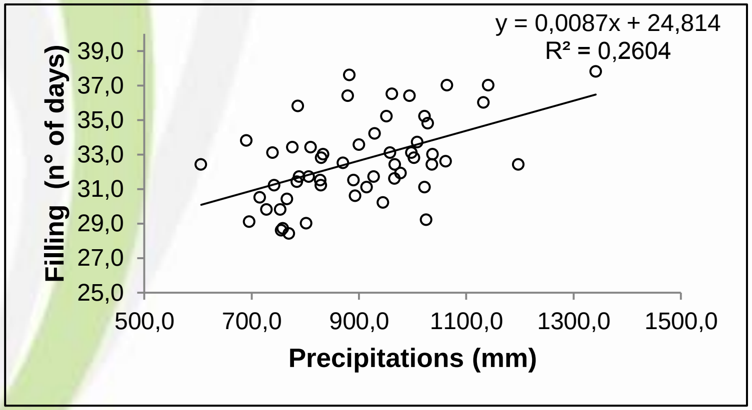










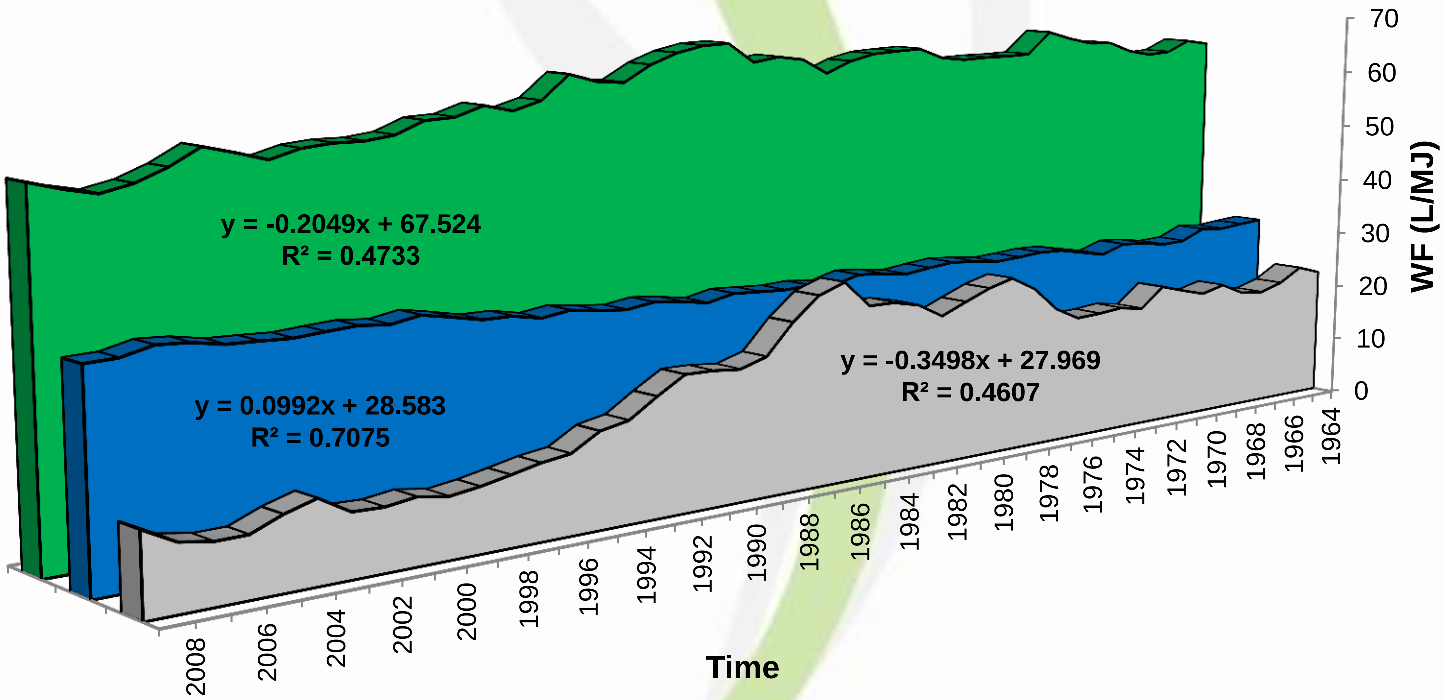


WF TRENDS

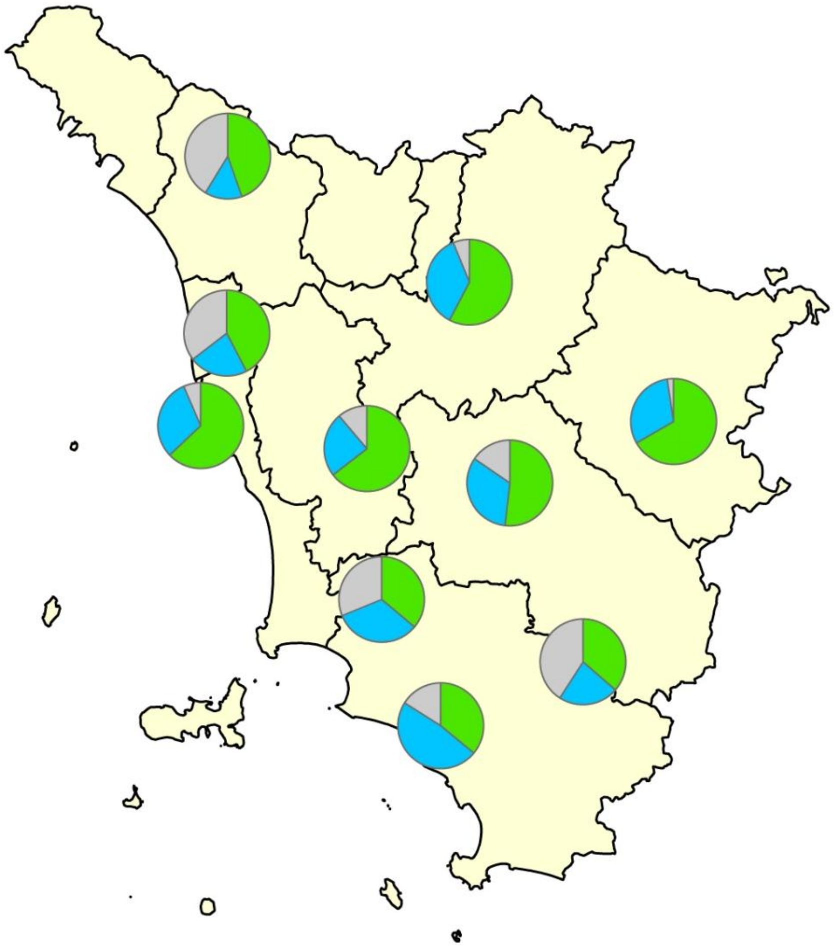
GREEN			
Site	R2	slope	sig
Are	0.32	0.16	***
Cdp	0.85	-0.42	***
Cng	0.70	-0.58	***
Gro	0.21	-0.17	**
Liv	0.36	-0.22	***
Mama	0.41	-0.28	***
Per	0.15	-0.18	**
Pis	0.30	-0.20	***
Sie	0.01	0.03	
Volt	0.28	-0.20	***

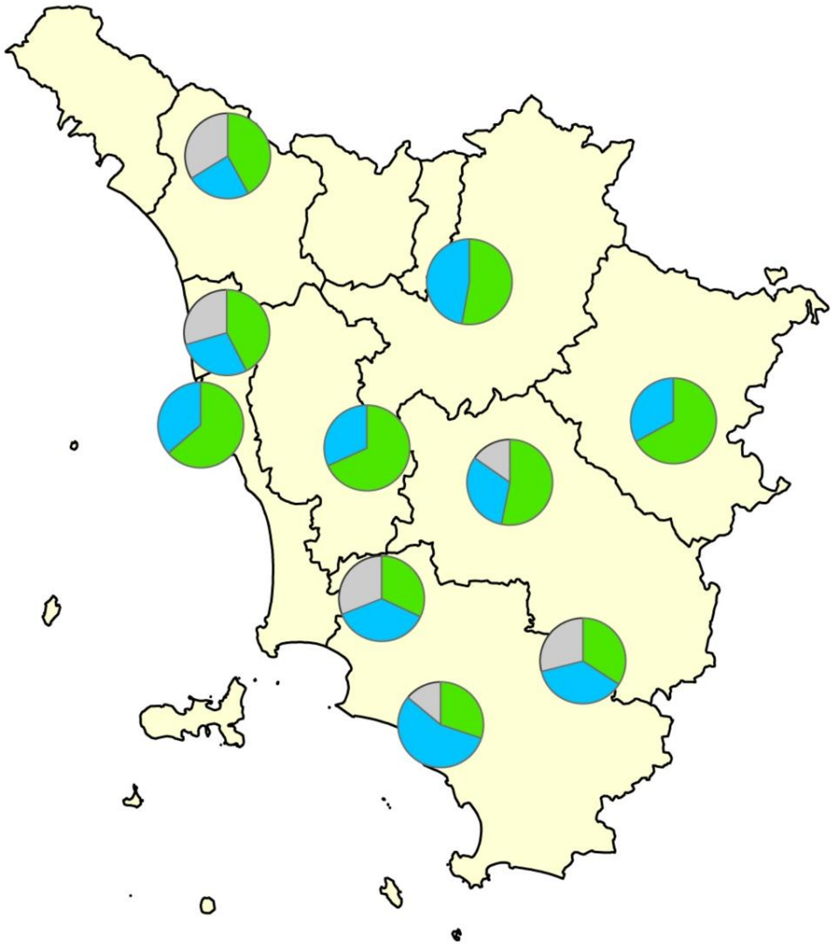
BLUE			
Site	R2	slope	sig
Are	0.08	0.06	
Cdp	0.73	0.24	***
Cng	0.66	0.15	***
Gro	0.38	0.10	***
Liv	0.03	0.02	
Mama	0.62	0.11	***
Per	0.67	0.15	***
Pis	0.20	0.09	**
Sie	0.11	0.03	*
Volt	0.22	0.06	**

GRAY			
Site	R2	slope	sig
Are	0.65	-0.21	***
Cdp	0.63	-0.65	***
Cng	0.56	-0.90	***
Gro	0.02	-0.04	
Liv	0.53	-0.34	***
Mama	0.09	-0.25	*
Per	0.36	-0.50	***
Pis	0.42	-0.38	***
Sie	0.02	0.04	
Volt	0.26	-0.29	***

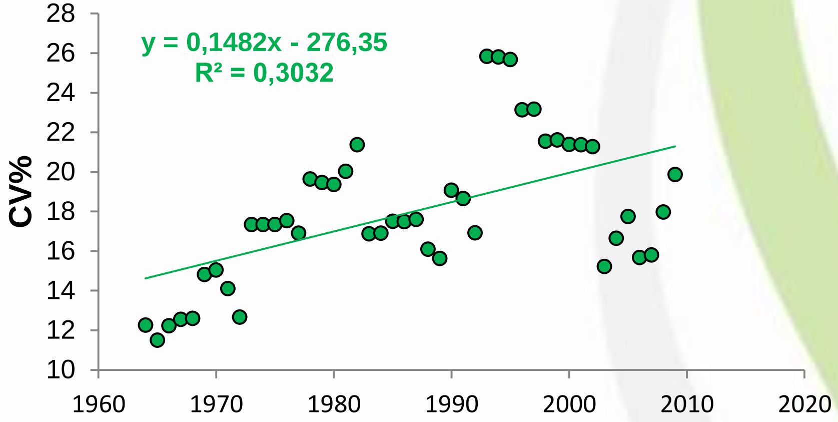


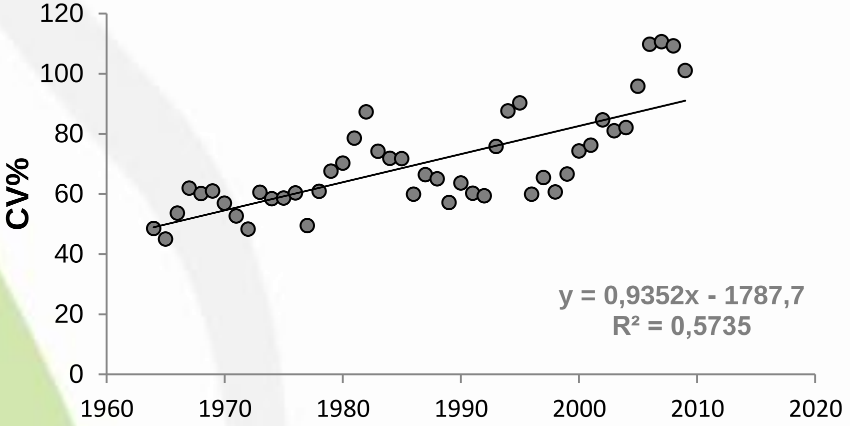
CHANGE OF WF FROM 1955 TO 2009

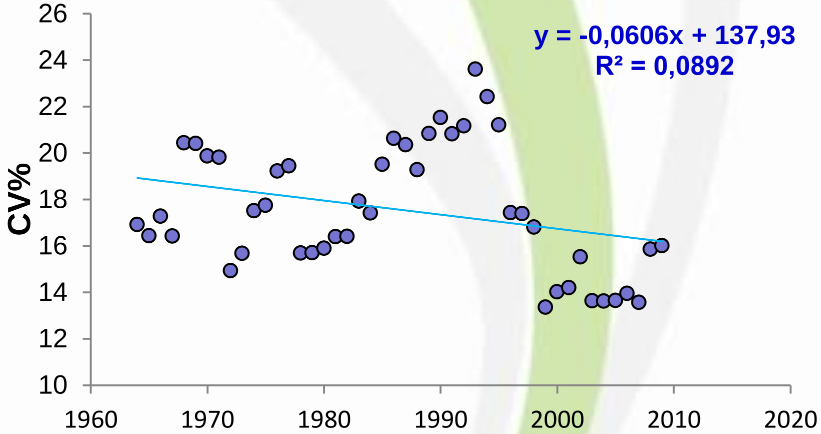




WF VARIABILITY







THE BIOETHANOL WF

AVERAGE
113 L/MJ

AVERAGE
2378 L/L

L of water per MJ

	GREEN WF	BLUE WF	GRAY WF	TOTAL WF
Are	52	29	8	**89**
Cdp	63	28	21	**111**
Cng	86	26	73	**185**
Gro	46	40	3	**88**
Liv	61	33	10	**104**
Mama	62	33	19	**114**
Per	65	30	20	**115**
Pis	59	32	16	**107**
Sie	61	31	8	**99**
Volt	71	29	19	**119**

L of water per L of ethanol

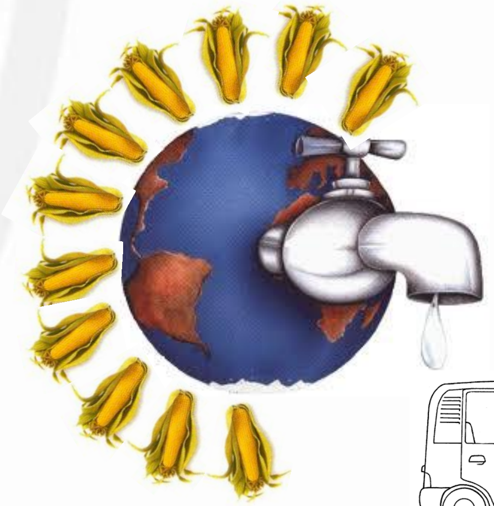
	GREEN WF	BLUE WF	GRAY WF	TOTAL WF
Are	1086	618	161	**1865**
Cdp	1319	580	433	**2333**
Cng	1801	549	1530	**3880**
Gro	959	833	60	**1853**
Liv	1285	697	208	**2190**
Mama	1306	686	399	**2391**
Per	1372	620	423	**2415**
Pis	1231	680	346	**2257**
Sie	1274	654	160	**2088**
Volt	1486	610	409	**2505**

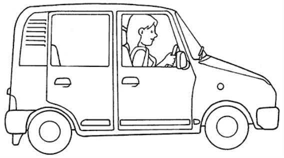
IN AN ENERGY-WATER NEXUS CONTEXT…

Primary energy carriers		Global average water footprint (l/MJ)
Non-renewable	Natural gas	0.11
	Coal	0.16
	Crude oil	1.06
	Uranium	0.09
Renewable	Wind energy	0.00
	Solar thermal energy	0.27
	Hydropower	22

Source: www.waterfootprint.org

BIOETHANOL FROM MAIZE
RANGE: 72 - 175





IN A WATER CONTEXT…

IN TUSCANY
The irrigated area is 32 000 Ha
The agriculture need of water is

150 million of m^3

IN SET-ASIDE LANDS (50 000 HA) THE WATER NEED WOULD BE

326 million of m^3

FOR CULTIVATION OF MAIZE FOR ENERGY PRODUCTION

180 million GREEN

90 million BLUE

56 million GRAY

IN AN ENERGY CONTEXT…

The annual energy demand of Tuscany region by the different productive sectors is about
9 Mtoe

SECTOR	DEMAND (Mtoe/year)
Agriculture	0.139
Industry	3.128
Residential	2.888
Transport	2.831
TOTAL	**8.986**

The total production of bioethanol from maize would be about

0.043 Mtoe/year

- ✓ INCREASING **60%** IRRIGATION
- ✓ INCREASING **100%** IRRIGATED SURFACE
- ✓ PRODUCING **1.5%** OF ENERGY DEMAND

CONCLUSIONS

- Climate change and variability indirectly affect the production of bioenergy through the impacts on crop development and production

- In particular the ratio between green and blue WF is changing especially in relation to the change of rainfalls

- A substantial increase in water pollution by fertilizers and pesticides is also a risk

- Particular attention has to be addressed to agricultural residues from permanent crops (vines, olives, etc.) or from forestry

- Take into consideration that, in general, just a small part of rainfall water (about 10%) is actually used, so there is a need to sustain water storage practices (i.e. small ponds where possible)