CLIMATE CHANGE IMPACTS ON CROP YIELD

LOCOMOTION

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Abstract

This document is the subject of a study on the impacts of climate change on crop yields. To do this, the study includes a literature review on this subject, followed by an implementation of data in the WILIAM model and an analysis of these data.
The aim of this study is to improve the accuracy of the environmental module of the WILIAM Model.

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Contents

Introduction

This study was carried out as part of a research dissertation from September 2023 to January 2024 in the GEEDS (Grupo de Energía, Economía y dinámica de Sistemas). The research group is based at the University of Valladolid in Spain and specialises in dynamic systems, particularly the WILIAM model.

WILIAM is an Integrated Assessment Model (IAM), which is being developed in the proprietary Vensim software. Integrated assessment models (IAMs) are simplified representations of complex physical and social systems, focusing on the interaction between economy, society and the environment. IAMs aim to provide policy-relevant insights into global environmental change and sustainable development issues by providing a quantitative description of key processes in the human and earth systems and their interactions.

WILIAM is a system dynamics policy-simulation model which has been designed to explore long-term decarbonization pathways within planetary boundaries. WILIAM follows a complex system approach, in which the interactions between dimensions are more relevant than the complexity within each module. System Dynamics allows to capture complex feedback loops and nonlinear relationships among social, economic, and environmental variables.

WILIAM comprises 8 modules of Earth and human systems: Demography, Society, Economy, Finance, Energy, Materials, Land and Water, and Climate. *Figure 1* in the Appendix shows the structure overview with the main linkages between modules. Different modules reach different levels of detail and complexity. WILIAM starts to run in 2005 and typically runs until 2060, although the simulation horizon may be extended to 2100. It is a multi-regional world model with eight global regions and the integration of twenty-seven European countries individually for some dimensions. Therefore, the nine global regions are the twenty-seven European countries (EU27), United Kingdom (UK), China, East African Society (EASOC), India, Latin America (LATAM), Russia, United States-Mexico-Canada Agreement (USMCA), and the Rest of the World (LROW). WILIAM integrates knowledge and methods from different disciplines aiming to capture the main dynamics between human and natural systems. Ultimately, WILIAM aims to examine the global and regional implications, at both socio-economic and environmental levels, of long-term socio-ecological transition pathways.

This document focuses on the 'Land and Water' module of the WILIAM model, and more specifically on the LAND part (see *Figure 2* in the appendix). The aim is to improve the accuracy of this module by looking at the impact of climate change on crop yields. Indeed, an initial study on this subject was carried out but the results obtained were not satisfactory since the predictions given by the equations were judged to be inconsistent. Since the previous study only considered changes in temperature as a climatic variation, the aim of a new study would be to define new climatic factors that influence crop yields.

The study begins with a literature review to establish the state of the art on the subject, followed by the application of a method in the WILIAM model.

Assessing Climate Change Impacts on Crop Yields in Integrated Assessment Models: A Comprehensive Literature Review

Definition of the subject

Before delving into the literature review, it was imperative to precisely define the subject to effectively target relevant articles. The primary focus of the literature review was to examine the methods employed by other Integrated Assessment Models (IAMs) in studying the impacts of climate change on crop yields. The aim was to compile a comprehensive understanding of the existing methodologies, paving the way for the integration of a novel calculation method within the WILIAM model.

The central question guiding the research can be formulated as follows: ***How does climate change impact crop yields within the context of IAMs, and what diverse approaches have been employed by various Modelling and Research Institutes (MRIs) to study this phenomenon?*** This question forms basis of the literature review, with the objective of providing insights that will contribute to refining the WILIAM model.

Research method

After delineating the research topic, the subsequent phase involves searching for pertinent articles. To conduct a focused search, we establish keywords derived from the subject matter. This list is employed to expand the search scope, including relevant synonyms. So, next keywords list will be used:

- Integrated assessment model
- System dynamics
- Climate change
- Impact
- Damage
- Crop yields
- Crops

We also define several document selection criteria, which will enable us to refine the search. For this literature review, we will only keep articles and review articles that were published after 2005. This allows us to focus on the most recent studies. In the research process, we make use of bibliographic databases, in particular Scopus and Web of Science. These databases enjoy a reputation for reliability in the research field, being widely used by university laboratories and research institutes.

So, we launched an initial search using the previous conditions and came up with a total of 100 items. The research was conducted employing the following search sequence: ("integrated assessment model" OR "system dynamics") AND ("climate change") AND ("impact" OR "damage") AND ("crop yields" OR "crops").

Literature Database	**Numbers of items**
Scopus	77
Web of science	16

Distribution of articles in databases

We launched a second search adding other keywords to broaden the search and have a database of articles that could include all the documents of interest to our research. We added these new keywords to the list:

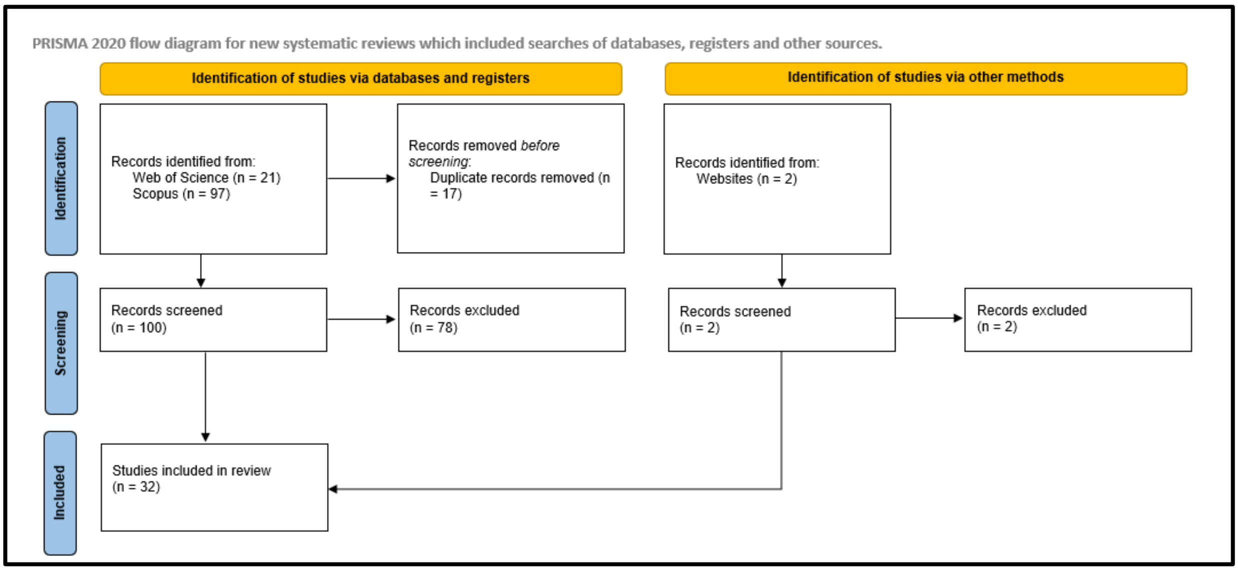
- Effect
- Global warming

The new research was conducted employing the following search sequence: ("integrated assessment model" OR "system dynamics") AND ("climate change" OR "global warming") AND ("impact" OR "damage" OR "effect") AND ("crop yields" OR "crops").

Data title file	**Literature Database**	**Numbers of items**
scopusdata	Scopus	96
wosdata	Web of science	21

Distribution of articles in databases

The article database generated from this research was downloaded on September 18, 2023, and subsequently transferred to an Excel file. To assess the quality assessment criteria, first, duplicated records were removed by the Digital Object Identifier (DOI). Lack of DOI in articles was a reason to be also removed. We removed 17 duplicate articles, resulting in a database of 100 unique articles from the initial search. Additionally, we augmented this article set by including 2 articles discovered through unconventional methods (e.g., forums), considering their potential relevance to this literature review. The remaining articles (102) were screened and filtered in a second subjective assessment based on deeply checking the quality of abstracts regarding the research questions. Only those abstracts writing about the topic of interest were saved to be further analysed. After the second round of filtering, we preserved 32 articles that directly addressed the initial research inquiries regarding the impacts of climate change on crop yields. The following diagram, the PRISMA flow diagram, summarises the process followed to establish the article database.



Prisma flow diagram

With the article selection process concluded, our next step involves conducting a more thorough analysis of the 32 chosen articles. In these articles, we are looking for a method with equations including different climate change factors that would have an impact on crop yields. To analyse the articles and keep a written record of the analyses, we produced a PowerPoint presentation of the articles. After a few revisions of the articles, we noticed that the main factors influencing crop yields are temperature increase and precipitation. Research is now focusing on finding equations that depend on these two factors.

The article "Future climate impacts on global agricultural yields over the 21st century" written by Stephanie T. Waldhoff in 2020 details a method for calculating the coefficient of impact of climate change on crop yields. They use historical crop yield and weather data to empirically estimate annual crop yield responses to temperature and precipitation, constructing reduced-form statistical models that are then coupled with earth system model outputs for the same variables to project future yields. They also provide data calculated from their equations as a supplement to the article. As the equations are complex and made up of many factors, we decided to use the data to replace the equations in the WILIAM model.

We therefore focus on the data in this article and the modelling of the method in the WILIAM model, and we pause the literature review.

Integration of a Method into the WILIAM Model.

The article titled "Future climate impacts on global agricultural yields over the 21st century" written by Stephanie T. Waldhoff in 2020, provides useful data for the “LAND and WATER” module of the WILIAM model. This data includes coefficients for the impact of climate change on various types of crops, calculated according to the methodology detailed in the article. The formulas used incorporate coefficients that depend on both temperature and precipitation (see *figure 3*).

These climate impact factors are evaluated for 12 different crops (Cassava, Cotton, Maize, Potatoes, Rice, Sorghum, Soybean, Sugar beet, Sugarcane, Sunflower, Wheat) in several countries around the world. The coefficients vary according to different climate scenarios, influencing variations in temperature and precipitation. The CCSM4, GFDL and HadGEM_ES climate models, developed by various research centres to simulate the Earth's climate, are used in the study. Each of these models has its own characteristics and parameters, contributing to climate change research. The use of several climate scenarios makes it possible to obtain a diversity of results, offering a better understanding of the uncertainties associated with climate projections. In addition, the coefficients depend on the Representative Concentration Pathway (RCP) scenario, which is an estimate of future greenhouse gas concentrations. In this study, the RCP4.5 and RCP8.5 scenarios are used, the latter being more pessimistic in terms of future CO2 concentration, as illustrated in the *figure 4* in the appendix.

The data, generated for the HadGEM_ES climate scenario, spans from 2006 to 2099, while for the other two scenarios, it covers the period from 2007 to 2099. It's important to mention that data for wheat is only calculated up to 2014.

Adapting the database to the WILIAM model

The climate impact coefficient database was downloaded and transformed into an Excel file compatible with WILIAM. The Excel files used for adaptation to the WILIAM model are attached to this report. Each file is accompanied by a detailed explanation of its contents on the first sheet.

The “*Data_Waldhoff*” file corresponds to the data extracted directly from the article written by S. Waldhoff, without any modification.

The "*Data_yield_impact*" document marks the first phase in the transformation of the data to adapt them to the WILIAM model. In this stage, the countries were assigned to the regions corresponding to those used by WILIAM, as were the crop types. The WILIAM model, in fact, is configured with nine world regions: the twenty-seven European countries (EU27), the United Kingdom (UK), China, the East African Society (EASOC), India, Latin America (LATAM), Russia, the United States-Mexico-Canada Agreement (USMCA), and the Rest of the World (LROW). A specific organisation has also been adopted for crop types by the WILIAM model. The crop grouping is detailed below, and the country grouping is detailed in the *figure 5*.

Data_crop	WILIAM_crop
cassava	TUBERS
cotton	OTHER_CROPS
maize	CORN
rice	RICE
root_tuber	TUBERS
sorghum	CEREALS_OTHER
soybean	SOY
sugarbeet	SUGAR_CROPS
sugarcane	SUGAR_CROPS
sunflower	OILCROPS
wheat	CEREALS_OTHER

Crop grouping

Once the countries and cultures have been grouped together, we obtain an Excel table as shown the *figure 6* in the appendix. The first column lists the countries, identified by the 3-letter ISO 3166 code. The second column shows the WILIAM region to which these countries belong. The following data is then provided: the year for which the climate impact coefficient is calculated, the coefficient itself, the associated climate scenario, the RCP scenario, *and* finally the type of crop. The CFE column represents the effect of CO2 fertilisation but is not used here because it is too uncertain.

However, these data are not yet usable because, as can be seen in Figure 6, some crop types are present twice for the same criteria. This is due to the grouping of crops where two crops can belong to the same crop type in the WILIAM model. Subsequently, an average will have to be calculated to obtain a single factor for the *CEREALS_OTHER, SUGAR_CROPS* and *TUBERS* crops. In addition, the aim is to obtain data based on regions rather than countries.

The "*Data_yield_impact_Hadgemes_8p5*" file contains the data for the Hadgemes scenario, rcp8p5. These data are those adapted to the WILIAM model. The aim of this file is firstly to group the crops together, i.e. to average the climate impact coefficients if we have several values for the same country, the same year and the same crop, in order to obtain a single climate impact value. This only happens for the CEREALS_OTHER, SUGAR_CROPS and TUBERS crops.

One spreadsheet is dedicated to these three types of crops, where the average climatic impact is calculated. Another sheet is then created to format the new data so that it can be used later. The following formula is used for the calculation:

```
=IF(AND(C3=C2,C3<>C4),AVERAGEIFS(D:D,C:C,C3,A:A,A2),IF(C2=C1,"",D2)).
```

This formula checks whether two values share the same year and country, then averages them if this is the case. Once the new data has been calculated, it is grouped together in the *Data_Hadgemes_8p5_wiliam_crop* sheet, with a final yield impact value for each crop and each year.

The second objective is to obtain yield impact values by region, whereas we have these data by country. To do this, we need to calculate a weighted average of the coefficients according to the area harvested, using the following formula:

$$Yield\ impact_{region} = \frac{\sum\ (yield\ impact_{country} * area\ harvested_{country})}{Area\ harvested_{region}}$$

To perform this calculation, it is essential to possess data regarding the harvested areas for each country. This data was retrieved from the file *"Area harvested by Stavroula"*, which was written by Stavroula, a researcher on the LOCOMOTION project. This file gives historical values for harvested areas for different countries and types of crops, but no forecasts for future years. So, to obtain a consistent harvested area value, the harvested area we use is an average of the harvested areas from 2015 to 2020 for each type of crop and for each country. The data is summarised in the Excel file "*Area*", which looks like this:

Region	Country	LOCOMOTION categories	Area (ha)
EU27	esp	CORN	352 357
EU27	esp	RICE	106 101
EU27	esp	CEREALS_OTHER	5 625 020
EU27	esp	TUBERS	70 217
EU27	esp	SOY	1 417
EU27	esp	OILCROPS	3 395 811
EU27	esp	SUGAR_CROPS	33 382
EU27	esp	OTHER_CROPS	15 963

Area harvested in Spain.

To incorporate these values, we integrate them into the *"Data_yield_impact_Hadgemes_8p5"* file. The formula below is used to retrieve the harvested area value for each country and each crop from the database created in the *"Area"* file. Thanks to this incorporation, we can determine the harvested area according to region and crop type. These areas by region are detailed in the *"Area"* file. For areas that depend on the *CEREALS-OTHER* crop, the areas are calculated for the period before 2014 and then after 2014. This is because we only have wheat data up to 2014.

```
=SUMPRODUCT(('[Area.xlsx]Area by country'!$B$2:$B$1433=Tableau4[@iso])*('[Area.xlsx]Area by country'!$C$2:$C$1433=Tableau4[@crop])*('[Area.xlsx]Area by country'!$D$2:$D$1433))
```

The harvested area is then multiplied by the yield impact coefficient, which is then used to determine the yield impact coefficient according to the WILIAM region, the year and the type of crop.

The table below summarises the previous steps:

iso	WILIAM_region_name	year	yield_impact	model	rcp	cfe	WILIAM_crop	Area (ha)	Area*yiel impact
esp	EU27	2006	1,017120497	hadgemes	8p5	noCFE	CORN	352 357	358 389
esp	EU27	2006	1,003756645	hadgemes	8p5	noCFE	RICE	106 101	106 500
esp	EU27	2006	1,046081459	hadgemes	8p5	noCFE	CEREALS_OTHER	5 625 020	5 884 229
esp	EU27	2006	1,01464622	hadgemes	8p5	noCFE	TUBERS	70 217	71 246
esp	EU27	2006	1,04233287	hadgemes	8p5	noCFE	SOY	1 417	1 477
esp	EU27	2006	1,122178783	hadgemes	8p5	noCFE	OILCROPS	3 395 811	3 810 706
esp	EU27	2006	0,988047613	hadgemes	8p5	noCFE	SUGAR_CROPS	33 382	32 983
esp	EU27	2006	0,967958569	hadgemes	8p5	noCFE	OTHER_CROPS	15 963	15 451

<u>*Area harvested calculation for Spain.*</u>

The last step is to create a table in which the yield impact coefficient will be a function of region, year and crop type, as we are working on values that depend only on the Hadgemes scenario, rcp8.5. The table looks like this:

HISTORICAL YIELD IMPACT BY CROP BY REGION RCP 8.5 *HADGEMES* CLIMATE MODEL	YEAR	2006	2007	2008	2009	2010
REGIONS_I	LAND_PRODUCTS_I	[DMNL]	[DMNL]	[DMNL]	[DMNL]	[DMNL]
EU27	CORN	1,0387	1,0250	1,0184	0,9842	1,0177
	RICE	1,0285	0,9936	1,0009	1,0153	0,9974
	CEREALS_OTHER	1,0172	1,0440	1,0345	0,9986	0,9734
	TUBERS	0,9632	1,0448	1,0233	0,9562	0,9930
	SOY	1,0627	1,0452	1,0092	0,9958	0,9769
	PULSES_NUTS	0,0000	0,0000	0,0000	0,0000	0,0000
	OILCROPS	1,0681	1,0888	0,9900	0,9979	1,0100
	SUGAR_CROPS	0,9881	0,9593	0,9624	1,0106	1,0425
	FRUITS_VEGETABLES	0,0000	0,0000	0,0000	0,0000	0,0000
	BIOFUEL_2GCROP	0,0000	0,0000	0,0000	0,0000	0,0000
	OTHER_CROPS	0,9396	0,9708	0,9777	0,9416	1,0092
	WOOD	0,0000	0,0000	0,0000	0,0000	0,0000
	RESIDUES	0,0000	0,0000	0,0000	0,0000	0,0000

<u>*Yield impact by crop by region rcp 8.5 hadgemes climate model*</u>

The coefficients correspond to the weighted average of the coefficients according to the area harvested and are calculated using the following formula:

```
=SOMMEPROD(($B$2:$B$89866=$M$3)*($H$2:$H$89866=$N3)*($C$2:$C$89866=O$1)*($J$2:$J$89866))/SOMMEPROD(('[Area
.xlsx]Area by region'!$C$5:$C$13=$M$3)*('[Area.xlsx]Area by region'!$D$4:$P$4=$N3)*('[Area.xlsx]Area by
```

Other types of crops are also present, representing all the crops found in the WILIAM model. We need to show them so as not to interfere with WILIAM's calculations.

The data has now been organized based on years, crop types, and WILIAM regions. This process is iteratively applied for the remaining scenarios and Representative Concentration Pathways (RCPs), leading to the creation of six distinct documents:

- *"Data_yield_impact_Hadgemes_8p5"*
- *"Data_yield_impact_Hadgemes_4p5"*
- *"Data_yield_impact_gfdl_8p5"*
- *"Data_yield_impact_gfdl_4p5"*
- *"Data_yield_impact_ccsm4_8p5"*
- *"Data_yield_impact_ccsm4_4p5"*.

The document *"YIELD IMPACT WILIAM MODEL"* contains summary tables of the yield impact coefficients for the different climate scenarios and RCPs.

Finally, the data is placed in the *"land_and_water"* document. This document serves as the database for the "LAND and WATER" module of the WILIAM model. This will enable us to obtain curves from the Vensim software in which WILIAM is modelled. Obviously, the module has been adapted in Vensim to receive information on climate impact factors on crop yields. A new branch has been created in Vensim, which is connected to the rest of the model (*figure 7*).

Analysis of compilation results

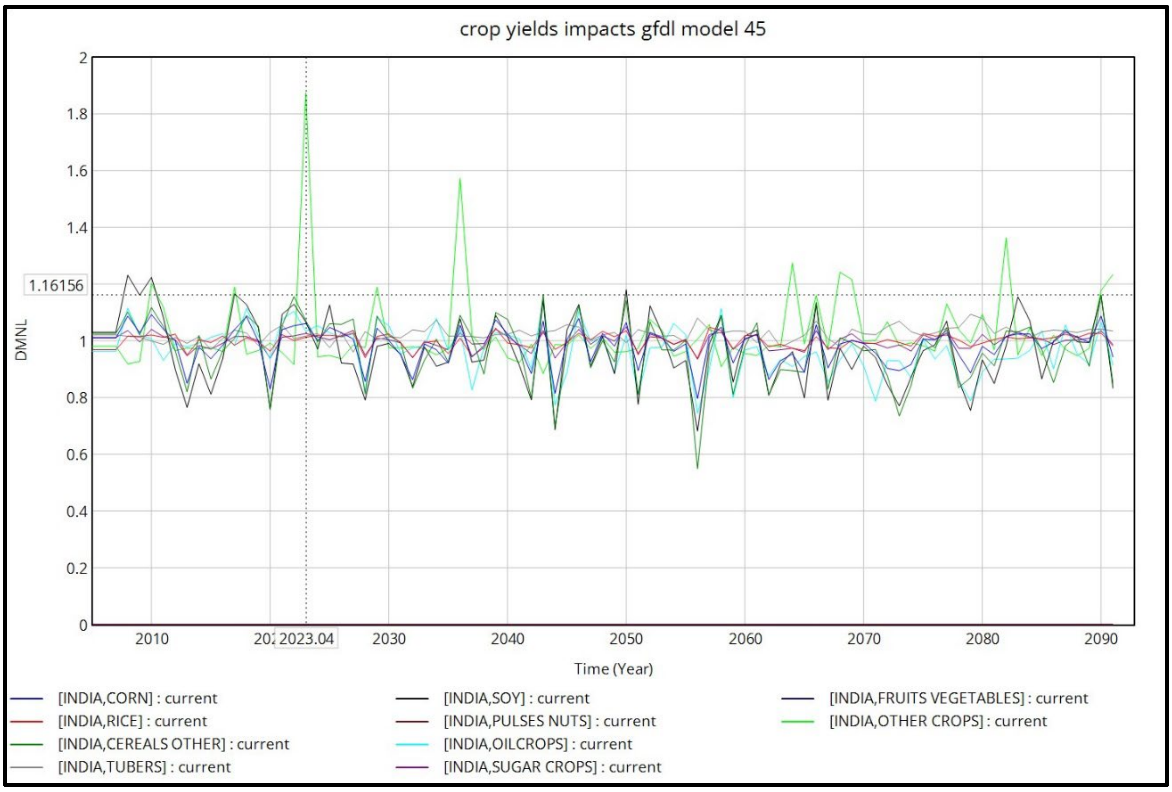
Now that we've finished preparing the data, we can run the model simulation. What we want to recover from this simulation are the curves showing the evolution of the coefficient of impact on yield, which will enable us to analyse the relevance of these data.

Thanks to the Vensim software, we can concentrate on one of the 9 regions of the WILIAM model. In addition, the possibility of selecting one of the 6 scenarios presented above strengthens our ability to analyse and clarify the curves associated with the chosen region. This function of the Vensim software is particularly valuable as it allows us to obtain region-specific information and a more detailed understanding of the model's behaviour in different scenarios.

The first simulation is satisfactory, with the curves clearly showing that most of the coefficients are between 0.5 and 1.5. However, we also observe several peaks, which do not correspond to the trends in the other data. This discrepancy, which needs to be corrected, can be attributed to a lack of precision in the calculation of climate impact factors in certain regions, for example, or an error in downloading the data. In order to remove these outliers, we have replaced them with the average of the previous and next values in the database file. These values are framed in red in the *"land and water"* document.

We can also see that some curves are not usable because the variation in values is too great. This is particularly the case for certain climate scenarios where all the curves for a given region are unreliable. This may be due to the accuracy of the calculation data in certain regions of the world.

The curve below represents the previous explanations. It corresponds to the impact of climate on crop yields in India, according to the GFDL climatic scenario and rcp4.5.



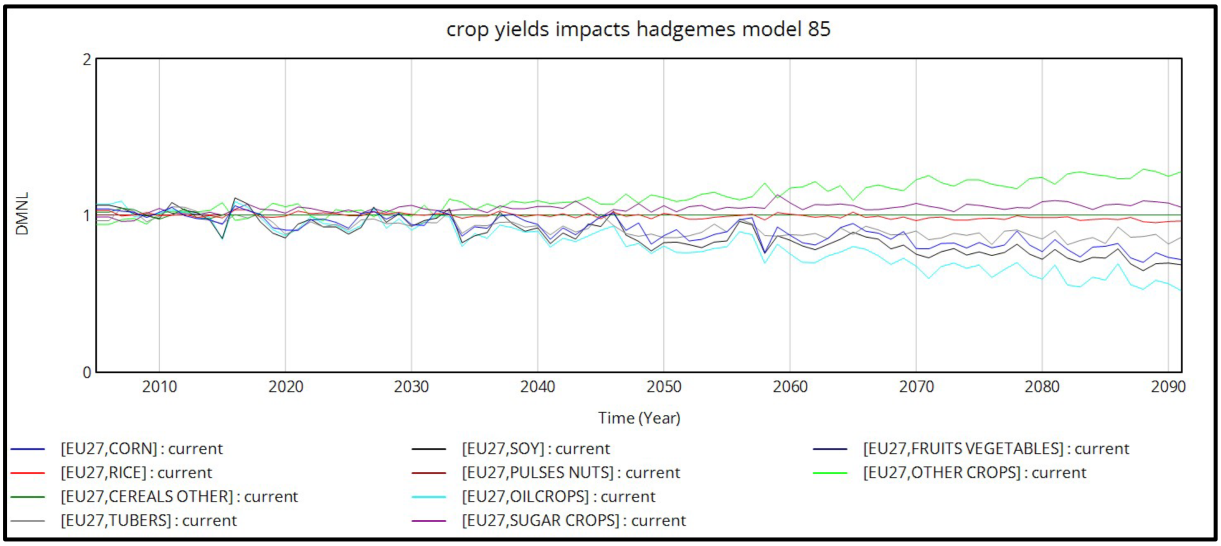
<u>*crop yields impact in India, gfdl model, rcp4.5*</u>

After the first compilation, we noticed that values equal to 0 would interfere with the other calculations in the module. In fact, as the climate impact factor is multiplied by crop production, another data item in the module, a zero value would inhibit the simulation results. As a result, all the zeros are replaced by a 1, so that the calculations remain unchanged. This is particularly valid for crops for which we have no climate impact data.

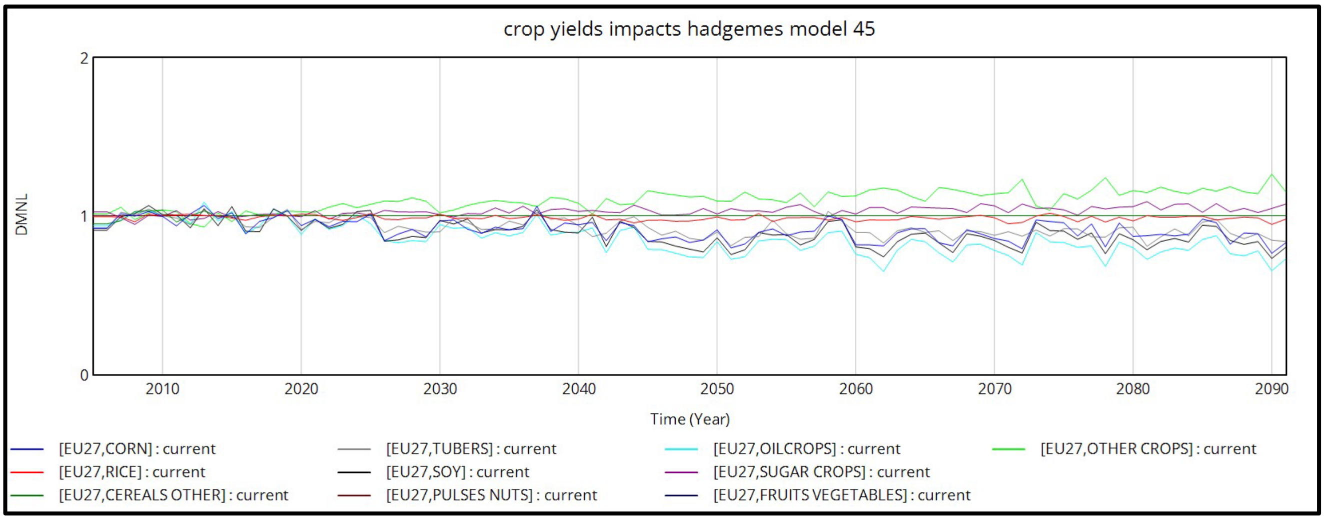
We have also decided to modify the values for the *CEREALS_OTHER* crop. This crop is made up of wheat and sorghum values, but we only have data for wheat up to 2014. Furthermore, wheat is much more widely produced than sorghum: in 2022/2023 wheat production was 783.8 million tonnes compared with 58.54 million tonnes for sorghum, according to Statista* data. It therefore seemed inconsistent to keep values that did not represent most of the production. In response to this problem, we opted to replace the post-2014 values with a unit value for the *CEREALS_OTHER* crop, for all regions and all scenarios.

* https://www.statista.com/statistics/263977/world-grain-production-by-type/

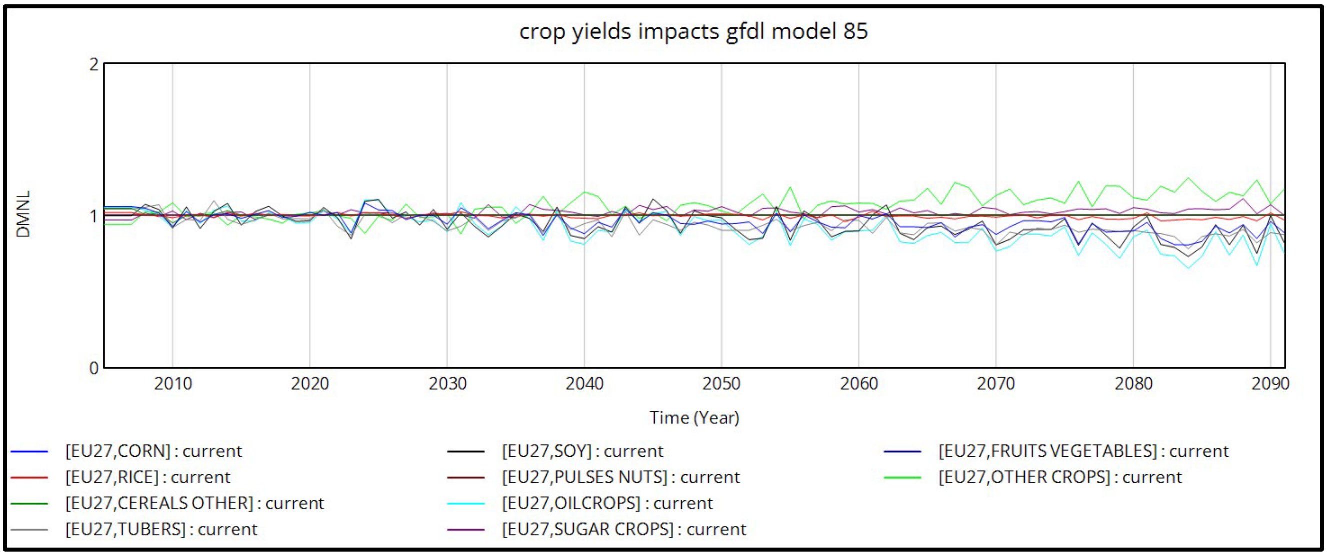
Once the above corrections have been made, we can run a second simulation. This allows us to compare the different models and analyse the relevance of the curves. To do this, we take the case of the EU27 region, which represents Europe. To do this, we take the predictions for the following cases: hadgemes/RCP8.5, hadgemes/RCP4.5 and gfdl/RCP8.5.



crop yields impact in EU27, hadgemes model, rcp8.5



crop yields impact in EU27, hadgemes model, rcp4.5



crop yields impact in EU27, gfdl model, rcp8.5

The general trend is the same: for SUGAR_CROPS and OTHER_CROPS, the change in climate will have a positive impact on the yield of these crops, whereas for the other crops, the impact will be more or less negative. If we examine the results of the Hadgemes climate model, the values obtained with the RCP8.5 scenario show a greater deviation from the reference with no climate impact (i.e. a value of 1) than those associated with the RCP4.5 scenario. This indicates that the climate impacts are more pronounced in the case of the RCP8.5 scenario, which is consistent with the more pessimistic outlook for this scenario.

We can now compare the curves of the Hadgemes and GFDL climate models, both following RCP8.5, for the EU27 region. We can see that the Hadgemes model curves are more linear, with less variation in the values. The Hadgemes model appears to be more reliable than the GFDL model for the EU27 region, for RCP8.5.

Finally, the values for climatic impact on crop yield in the article by S. Waldhoff can be used in the WILIAM model. It is clear that variations in temperature and precipitation have and will have an impact on crop yields, but this impact is not disproportionate, with most of the values lying between 0.5 and 1.5. If there is no impact from climate change, then the value is 1.

Conclusion

The first part of the literature review enabled us to obtain new data on the impacts of climate change on crop yields. After modifying and adapting the WILIAM model, we were able to use this data and obtain curves to validate the consistency of the data. Finally, this new data will help to improve the land and water module of the WILIAM model.

From a personal point of view, the study for this scientific dissertation was my first introduction to the world of research. I discovered the methods and tools used to produce a literary review, which gave me a sense of rigour. It was also an opportunity to discover dynamic systems through the WILIAM model, and the use of IAMs in today's world.

The work carried out in this dissertation has improved the accuracy of the WILIAM model, but it can still be optimised. Using data from the article "Future climate impacts on global agricultural yields over the 21st century", it is possible to obtain equations and endogenise the factors. It is also possible to filter the values to eliminate errors. This work provides a new basis for improving the Land and Water module.

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Appendix

Figure 1

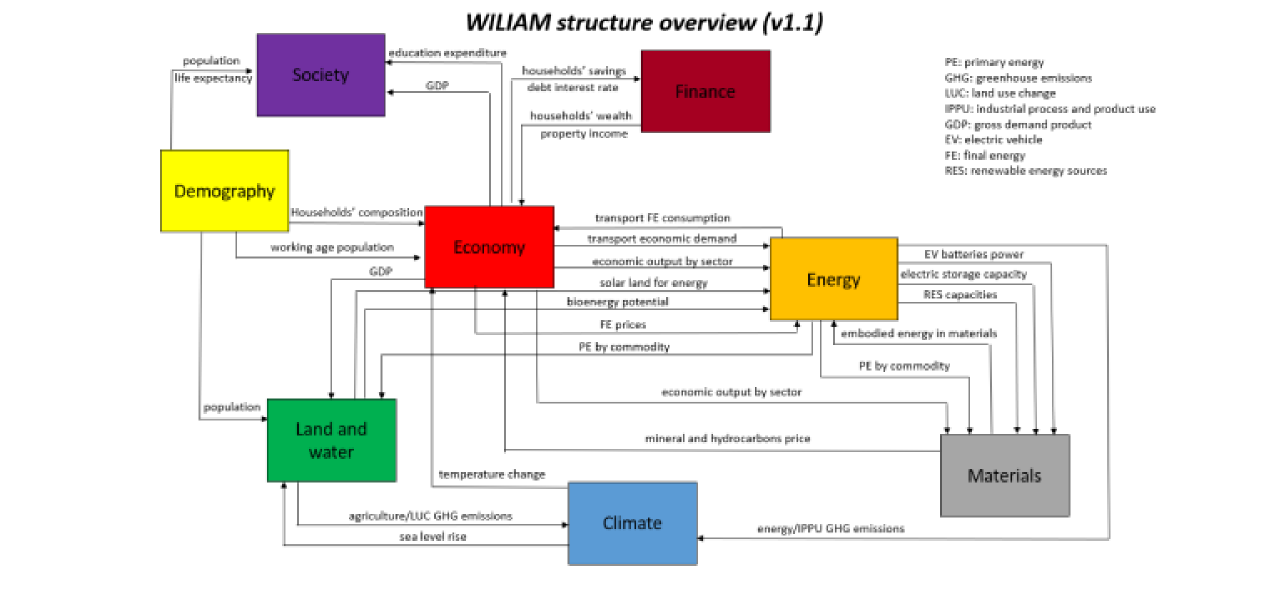

Figure 12: WILIAM (v1.1) simplified structure overview. Main linkages between modules.

Figure 2

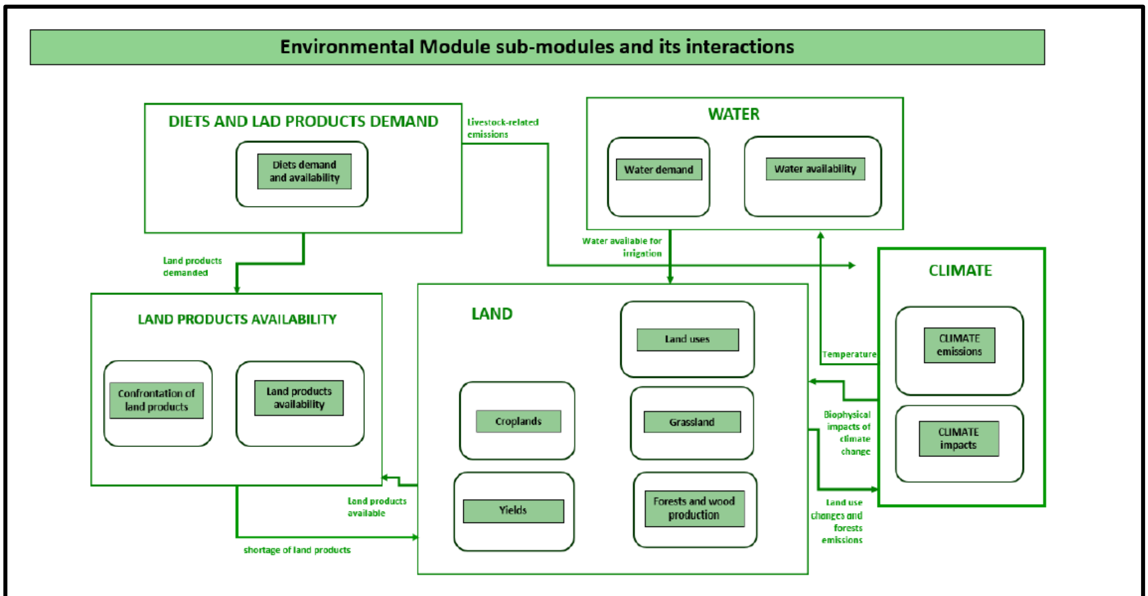

Figure 30: Submodules of the Land and Water module.

Figure 3

$$
\begin{aligned}
y_{i,t} = {} & \mu_i + \lambda t + \chi m_{i,t} + \beta_1^{Mean} T_{i,t}^{Mean} + \beta_2^{Mean} \left(T_{i,t}^{Mean}\right)^2 \\
& + \beta_1^{Min} T_{i,t}^{Min} + \beta_2^{Min} \left(T_{i,t}^{Min}\right)^2 + \beta_1^{Max} T_{i,t}^{Max} \\
& + \beta_2^{Max} \left(T_{i,t}^{Max}\right)^2 + \gamma_1^{Mean} P_{i,t}^{Mean} + \gamma_2^{Mean} \left(P_{i,t}^{Mean}\right)^2 \\
& + \gamma_1^{Min} P_{i,t}^{Min} + \gamma_2^{Min} \left(P_{i,t}^{Min}\right)^2 + \gamma_1^{Max} P_{i,t}^{Max} \\
& + \gamma_2^{Max} \left(P_{i,t}^{Max}\right)^2 + u_{i,t}.
\end{aligned}
\tag{1}
$$

- i and t index countries and years.
- y and m are the natural logarithms of yield and per capita GDP.
- T^k and P^k with k ∈ (Mean,Min,Max) denote the mean, minimum, and maximum growing season monthly average daily temperature and total precipitation in each country and year.
- u is a random disturbance term.
- µ vector of country fixed effects.
- β1 and β2 define the response of log yield to average, minimum, and maximum temperature.
- γ1 and γ2 define the response of log yield to average, minimum, and maximum precipitation.

Figure 4

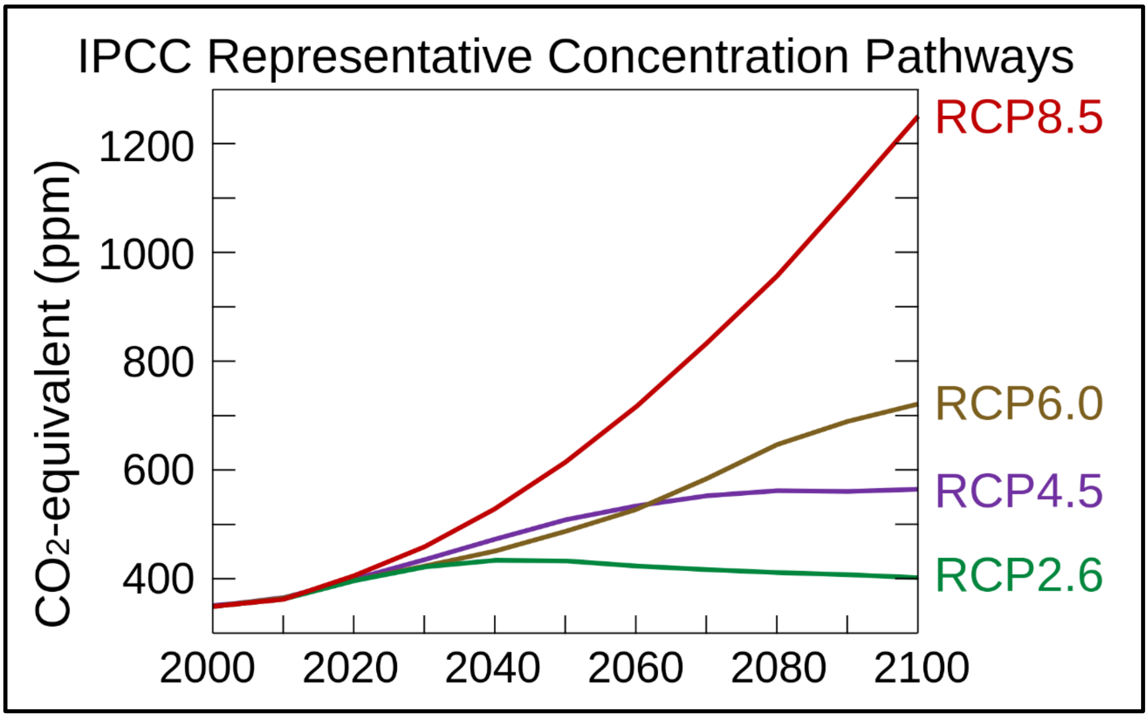

Figure 5

UK	China	EASOC	India	EU27	LATAM	Russia	USMCA	LROW		
gbr	chn	aus	ind	aut	arg	rus	can	afg	gnb	omn
		brn		bel	bra		mex	ago	gnq	pak
		idn		bgr	chl		usa	alb	gtm	pan
		jpn		cyp	col			and	guf	png
		khm		cze	cri			are	gum	pri
		kor		deu	per			arm	guy	prk
		mys		dnk				atg	hnd	pry
		nzl		esp				aze	hti	pse
		phl		est				bdi	irn	qat
		tha		fin				ben	irq	reu
		twn		fra				bfa	isr	rwa
		vnm		grc				bgd	jam	sau
				hrv				bhr	jor	sdn
				hun				bih	kaz	sen
				irl				blr	ken	slb
				ita				blz	kgz	sle
				ltu				bol	kwt	slv
				lva				brb	lao	som
				mlt				btn	lbn	srb
				nld				bwa	lbr	stp
				pol				caf	lby	sur
				prt				che	lka	swz
				svk				civ	lso	syr
				svn				cmr	mar	tcd
				swe				cod	mda	tgo
								cog	mdg	tjk
								com	mkd	tkm
								cpv	mli	tto
								cub	mmr	tun
								dji	mne	tur
								dma	mng	tza
								dom	moz	uga
								dza	mrt	ukr
								ecu	mtq	ury
								egy	mus	uzb
								eri	mwi	vct
								eth	nam	ven
								fro	ncl	vut
								gab	ner	yem
								geo	nga	zaf
								gha	nic	zmb
								gin	nor	zwe
								gmb	npl	

Figure 6

iso	WILIAM_region_name	year	yield_impact	model	rcp	cfe	WILIAM_crop
esp	EU27	2007	0,925120557	hadgemes	8p5	noCFE	OTHER_CROPS
esp	EU27	2007	1,076215476	hadgemes	8p5	noCFE	CORN
esp	EU27	2007	1,004519362	hadgemes	8p5	noCFE	TUBERS
esp	EU27	2007	1,007739119	hadgemes	8p5	noCFE	RICE
esp	EU27	2007	1,128062082	hadgemes	8p5	noCFE	CEREALS_OTHER
esp	EU27	2007	1,070358158	hadgemes	8p5	noCFE	SOY
esp	EU27	2007	0,906157802	hadgemes	8p5	noCFE	SUGAR_CROPS
esp	EU27	2007	1,012336045	hadgemes	8p5	noCFE	SUGAR_CROPS
esp	EU27	2007	1,141905042	hadgemes	8p5	noCFE	OILCROPS
esp	EU27	2007	1,138440013	hadgemes	8p5	noCFE	CEREALS_OTHER
esp	EU27	2007	1,045876597	hadgemes	4p5	noCFE	OTHER_CROPS
esp	EU27	2007	0,977997692	hadgemes	4p5	noCFE	CORN
esp	EU27	2007	0,998473259	hadgemes	4p5	noCFE	TUBERS
esp	EU27	2007	0,990826836	hadgemes	4p5	noCFE	RICE
esp	EU27	2007	0,864235004	hadgemes	4p5	noCFE	CEREALS_OTHER
esp	EU27	2007	0,957057871	hadgemes	4p5	noCFE	SOY
esp	EU27	2007	1,008984084	hadgemes	4p5	noCFE	SUGAR_CROPS
esp	EU27	2007	0,966272044	hadgemes	4p5	noCFE	SUGAR_CROPS
esp	EU27	2007	0,921302164	hadgemes	4p5	noCFE	OILCROPS
esp	EU27	2007	0,874893162	hadgemes	4p5	noCFE	CEREALS_OTHER
esp	EU27	2007	1,014176128	ccsm4	8p5	noCFE	OTHER_CROPS
esp	EU27	2007	0,972531571	ccsm4	8p5	noCFE	CORN
esp	EU27	2007	1,015380597	ccsm4	8p5	noCFE	TUBERS
esp	EU27	2007	0,987398698	ccsm4	8p5	noCFE	RICE
esp	EU27	2007	0,948871185	ccsm4	8p5	noCFE	CEREALS_OTHER
esp	EU27	2007	1,030738179	ccsm4	8p5	noCFE	SOY
esp	EU27	2007	1,027079959	ccsm4	8p5	noCFE	SUGAR_CROPS

Figure 7