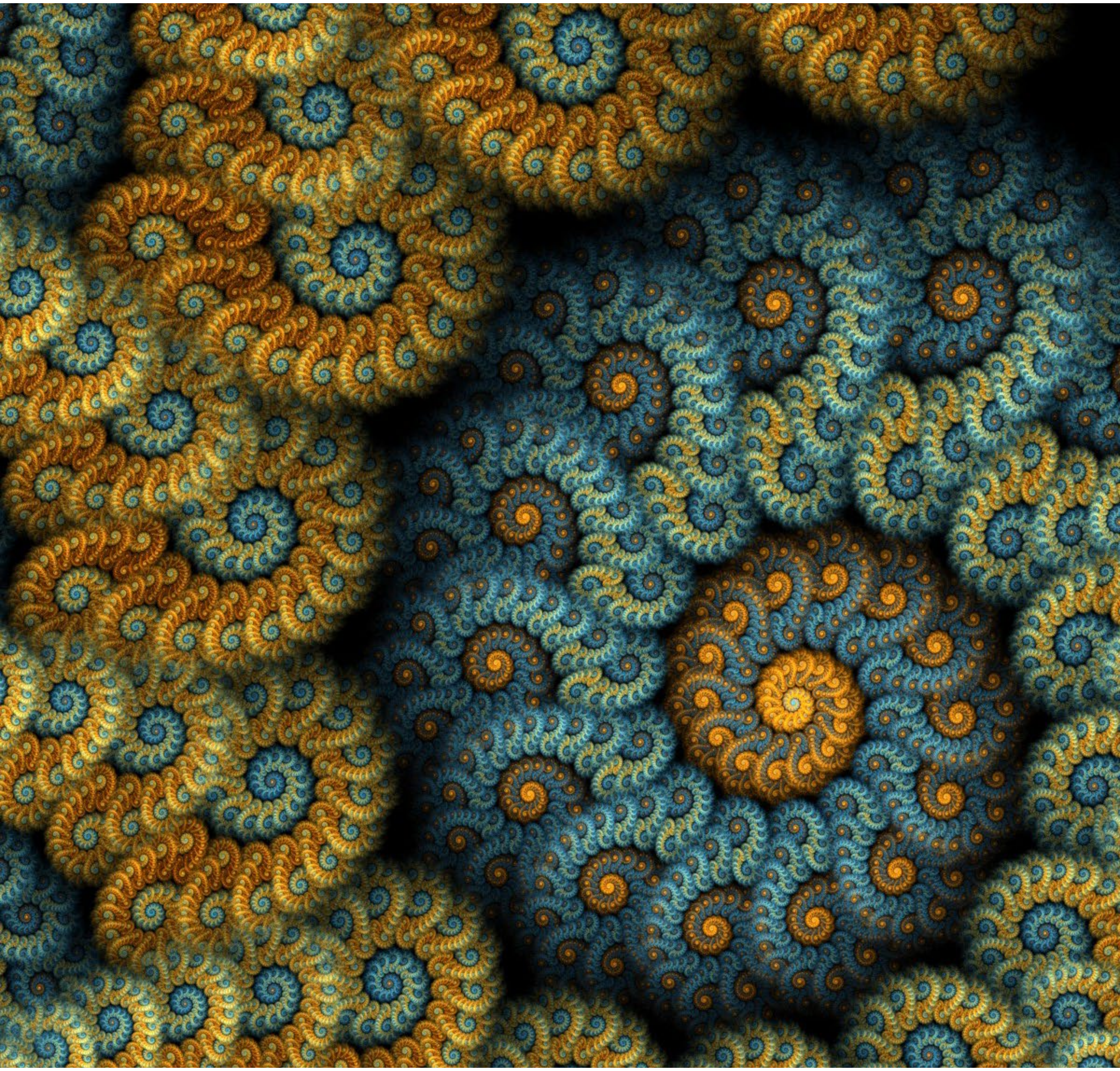
Food Security: Impact of Climate Change and Technology



Editors
Rachna Sehrawat, Hong-Wei Xiao, Sachin Vinayak Jangam,
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PREFACE

With the global population to reach a staggering figure of 9.8 billion by 2050 requiring about 50 percent increase in production of food. There is no new landmass available to continue production and consumption of food at current rate. Indeed, the extra landmass needed to meet this production level is estimated to be an area twice that of India. Clearly, food security is by far the most critical BIG problem of this century. Problems of climate change and water shortage are critically important as well as they directly affect issues of food security.

Fortunately, both developed and developing countries now recognize the multifarious issues affecting food security. There is no multidimensional, multi- and trans-disciplinary problem that matches the complexity of food security issues. A holistic solution requires political, cultural, social, scientific as well as technological approaches on a truly global scale. Food insecurity can lead to geopolitical skirmishes leading to lack of peace around the world. This freely-downloadable e-book is being brought out to provide a simple practical guide to identify the scope of the problem and potential technological solutions to alleviate it. Clearly, a concise book like this cannot cover all the important issues but we hope it makes a serious first attempt to uncover the problem and identify some of the technological problems. We believe most readers will be able to come up with their own ideas and make a positive contribution to solving this big problem in decades to come. The sooner we begin the better.

Drying is a unit operation that has been critical to food security since time immemorial. Early humans recognized the need to get rid of water to be able to store animal and plant based edible foods over longer periods which is essential to their survival. Obviously, we can safely claim “drying” has been central to the survival of the human race itself. In this book we present a general overview of the role of drying in ensuring food security as it encompasses a whole range of dehydration problems from drying of seeds, grains, fruits and vegetables, meats, marine products, biomass and fertilizers. Drying is important to allow long term shelf-life, economic transport of perishable foods and even to minimize food waste or generate energy or by-products from food waste.

Climate change resulting in global warming has a massive adverse effect on the production of foods of all kind. The first chapter discusses this matter in considerable detail. It is clear that it is essential to follow practices that will minimize greenhouse gas emissions in order to secure food supplies. The chapter on diet explains why plant-based foods are much more sustainable and indeed healthier choices. Increased consumption of plant based foods will reduce strain on resources. Indeed, new sources of nutritious foods are needed. Much interest has appeared in including a wide variety of insects as a source of proteins. Furthermore, as all foods are perishable and subject to microbial degradation it is necessary to devise ways of mitigating such loss. Indeed, wastage of food at various stages of its production, processing, storage as well as consumption is a critical factor in influencing the potential of food insecurity. It is impossible to eliminate waste but it is possible to minimize it. These topics are covered in some depth in this book in a series of chapters. The importance of drying technology in the areas of preservation, storage and transportation of various goods has already been mentioned. Various dryer types and their applications relevant to food security are discussed in a separate chapter.

We hope that this concise e-book will be of wide interest to readers in a wide range of disciplines. We feel that it is high time everyone needs to do her/his part in ensuring food security in the next several decades. The topic of food security indeed needs an encyclopedia to do justice to all the topics and subtopics that are crucially important to food security. We believe this book is a brief introduction to the important aspects of the problem and some ideas about how the problem may be resolved in the coming decades.
We welcome feedback from our readers.

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Chapter 2

Climate Change and Food Security

Rubén D.Piacentini, Lara S Della Ceca, Marcelo Vega, Fernando Bertoni, Anibal Arancibia, Iván Novara, Sofía Garro, Susana R. Feldman

Contents

2.1 TEMPERATURE AS A BASIC INDICATOR OF CLIMATE CHANGE

Climate is the state of the atmosphere in a given period of time and in a specific region, *e.g.* summer climate, desert climate, high mountain climate, etc. Natural and human produced vegetables and animals used for food production are strongly influenced by the climate. Therefore, its knowledge and possible change are of importance in present time, since climate influences food production for about 7.5 billion inhabitants, as well as its future evolution, considering that it is expected to increase at about 9.7 billion inhabitants by the middle of this century (UN Population Division, 2017).

Ambient (air) temperature is the main atmospheric variable that determines a given climate. Consequently, its behavior along the past and future times is of great importance. Considering the annual evolution of Northern Hemisphere temperature data in the last millennium presented by Jones and Mann (2004) and obtained from the analysis of different sources (tree rings, etc.), Piacentini and Mujumdar (2009) were able to determine the slopes in the period 1000-1900 using a mathematical approximation called the Fast Fourier Transform technique (see for example, Walker, 1996). They obtained a small negative trend of -0.02 °C/century. Around this last year (1900) and mainly due to the propagation all over the world of the Industrial Revolution that was born in UK about the year 1750, a strong modification in sign and value of the trend occurs, with a figure of0.6°C/century for the 20thcentury.

Figure 1 describes the time evolution of the annual global ambient air temperature near surface as a mean of measurements done in the period 1880-2016 by thermometers of the National Weather Service meteorological stations, and more recently of satellite thermal sensors. The data, provided by NASA Goddard Institute for Space Studies (GISTEMP Team, 2018, see also: IPCC, 2013), are very near those of other three independent statistical analysis done by the following prestigious Institutions/Organizations of the World related to climate: National Oceanic and Atmospheric Administration (NOAA) of United States, Meteorological Office Hadley Centre of Great Britain and Japan Meteorological Society. This Figure 1 shows that, from the reference period 1880-1900 up to the average period 2012-2016, the mean global air temperature increased about1 °C, with the largest contribution to this increase, of about 80%, coming from the last decades (1970-2016).

The World Meteorological Organization (WMO) in its 2017 Report (WMO, 2018) presents similar results: *Global mean temperatures in 2017 were 1.1 °C ± 0.1 °C above pre-industrial levels. Whilst 2017 was a cooler year than the record setting 2016, it was still one of the three warmest years on record, and the warmest not influenced by an El Niño event.*

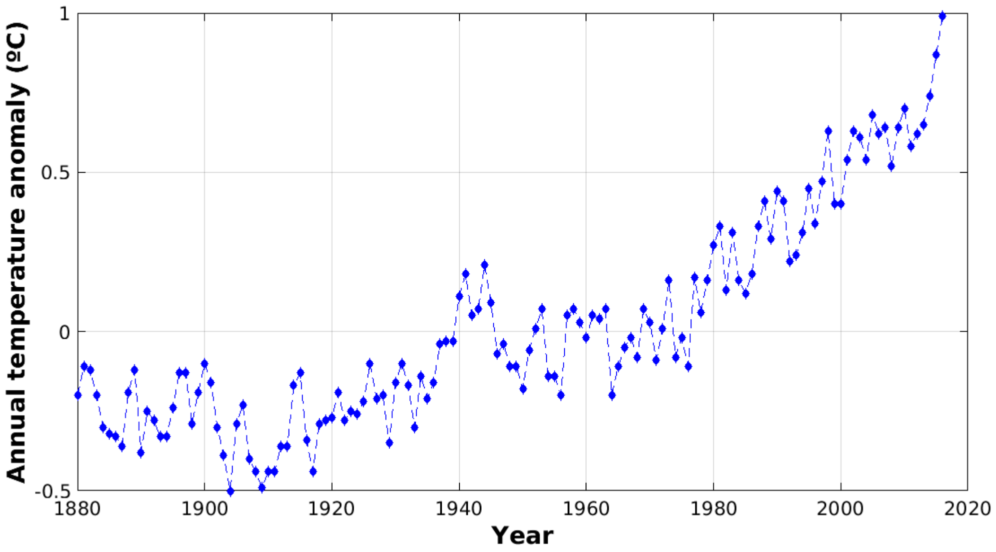

Figure 1: Time evolution of the annual mean global air temperature near surface done by thermometers of National Weather Service meteorological stations and more recently by satellite thermal sensors. Source: Based on data collected by NASA Goddard Institute for Space Studies, 2015 (Hansen, 2010; GISTEMP Team, 2018). Available at: https://www.giss.nasa.gov/research/features/201501_gistemp/)

One of the climatic phenomena that influences significantly the ambient temperature worldwide is the El Niño event, which is part of a larger event called ENSO (El Niño Southern Oscillation) that includes also La Niña event. The first one is an anomalous heating of the Tropical Pacific Ocean surface water that usually can produce large rains (and associated floods) in some regions of the World and droughts in others, affecting significantly food production. La Niña is the reverse situation, an anomalous cooling of the same waters, producing also reverse climatic situations. For example, in the very fertile Humid Pampa of the Central Argentina region, the Strong El Niño event of 2015-2016 produced an excess of precipitation with floods of the Paraná and other rivers; but in the last part of the year 2017 and the beginning of 2018, a Moderate (and even a Weak) La Niña determined a significant reduction in soybean and corn production (NASA report, 2018).

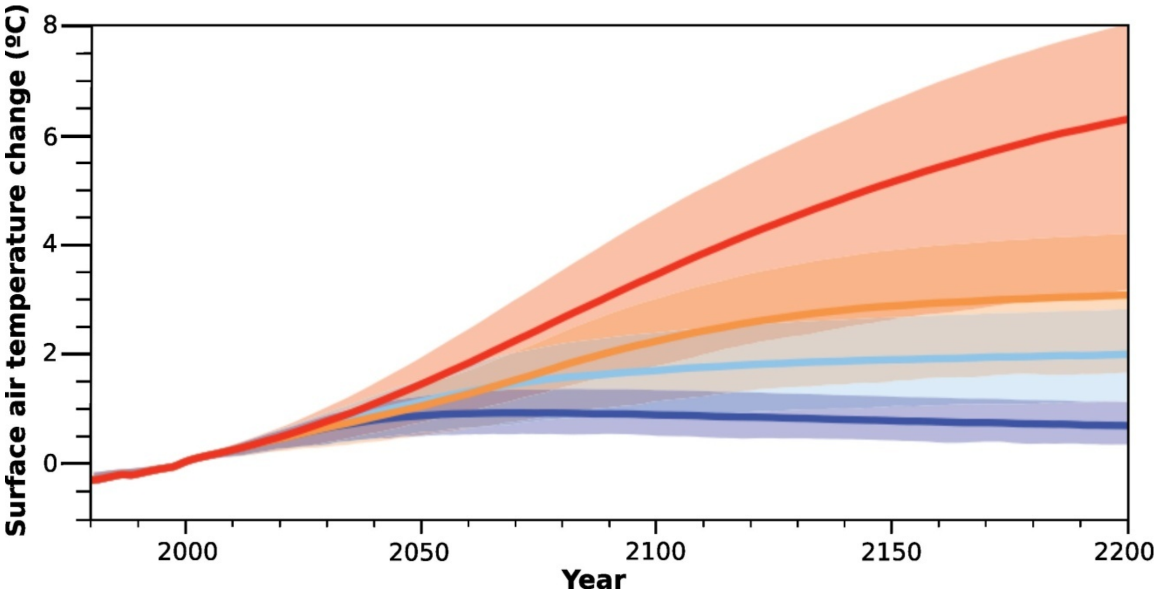

Figure 2: Projected global mean (near) surface temperature change during the period 2000-2200, for the different scenarios of radiative forcing (the net energetic atmospheric balance directly related to greenhouse gases emissions): RCP2.6 (blue), RCP4.5 (light blue), RCP6.0 (orange) and RCP8.5 (red). The color bands correspond to the uncertainties due to the combination of different model calculations. Source: First part (from 2000 up to 2200) of Figure 12.43 of the IPCC Working Group 1 Report (Collins et al., 2013, in particular: https://www.ipcc.ch/report/graphics/index.php?t=Assessment%20Reports&r=AR5%20-%20WG1&f=Chapter%2012)

The future temperature evolution is unknown, but it is possible to propose different scenarios based on the way humanity will react to the global warming problem. A systematic analysis of a large number of results has been made by the United Nations Intergovernmental Panel on Climate Change (IPCC) that is integrated by specialists all over the World. The main scenarios of Representative Climate Pathways (*RCPx*) for four different *x* values of the *radiative forcing* (the net energetic atmospheric balance directly related to greenhouse gases emissions) are: RCP2.6, RCP4.5, RCP6.0 and RCP8.5. The temperature time dependence forecasted by IPCC in the last report (IPCC, 2013) is represented in Figure 2. The trend in each scenario goes toward different final increase values, with respect to the reference period (year 2000) at the end of the present century (2100): *1.0 °C* for the optimistic scenario RCP2.6, 1.75 °C for the low intermediate RCP4.5, 2.31 °C for the high intermediate RCP6.0 and 3.50 °C for the pessimistic RCP8.5. At the end of the next century (2200) similar data are: *0.75 °C* for the optimistic scenario RCP2.6, 2.04 °C for the low intermediate RCP4.5, 3.13 °C for the high intermediate RCP6.0 and 6.33 °C for the pessimistic RCP8.5.

In **Figure 2** and in a similar way as was done in another work that relates climate change with health risk (see item 1.4 of the present Chapter and also, Piacentini et al, 2018), we extended the analysis to the 22nd century, since people that was born at the beginning of the present century (like the Z and T generations) will have a life expectancy extending to the final decades of the present century and even to the next century (Office of National statistics/UK, 2016).

Another way to predict the future is to extrapolate the past behavior through a mathematical approximation curve, as was done by Piacentini (2018). In this case, the result at the end of the century is 5 °C, which is an alert to modify this behavior, since the negative impacts would be significant (IPCC, 2014). Even increases in temperature larger than 1.5 °C but lower than 2 °C, with respect to pre-industrial era, can produce significant effects in the planet, as reported recently by the IPCC (2018).

2.2 MAIN FACTORS RESPONSIBLE FOR CLIMATE CHANGE

Now that enough scientific information is available of the fact that the global warming is real, it is necessary to analyze who are the main responsible of climate change. The most detailed and comprehensive analysis has been done in the last IPCC Report (IPCC, 2013), through the introduction of the concept of *radiative forcing* of the atmosphere: the net balance of the incoming solar radiation (that is the main heating source of the Earth atmosphere, ocean and land) and the outgoing radiation (sum of the reflected solar radiation and the Earth emitted one).The corresponding values for the main components of the atmosphere that contribute to global warming are (in decreasing order of importance):

- *Carbon dioxide* (CO_2, produced mainly by fossil fuel combustion and non-retired from the atmosphere due to deforestation and other areas with lack of vegetation) are, in units of irradiance or intensity: *1.68 W/m*^{2}.
- *Methane* (CH_4, generated mainly during cattle digestion, rice production, and emissions from open air urban landfills): *0.97 W/m*^{2}.
- *Carbon monoxide* (*CO*, a short lived gas in the atmosphere)*: 0.23 W/m*^{2}.
- *Halocarbons (HCFC,* included mainly in the new refrigeration systems, that replace the old ones, the *CFC*, that were responsible of the Ozone layer destruction, as detailed in WMO/UNEP, 2014): *0.18 W/m*^{2}.
- *Nitrous oxide* (produced mainly by land fertilization for increasing vegetables growing for food production): *0.17W/m*^{2}.
- *NMVOC* (non-methane volatile organic compounds, mainly produced by vegetation):*0.10 W/m*^{2}.
- *Solar irradiance change: 0.05 W/m*^{2}.

Therefore, the total positive contribution to the radiative forcing that heats the atmosphere equals to: 3.38 W/m^2. The atmospheric components that contribute negatively to the radiative forcing (so to global warming), cooling the atmosphere, are:

- *Cloud adjustments due to anthropogenic aerosols: -0.55 W/m*^{2}.
- *Allanthropogenic aerosol contributions:* They are mainly: mineral dust, sulphate, nitrate, organic carbon and black carbon. In this last case the

radiative forcing is positive (the only one with this characteristics) and equals to 0.6 W/m^2.
- *Albedo change due to human land use* (more solar radiation is reflected to the outer space if a forest is deforested, since the reflectivity of this radiation normally increases for bare land): *-0.15* W/m^2.
- *Nitrous oxides* (*NOx* with x = 1 or 2, mainly produced by internal combustion of fossil fuels in vehicles)*:- 0.15* W/m^2.

Consequently, the total negative contribution to the radiative forcing equals to:- 1.12 W/m^2, being the final net (positive) contribution: (3.38- 1.12) W/m^2 = *2.26W/m^2.*

We can see that the only significant natural contribution to the global warming through the radiative forcing is the increase in *Sun activity* (about this solar activity, see for example, Calvo, Ceccatto and Piacentini, 1995). However, it has only *2%*contribution to the total global warming, being the rest (98 %) due to anthropogenic activity (IPCC, 2013).

2.3 SCIENTIFIC EVIDENCE OF CLIMATE CHANGE

As already stated, climate is the state of the atmosphere in a given time interval, like the winter climate, the mountain climate, etc. During hundreds of thousand years the Earth climate was changing (see for example, Weart, 2018). However, for the first time humans had the possibility to modify the climate, starting in the Industrial Revolution, around 1750 and evolving mainly the last (20) century and in the first years of the present (21) century. Piacentini and Mujumdar (2009) determined that the main variable that characterize the climate, the ambient temperature, from the beginning of the last millennium (year 1000) varies very little, decreasing at a rate of -0.02 °C/century up to around 1900 and then increases suddenly, at a rate of +0.57 °C/century. The most plausible explanation of this behavior is the increase in the atmosphere of the so-called greenhouse gases (GHG) and the type of particulate matter called black carbon (IPCC, 2013; IPCC, 2018). From thousand years up to the beginning of the industrial revolution, these three gases evolved almost constantly in atmospheric concentration, but with the increase in population and consequently with the use of fossil fuels, the deforestation and expansion of food production and related waste, among many other contributions, they increased significantly. In particular, CO_2 that never overpassed 300 ppm during a period as large as 800000 years (Petit et al., 1999; Higgins et al., 2015) in April 2018 reached 410 ppm, as registered at Mauna Loa, Hawai, USA (SCRIPS, 2018).

An important series of data that gives a strong support to the increase of the ambient temperature due to human activity, are those of the Borehole project (NCEI, 2018)

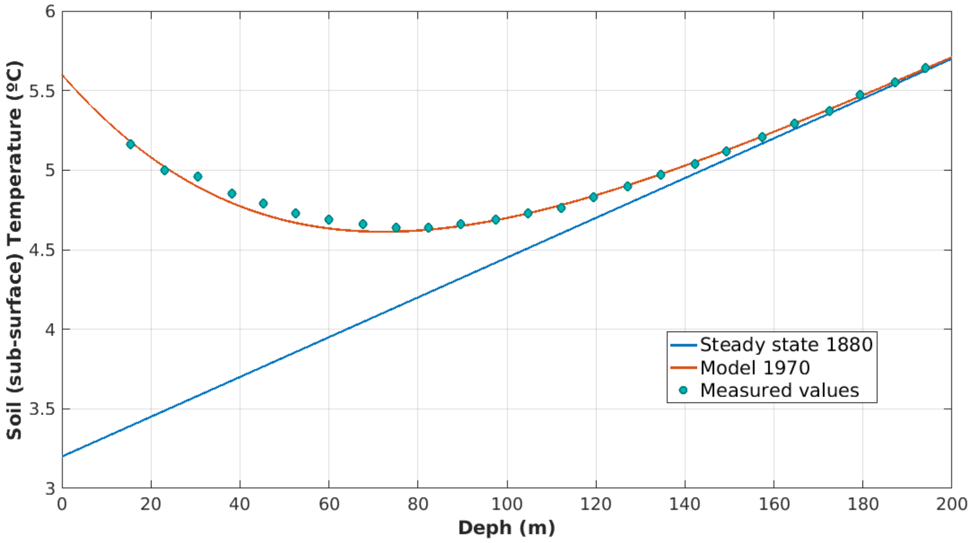

Figure 3: Sub-surface temperature registered at the Kapuskasing, Canada, borehole site in 1970 (Cermak, 1971) (green points) and modeled employing the solution to the dynamic Fourier heat transfer equation (red curve).

The asymptotic behavior given by the straight (blue) line corresponds to the 1880 stationary behavior, when global warming started to influence the boundary (surface) condition that collect the subsurface temperatures registered in different parts of the world at depths varying from near surface and hundreds of meters. Figure 3 displays the data obtained by Cemark (1971) in Kapuskasing, Canada, in the 20-200 meters of depth for the year 1970, in comparison with present model calculations.

We obtained these latter results considering that soil is a semi-infinite solid with boundary conditions at very near sub-surface, similar to the annual mean ambient temperature. The following solution to the dynamic Fourier heat conduction equation (see for example Carslaw and Jagger, 1959) was used to represent the sub-surface temperature, assuming as boundary condition, mean linear time dependence at near sub-surface

$$T(z,t) = \Delta T.\left(\left(1+\frac{z^2}{2st}\right).erfc\left(\frac{z}{2\sqrt{st}}\right) - \frac{z}{\sqrt{\pi st}}.exp\frac{-z^2}{4st}\right) \quad (1)$$

where:
z: depth being zero at surface and positive in the sense of the inner soil,
T: time (in years),
s: the soil diffusivity (equals to 1,06 mm/s^2 as given by Cemark, 1971),
ΔT: change in sub-surface temperature assumed to be due to climate change,
erfc function, that is related to the *erf* function in the following way:

$$erfc(x) = 1 - erf(x) = \frac{2}{\sqrt{\pi}}\int_x^\infty e^{-t^2}dt \quad (2)$$

We can see in **Figure 2** that there is good agreement between the model calculation and the measured values, with a maximum difference between measured data and model calculation results in the range of only 0.1 °C, in all the analyzed soil region (up to 200 m depth). So, it is possible to determine, going back in time up to a linear (stationary) behavior asymptotic to the previous curve, at which year the soil started to be significantly affected by the air temperature increase, that introduce a modification in the boundary condition at surface. This year corresponds to 1880, which it is also in good agreement with the period at which the ambient temperature changed in slope (near 1900) (Piacentini and Mujumdar, 2009). In conclusion, the particular behavior of the sub-surface temperature (with a change of slope in the first part of the curve, between near surface up to around 160 m depth) can only be explained if a modification in the surface temperature is considered, in the sense of a positive increase, corresponding to global warming. This statement is also supported by the work of Beltrami et al. (2003) that analyzed spatial and temporal variability of ground surface temperatures in Canada in general and in the region of Kapuskasing, in particular.

2.4 IMPACTS OF CLIMATE CHANGE

The increase in temperature values is producing different impacts on the ecosystems and society. In this section we present impacts on non-food related subjects, since the food impacts will be described in the item 1.5.

- Impacts on sea level rise and extreme events*.* The increase in ambient temperature, mainly in the Polar regions and at high altitudes (IPCC, 2013) and of the heat content of the ocean water is producing ice and snow meltings and consequently an increase in the sea level. Both contributions produced a level rise of near 20 cm from the industrial revolution to the present. Future projections are even a larger increase, between 0.26 cm (the minimum value in the optimistic RCP2.6 scenario) and 0.98 cm (in the pessimistic RCP8.5 scenario) by 2100 (IPCC, 2013b). Frieler et al. (2016) of the prestigious Potsdam Institute for Climate Impact Research (PIK) in Germany predicts that: "*even if greenhouse gas emissions were stopped today, sea level would continue to rise for centuries, with the long-term sea-level commitment of a 2°C warmer world significantly exceeding 2 meters*". Researchers of this Institute propose that sea level could rise even more than 130 cm by 2100 (PIK, 2016).

Concerning extreme events, Coumou and Rahmstorf (2012) analyzing world data of these types of events, concluded that "*many lines of evidence, -statistical analysis of observed data, climate modeling and physical reasoning-, strongly indicate that some types of extreme event, most notably heatwaves and precipitation extremes, will greatly increase in a warming climate and have already done so*".

- Impacts on health*.* Higher temperatures determine the expansion of diseases to higher latitudes and altitudes, as is the case of Dengue (Liu-Helmersson et al., 2014). Van der Leun, Piacentini and de Gruijl (2008) and Piacentini, Della Ceca and Ipiña (2018), determined that even if solar radiation is the main responsible of skin cancers, ambient temperature increase can also produce an increase of these type of cancers, by considering statistical analysis of Skin Cancer Surveys in the USA.

- Impacts on social problems. The increase in sea level is producing the flooding of low altitude coastal zones, that it is generating large human migrations, as is the case of Bangladesh in the Ganges delta (Karim and Nimura, 2008). Also, the migration of hundred thousand people from the Civil war region of Syria to Europe, has been explained, partially, by an intense drying period in a large fraction of the country induced by climate change (Kelley et al, 2015).

- Impacts on ecosystems. The WWF (World Wild Foundation) in its 2014 Report (WWF, 2014), estimated that *Population sizes of vertebrate species, -mammals, birds, reptiles, amphibians, and fish-, have declined by 52 percent over the last 40 years. In other words, those populations around the globe have dropped by more than half in fewer than two human generations*. A fraction of this decline can be attributed to global warming. In the last (2018) Living Planet report, WWF states that: *The Living Planet Index tracks the state of global biodiversity by measuring the population abundance of thousands of vertebrate species around the world. The latest index shows an overall decline of 60% in population sizes between 1970 and 2014. Species population declines are especially pronounced in the tropics, with South and Central America suffering the most dramatic decline, an 89% loss compared to 1970. Freshwater species numbers have also declined dramatically, with the Freshwater Index showing an 83% decline since 1970.* It is also explained in the same report why Biodiversity matters: *Our health, food and security depend on biodiversity. From medical treatments to food production, biodiversity is critical to society and people's well-being.*

Two important publications analyze different impacts:

Mora et al (2018), consider that the emission of greenhouse gases is producing changes in different climate hazards, in particular, they *found traceable evidence for 467 pathways by which human health, water, food, economy, infrastructure and security have been recently impacted by climate hazards such as warming, heatwaves, precipitation, drought, floods, fires, storms, sea-level rise and changes in natural land cover and ocean chemistry. These findings highlight the fact that GHG emissions pose a broad threat to humanity by intensifying multiple hazards to which humanity is vulnerable.*

- NCA (US National Climate Assessment) published in November2018 its 4th National Climate Assessment. In particular, in its Volume II related to Impacts, Risks, and Adaptation in the United States, established that: *a) Climate change creates new risks and exacerbates existing vulnerabilities in communities across the United States, presenting growing challenges to human health and safety, quality of life, and the rate of economic growth, b) Without substantial and sustained global mitigation and regional adaptation efforts, climate change is expected to cause growing losses to American infrastructure and property and impede the rate of economic growth over this century, c) Climate change affects the natural, built, and social systems we* *rely on individually and through their connections to one another. These interconnected systems are increasingly vulnerable to cascading impacts that are often difficult to predict, threatening essential services within and beyond the Nation's borders.*

2.5 CLIMATE CHANGE INFLUENCE ON FOOD SECURITY

The generally accepted definition of Food Security is that stated at the Rome Declaration on World Food Security, in November 1996, by the United Nations Food and Agriculture Organization (FAO), which was refined in the FAO's State of Food Insecurity in the World in 2001: *"Food security exists when all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food which meets their dietary needs and food preferences for an active and healthy life."*

This definition considers the four components of food security: food availability, food accessibility, food utilization and food system stability. When one or more of these components is uncertain or unreliable, the food system is considered vulnerable.

Some of the most important effects produced by climate change are affecting food systems at different scales (regional, local) and stages along food value chain, including food production and storage, food access and price stability. A great effort has been made to understand d the impacts of climate change on food production (Parry et al., 2004; Porter et al., 2014; Ali et al., 2017), but those impacts that might affect the aspects of food security not linked to production still present great uncertainties.

Moreover, the effects of climate change on the different dimensions of food security present great variation from one region to another throughout the world, and is expected to have a notable impact on patterns of trade between nations and development. Therefore, to evaluate the possibilities of adapting to climate change, the food system should be considered as a whole. The following items describe how climate change can affect the different dimensions of food security.

2.5.1 Food production and food availability

Food production is considered the basis of food security because it is a decisive step in food access. Most of the climate changes observed in different regions negatively affects local and regional food production. However, in some places, changes in climatic conditions favor the development of new crops and economic activities and, therefore, these changes can be considered positive. Anyway negative effects have been predominant with respect to the positive ones (Porter et al., 2014).

Agriculture, livestock and fisheries are all climate-sensitive economic activities and, therefore, they are likely to be affected by climate change. However, the possible impacts can be mitigated by the adoption of risk management measures and adaptation strategies that strengthen the productive systems and their capacity for recovery, which will also depend on the economic capabilities of each region.

Agriculture

Agriculture is one of the most important activities for food security. In addition to producing food, agriculture is the main source of work for a large part of the world's population. According to data obtained from the '*World Urbanization Prospects: The 2014 Revision from the UN Population Division'* (United Nations, 2014), the world rural population comprises approximately the 45% of the total and the regions with the largest rural population are: central, north and west Africa (51%, 46%, 53%, respectively) and central, south and south-east Asia (57%, 63% and 51%, respectively). In these areas with greater dependence on agricultural production, the negative effects of climate change on agriculture will affect their main economic activity, increasing their vulnerability to food insecurity.

Concerning the contribution of Agriculture to the Greenhouse gases emissions (GHGe), Smith et al (2014; see also Ramankutty et al., 2018), in the 2014 IPCC/WGII Climate Change report, established that: *Globally today, agricultural management on already-converted lands is thought to make up ~13% of GHGe (5.0–5.8 GtCO2eq/year). Over one-third of this results from CH4 from enteric fermentation, ~15% from N2O emissions from manure and synthetic fertilizer application, and ~12% from CH4 in rice paddies.*

Among the effects that climate change can produce in agricultural production is the so-called *greenhouse fertilization effect*, which refers to the fact that higher levels of atmospheric CO2 stimulate plant growth (Erda et al., 2005). In temperate zones, assuming that CO_2 levels in the atmosphere reach 550 parts per million, it has been estimated that yields of crops with a lower rate of photosynthetic efficiency (C3 crops, i.e: wheat, soybean, alfalfa) could increase approximately by 10-25% and those with a higher rate of photosynthetic efficiency (C4 crops, i.e: maize, sugarcane, sorghum) up to 10% (Porter et al., 2014). However, given that this effect is also expected to facilitate the distribution and increase in the competitiveness of invasive weeds, it is not considered a positive effect.

The *greenhouse fertilization effect* is one of the parameters that present the greatest uncertainties in the models used to evaluate the impacts of climate change because there is limited experimental data on crop responses to increases in atmospheric CO_2. In addition, observed CO_2 increase is highly correlated with the main changes in technology, crop management and other factors that improved crop yield over time.

Regarding the increase in the mean temperature, projected impacts vary across crops and regions. For example, a moderate warming (1-3°C) in temperate regions is expected to benefit crop yields but to have negative effects in tropical and seasonally dry regions, in particular for cereal crops. All world regions would be negatively affected if the increase in average temperature exceeds 3°C (Porter et al., 2014). Extreme weather events frequency is expected to increase, and for example, abnormally high temperatures during short periods of time could significantly negatively affect crop growth and final yield (Wheeler et al., 2000; Innes et al., 2015). During the European heat wave of 2003, significant decreases in crop yields were observed, in particular, in the Central and Southern European agricultural areas. The increase of almost 6 ºC of the temperature, compared to the average in summer, seriously affected the potato, wine, maize and wheat production. The fall in cereal production in Europe was more than 23 million tons compared to 2002 (de Bono et al., 2004; Ciais et al., 2005).

Another of the expected consequences of climate change that can affect agriculture is the *precipitation gradual changes*. These changes imply modifications in the timing, duration, intensity of rain and snowfall. The changes observed vary according to the geographic location. An increase in the frequency and intensity of storms and floods has been observed in some areas. The agricultural area affected by floods increased in China, by 88% during 1970-2000 (Piao et al., 2010). In addition to direct flood damage, excess precipitation events led to excess soil moisture which affect crops in different ways: provides anoxic conditions, increases risk of disease and plant infections, delays agricultural processes (i.e., harvesting) because it makes the land inaccessible. Moreover, sea-level rises due to global warming will increase the risk of flooding of agricultural areas near the coastline.

An increase in rainfall can be considered a positive effect for agriculture in some areas. For example, in the Argentinean Pampas the increased precipitation led to the expansion of the agricultural frontier and an increase of up to almost 40% of the yield of soybean, maize, wheat and sunflower crops (Magrin et al., 2005).

On the other hand, some areas show a decrease in rainfall and, consequently, an increase in the frequency, duration and intensity of droughts. This will be particularly important in areas where production systems are based on rainfed agriculture. For instance, almost the 90% of Latin America farmed land is rain dependent (Vergara et al., 2014). Considering the fact that this region is the main source of sugar, soybeans and coffee (accounting for over 50% of worldwide exports; FAO, 2016), prolonged and repeated drought can cause a decrease in the availability of these basic foods in other parts of the world.
Other regions, such as the Asia-Pacific region, where a large part of the cultivated area is based on irrigation systems, would be less affected if there is a decrease in rainfall in this area (FAO, 2018). Expanding the use of irrigation in Latin America could be useful to ensure food production in this region, but this requires greater infrastructure and a large capital investment.

The expected greater *seasonal weather variability* and, as a consequence, changes in the start/end of growing seasons, will also have long-term implications on the viability of current agricultural systems and future food availability.

Since the space-time distribution of insects and plant pathogens is determined mainly by climate, an expansion of their geographic ranges to new warmer and more humid areas is expected, and as a consequence, greater vulnerability of crops to diseases, especially in the early stages of plant development (Bebber, 2015).

In summary, due to the changes in climate conditions, crop yield (as a global mean) is likely to be reduced and, consequently, cost of agricultural production (and food stuff) could increase. These changes will impact not only in large agro-industrial systems but also in smaller farm productive systems. Due to the fact that this last group presents in general less economic resources and resilience to face the impacts, the consequences for them would be greater. This is not a minor issue if we consider that in the current world there are around 500 million family farms which constitute the predominant agricultural model in developing countries and the largest provider of food for both developed and developing countries (FAO, 2014). For instance, in Latin America there are about 15 million family farms, covering almost 400 million ha which produce the 51% of the maize, 77% of the beans, and 61% of the potatoes consumed in the region (Altieri and Toledo, 2011).

Livestock

Livestock products account for the 33% of global protein consumption and are an important agricultural commodity for global food security (Rojas-Downing et al., 2017). Livestock production systems are also important because they employ close to 1.1 billion people, mainly in the poorest countries in the world (Hurst et al., 2005). In many arid and semi-arid regions, they represent the only viable system of food production.

Livestock production is affected by climate change in different ways. Forage crops represent approximately 25 percent of the world's cropland (Nardone et al., 2010). Changes in production and quality of feed crop and forage due to the combination of increases in temperature, CO_2 and precipitation variation will directly affect the availability and quality of feed for animals. The length of growing season, which determines the period of available forage, is also an important factor for forage quality and quantity. Moreover, temperature and precipitation changes impact on water availability, animal growth, reproduction and health (Thornton et al., 2009; Henry et al., 2012).

Though some research has been conducted on the effect of changes in temperature in livestock (Nardone et al., 2010), there is still little information on the physiological, immunological and livestock behavior and its possible adaptation to climate change (Hoffmann, 2010). A better understanding of the animals' biology (considering different varieties of livestock and species), and how they can be affected by changes in climatic variables and the indirect effects, such as exposure to heat stress or diseases, is necessary to predict impacts and develop adequate mitigation strategies.

Fisheries

The described climate trends are also affecting freshwater and marine aquaculture production in different regions of the world (Cheung et al., 2010 and 2013). The abundance and distribution of harvested aquatic species are being negatively impacted and the trend is expected to continue. This fact threatens food security and nutrition especially in some tropical developing countries, and in communities that base their economy and nutrition mainly on this activity.

Will the expected higher yields in temperate regions (partially) compensate for lower yields in tropical regions? This is a complex issue; we must consider that many developing countries have a limited financial capacity to trade and a great dependence on their own production to meet the food needs of their population. Impacts on agricultural production will affect subsistence and access to food globally, and will also affect livestock production. Food security and the well-being of the population in areas with less capacity to cope with the effects of climate change, for example the poorest rural areas in developing countries, are at greater risk.

2.5.2 Food processing, storage and transport

Climatic effects in the storage and processing of the grains will be different according to the area in question. In those areas where humidity and precipitation increase, the grains will be harvested with up to 15% more moisture than is acceptable for a correct and stable storage (Porter et al., 2014). This will be a problem for crop drying and storage, and also increasing the contamination risk by microorganisms, incidence of pests, diseases and mycotoxins. Greater investments requirements to use new storage technologies to avoid this problem could lead to an increase in food prices.

Food transport and distribution is, as important for food security as production, and could also be affected by climate change. Food storage and processing technology has allowed the development of long-distance marketing chains, in which packaged food products are sent around the world at a relatively low cost and high speed. However, the increase in the frequency and intensity of severe climates (for example, storms) increases the risk of damage to transport infrastructure, impacting on the distribution of food and increasing the vulnerability of food supply chains.

On the other hand, there is a need to reduce the use of fossil fuels along the food chain. The expression '*food miles*' refers to the distance food is transported from its production center until it reaches the consumer. Food miles should be reduced as low as possible to reduce emissions of greenhouse gases, responsible for the global warming (see for example, Piacentini et al., 2015).

2.5.3 Food system stability: Marketing and retail

Food system instability is a result of the constant tensions between food system resiliencies and food system vulnerabilities (Jahn et al., 2018). Since climate is an important determinant of the price of food in the short and long term, the stability of the entire food system is at risk. The increase in the price of basic foods will affect mainly the food security of the poorest, which spend a large part of their income on basic food. For instance, in 2008, the combination of a general reduction of agricultural productivity and poor policy decisions, such as increased export restrictions applied by many countries and poor regulation of financial commitment in food markets, derived in a global food crisis which caused political, economic and social instability affecting both undeveloped and developed nations (Headey and Fan, 2008).

2.5.4 Food consumption and utilization

Food utilization is described as ‘the way in which the body makes the most of various nutrients in the food’ by the Food and Agriculture Organization (FAO, 2008) and can be considered the final step to adequate nutritional status. There are two main ways in which climate can affect food utilization: health and diet (Aberman and Tirado, 2014).

Health impacts involve the safety of food, water, and diseases and infections that can jeopardize the body's ability to absorb nutrients. Most of the projected diseases linked to climate change are related to diarrheal diseases and malnutrition. Diarrheal diseases do not allow the efficient absorption of nutrients. Some studies have found an association between the increase in temperature and the increase in episodes of diarrheal diseases (Singh et al., 2001; Azage et al., 2017; Horn et al., 2018). Also, during extreme rain events, there has been an increase in monthly reports of outbreaks of waterborne diseases in different parts of the world (Confalonieri et al., 2007).

On the other hand, the impacts on the diet imply changes in the nutrient content of the food. Increased concentrations of carbon dioxide may reduce the nutrient content of food crops, including protein, iron, and zinc content (Taub et al., 2010; Zhu et al., 2018). Moreover, nutritionally important minerals including calcium, magnesium and phosphorus may also be decreased their concentration under elevated CO_2 (Moretti et al., 2010).

Finally, the combined effects on health and diet increase the susceptibility of the population to diseases; this could cause a decrease in productivity and lead to greater food insecurity.

2.5.5 Conclusions

Climate change is affecting plant and animal biophysical factors, water and nutrient cycles and, consequently agricultural and other food production systems. There is increasing evidence about the negative impacts of climate change on crop yields, fisheries, and livestock. Moreover, other indirect impacts related to physical/human capital (i.e, roads, storage and marketing infrastructure, electricity grids, human health) might affect the economic and socio-political factors and, consequently, food access and utilization, threatening the stability of food systems.

While some countries in the temperate zone may be benefited by climate change (allowing the cultivation of new species, for example), most countries in the tropics and subtropics, which also tend to be the poorest and vulnerable, will be negatively affected.

However, it should be noted that there are still great uncertainties regarding how climate change will affect the supply, demand and trade of food worldwide. There is still uncertainty about what the magnitude and scope of climate change will be, how efficient will be the adaptation measures applied in the different regions, how technological development will help. It must be also considered that the social, economic or technical limitations of many countries can hinder the application of adaptive measures.

So far, the Paris Agreement of the United Nations, signed in 2015, is the largest global effort to limit climate change. However, some of the measures to achieve the Agreement objectives may not benefit the decline of global hunger. In order to limit the increase in global average temperature to below 2 °C above pre-industrial levels, the Paris Agreement proposed some measures related to land-use. These measures, that include the re-planting of trees in recently cleared areas, the increment of biofuels production, would take place in former agricultural lands and therefore cause a reduction in the space available for food production, which will lead to an increase in food prices and greater food insecurity (Fujimori et al., 2018). Fujimori et al. (2018) consider that the Paris Agreement should incorporate global food security policies in order to avoid adverse effects and suggest interesting measures: the increase in international aid from more developed nations, taxes on biofuels and the reallocation of income to the less developed nations so that they yield less income from agriculture. As can be seen, food security is a multidimensional phenomenon.

2.6 SUSTAINABLE ENERGY USE IN FOOD PRODUCTION

Sustainable energy is defined as the sum of *Renewable energy* (having a source that normally does not end its power supply) and the *Energy efficiency*, even if this last term actually it is not an energy, but a given reduction in its use, it can be considered as a *virtual source.*

2.6.1 Efficiency

The first step to sustainability is to consider an efficient use of a given resource (energy, water, soil, air, and ecosystem). We can define the resource efficiency coefficient as:

$$\eta_x = R_{used,x}/R_{total,x} \quad \text{or in percents: } \eta_x(\%) = 100*(R_{used,x}/R_{total,x}) \qquad (1)$$

being $R_{total,x}$ (= $R_{used,x}$ + $R_{loss,x}$) the total considered incoming or available resource of a type *x* introduced in a system (machine, vehicle, building, etc.), $R_{used,x}$ the useful resource and $R_{loss,x}$ the loss resource, as shown in **Figure 4**.

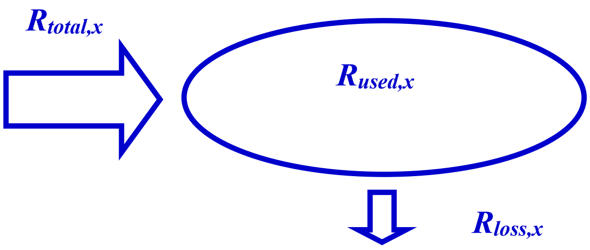

Figure 4: Schematic representation of a system with incoming (available) resource $R_{total,x}$ (energy, row material, water, etc.), used resource $R_{used,x}$ and loss resource $R_{loss,x}$

For example, in the case of the analysis of the energy efficiency of a truck diesel engine, a large fraction of the total incoming energy to the system ($E_{total,diesel}$) is loss ($E_{loss,diesel} = 0.7E_{total,diesel}$), resulting in a quite small efficiency, $\eta_{energy,diesel}$ (%) = 30 % . One of the main reasons of the large expansion of the electric vehicles in the last years (even trucks) is that an electric motor has an efficiency which can more than double the diesel one (see for example, Gustafsson and Johansson, 2015).

We like to point out that the energy efficiency can also be defined in another way, through the introduction of *indicators* (or indexes). One of the most common indicators is the quantity of fuel employed per period of time (liter of diesel/month, m^3 of gas/year, etc.).

2.6.2 Resource intensity

The resource intensity measures the use that it is done to a given resource (energy, water, raw material, etc.) per unit of reference, in a given period of time (usually a year). For example, in the case of electricity consumption, the Intensity is the total electric energy (E_{energy}) used annually (I_{energy}) in a building of a given total surface: $I_{energy} = E_{energy}/(year \cdot surface)$, having units of KWh/(year.m^2).

It must be pointed out that this quantity permits to compare different systems, since the total resource (i.e., energy used annually) can be very high, but when referred to a given product (i.e., tons of grain produced with machines using this energy), is possible to realize if the system is working well. Resource intensity needs to be continuously decreased and resource efficiency on the contrary, needs to be increased.

2.6.3 Renewable energy

Renewable energy normally has a source that depends on natural supply: Sun, wind, water (river, sea), underground soil, vegetables (through

photosynthesis). Several energetic substances, if produced with renewable energy like hydrogen or compressed air, are also considered as a renewable energy source.
We will start analyzing the primary energetic source, solar radiation, that it is largely available in many parts of the world. The large deserts of the world and the zones at high altitudes normally have the large solar irradiation or insolation (in units of KWh/m^{2}year). Detailed maps and data on this variable can be obtained at the following addresses: NASA (https://power.larc.nasa.gov/data-access-viewer/, monthly data are given in the web page https://svs.gsfc.nasa.gov/30367), IRENA (International Renewable Energy Agency) (https://irena.masdar.ac.ae/gallery/#gallery) and Solargis (http://solargis.info/doc/free-solar-radiation-maps-GHI). An interesting and basic bibliography for these energy sources is the Open University (Great Britain) book: Renewable energy. Power for a sustainable future (Boyle, 2004). IRENA is also a nice source of information (www.irena.org).

Solar thermal

One of the most common applications of solar radiation is the production of heat through solar collectors. In particular, solar water heating is a possibility for cleaning of vegetables devoted to food production. Solar heating can also be used for other applications, like: house inner climate, industrial processes, etc.

Solar photovoltaic

Other application of solar radiation is its conversion to electricity, through the photovoltaic effect. Solar cells of different types are used for capturing and converting solar photons in electric charges. These last years, a notable expansion in the production and consumption of solar cells has been experienced, in the range of 35-40 % per year (Razykov et al., 2011; NREL, 2018). The efficiency of solar energy conversion to electricity employing solar cells has also a significant increase in many different types. In particular, the perovskite solar cells efficiency increases at a rate of near 2 % per year in the period 2013-2018, arriving at a maximum value of 23.3 % in 2018, even surpassing the Silicon multicrystaline solar cell (having a maximum efficiency of 22.3 %). The cost of the most commonly used solar cells (Silicon mono and multicrystaline) has decreased in around an order of magnitude (a factor of about 1/10) in only a decade.

Exceptionally large solar power plant complexes (in some cases photovoltaic alone and in others photovoltaic + thermal or only thermal) in the range of GW (=10^{9}W) are in construction at present in China (1,547 MW of power occupying a surface of 43 Km^2, at Tengger Desert Solar Park, in Zhongwei), India (Bhadla Solar Park with 2,255 MW of power and covering a surface of 40 Km^2 in Bhadla, Rajasthan state. This state is projecting solar power plants as big as 26,000 MW (http://projectreporter.co.in/prcontentdetail.aspx?Id=2627). The largest project at present is that proposed by Saudi Arabia that is projecting solar power plant complexes of 200,000 MW by the year 2030 (https://www.bloomberg.com/news/articles/2018-03-28/saudi-arabia-softbank-ink-deal-on-200-billion-solar-project).

Wind

Another way to capture energy from a natural resource is to use wind turbines exposed to rather windy regions (AWEA, 2018). The amount of power that can be obtained from these turbines depends in a direct way on the density of the air, the circle area defined by the length of its blades and most important to the cubic power of the wind velocity. So, if a region of the planet has double annual mean velocity than another region, the power to be extracted from the turbines increases by a factor of eight. In a similar way as for photovoltaic solar power plants, wind power plants are rapidly expanding all over the world.

Water

A hydroelectric power plant (a dam that intercept a river current and increase the altitude of the water level and consequently its potential energy) is considered a renewable power plant if it has a maximum power of 50 MW. Also, water power can be produced converting the energy of the tidal, waves and thermal gradient between the surface and inner parts at higher temperatures, like on salt lakes. Hydroelectric power plants of small scale are also possible without dams and water reservoirs through a systems similar to a wind turbine but used underwater, where the water flows act as the energy driver.

Soil (or Geothermal)

Since the soil temperature near surface has monthly mean values usually lower than ambient temperature (higher in winter time and smaller in summer time), it is possible to use the soil as an energy source for climatization of buildings/houses. It is based in the placement of tubes for heat transfer under the soil (usually called *geotubes)* at depth that goes from some meters to hundreds of meters, since more depth corresponds to more temperature (GEA, 2014).

Bioenergy (biomass/biofuel/biogas)

Biomass energy is produced by the combustion of vegetables in different forms: a) used directly in the form of solid fuels (wood, crop residues, etc), b) used indirectly transforming vegetables (or part of them) in liquid biofuels (called *bioethanol* and *biodiesel*) and c) by decomposition of organic material and transformation in gas (called *biogas*). However, care must be taken when using vegetables that can also be used for food production, trying to reduce to the minimum the competition energy vs food. For example, soybean is used intensively in Argentina for both applications, with only around 9 % of the oil material that can be transformed in biodiesel, much of the rest are proteins for humans and animals.

Non-conventional fuels (Hydrogen, compressed air, electricity)

Hydrogen, compressed air and electricity can be used as a clean energy source if they are produced employing renewable energy sources. They are very efficient and do not produce greenhouse gases, as conventional (petrol and gas derived) fuels. There are different applications of this type of non-conventional fuels, mainly in cars. A Japan car company (see https://ssl.toyota.com/mirai/fuel.html) is going in the hydrogen direction as a fuel, a French car company (see https://www.citroen.co.uk/about-citroen/concept-cars/c4-cactus-airflow-2l) is promoting the compressed air plus conventional fuel, with a concept car consumption as low as 2 liter/100 Km and many car companies are developing electric cars (see for example https://www.whatcar.com/category/electric).

2.7 REDUCTION OF *FOOD MILES* AS A CONTRIBUTION TO CLIMATE CHANGE MITIGATION

Cities import most of the food they eat from outside their geographical boundaries. Sometimes, distances between the production centers and the markets or retail stores are considerably long. These distances traveled by food products are known as *food miles*.

After being produced in appropriate soils, transportation, processing, packaging and storage of food products contribute to the energy use. Moreover, if this energy is non-renewable (basically, oil, gas or coal), those processes are responsible for the GHG emissions that produce global warming (see item 1.1). Since distances are long, special acclimatization equipment are used for transportation, in order to preserve food for a longer period of time. Besides the most well-known gas, carbon dioxide, it must be taken into account that acclimatization equipment also emits hydrofluorocarbons (HCFC), another powerful greenhouse gas.

In several European countries, such as the Netherlands, 30% of the total greenhouse gases emissions are related to food consumption (W. Sukkel, University of Wageningen, Holland, 2012, personal communication). Similar trends can be expected in fast growing Southern cities, particularly in developing countries.

2.7.1 Calculation of energy consumption and CO_2emissions from the transportation of vegetable foods: the case of Rosario city, Argentina

Rosario is located in a region called Pampa Húmeda (32.51ºS, 60.44ºW, and 25 meters above sea level). The city has an estimated population of 1.000.000 inhabitants (year 2018), and along with the metropolitan area (Greater Rosario), this population rises to 1.500.000. The population growth in the last decades has been rather low, since the number of immigrant and the births were compensated by the emigrants, who moved to surrounding towns. The three vegetable foods that are most consumed in Rosario city, Argentina, are potato, tomato and lettuce. A small fraction of these foods are produced in the near peri-urban region and the rest comes to Rosario from long distances.

For example, potato is mainly produced in the region of Balcarce, Buenos Aires province at 650 Km from Rosario and a small fraction in the peri-urban site of Arroyo Seco, Santa Fe province (at around 30 Km from the city).
Following the work of Piacentini and Vega (2014) and Piacentini et al. (2014, 2015), in order to make a *food miles* analysis of the possibility to produce all these vegetables in the peri-urban (local) region, we consider three different scenarios:

- *Scenario 1:* current situation of exclusive use of trucks to transport the vegetable foods from Balcarce to Rosario.
- *Scenario 2:* multi-modal transportation, using trains to travel long distances and trucks (to and from train stations and production/consumption points) for short ones.
- *Scenario 3:* current situation of exclusive use of trucks to transport from Arroyo Seco to Rosario.

To obtain the energy consumed by transportation (trains and/or trucks) considered in the different scenarios and the associated greenhouse gases emissions (especially CO_2, since the other gases emissions are quite low if there is no acclimatization), we use the following coefficients to convert fuel volume to energy consumption: 36.6 MJ/liter and to CO_2 mass: 2.9343 $KgCO_2$/liter. They are given by International Sustainability and Carbon Calculations (ISCC, 2011).

Food miles results for the three scenarios are presented in Table 1, where it can be seen that the lower energy consumption and thus, the lower CO_2 emission can be found in Scenario 3, related to *local production*. The corresponding reduction of this Scenario 3, with respect to Scenario 1 (actual situation of food transportation by trucks in long distances) is 96%.

Table 1: Fuel energy consumption and carbon dioxide emissions, related to the transportation of the most consumed vegetables (potato, tomato and lettuce) in Rosario, Argentina.

	Total Emissions/year (Ton CO2/year)			Total Energy/year (GJ/year)*		
Product	**Present case****	**Polymodal**	**Local production**	**Present case****	**Polymodal**	**Local production**
Potato	76030	34050	3140	6095	2641	252
Tomato	38860	23640	1413	2667	1895	113
Lettuce	90700	55120	6212	6865	4419	498
Total	***205590***	***112810***	***10765***	***15627***	***8955***	***863***

**GJ = 10^9 J. **Long distance transportation.

If the long distance transportation would be done by a multi-modal system (train+truck), as in Scenario 2, fuel and emission savings, (and, consequently, energy savings) compared to Scenario 3, would be of 51.2% and 55.2%, respectively (Figure 4). Moreover, this type of transportation favors traffic jam indicators, reduces car accidents and road infrastructure costs, among others.

Table 1 show that potato is the vegetable than consumes the highest amount of energy, and, therefore, emits the highest amount of greenhouse gases, followed by lettuce, since it is necessary to have a large volume truck for a low density vegetable and at the end tomato. We like to point out that researchers of the Faculty of Agricultural Sciences of the National University of Rosario (placed in the peri-urban area of Rosario), determined that about 50% of the lettuce were disregarded at the end of the commercialization chain, due to improper techniques of packaging, transportation and storage.

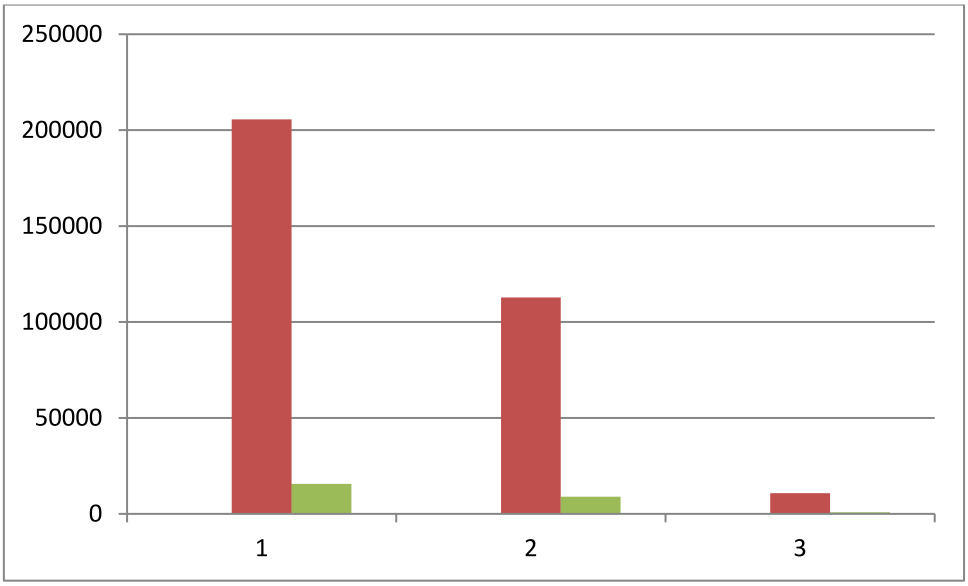

Figure 4: Fuel energy consumption (red bar, in GJ/year) and greenhouse gases emissions (green bar, in $TnCO_2$/year) for transportation of the main vegetable foods (potato, tomato and lettuce) consumed in Rosario per year, considering different transportation systems: Present case (long distance transportation) (1), Polymodal (2) and Local production (3).

Similar analysis can be made considering other vegetables and other cities, all of which would result in a bigger contribution to mitigate climate change, just as other proposals like energy efficiency, renewable energy and materials uses (Piacentini y Della Ceca, 2017). It is important to mention that emission related to production itself (for example, mechanization, fertilization and other production practices) are similar for the local and distant production and that other advantages of local production include the strengthening of the food security and an increase in the food quality since they are harvested and delivered within a short period of time.

Piacentini and Vega (2017) obtained similar results regarding energy consumption and carbon dioxide, methane and nitrous oxide emissions when analyzing the replacement of synthetic nitrogen fertilizers with compost obtained from urban food waste.

In conclusion, a detailed analysis of energy consumption and polluting emissions related to food as well as to food waste can make a considerable contribution to the global effort to mitigate climate change and to improve the quality of life of marginalized urban and peri-urban population, mainly in developing countries, where there has been a massive migration from rural to urban areas. Besides all this kind of reductions, urban a peri-urban agriculture development policy improves food quality and creates stable jobs.

2.8 SOLAR DRYING OF FOODS AS A CONTRIBUTION TO CLIMATE CHANGE MITIGATION AND ADAPTATION

To preserve foods, drying of vegetables is a very interesting and usually economic and simple technique. It can mitigate the global warning by replacing the fossil fuels as an energetic source by renewable energies, and also it can contribute to adapt to this warming, since higher temperatures will deteriorate more rapidly the product that it is not stored at convenient (low) temperatures (consuming a large amount of electricity) or that it is not reduced in its water content.

We present in two solar dryers, one devoted to the drying of fruits and the other to the grains.

2.8.1 The design and test of family solar dryers for food security

Dehydrating food is one of the oldest techniques used by man to maintain food for a longer time than in normal conditions. This technology allows decreasing the aqueous and microbial activity, while minimizing chemical and enzymatic reactions keeping bacteria and fungi growth under control. In order to get the correct dehydration, it is necessary to evaporate as much water content as possible, which can be achieved by delivering directly thermal energy (heat) to produce evaporation or indirectly by air circulation causing homogeneous dehumidification.

Solar energy can be used in a direct or an indirect form for food dehydration. In the direct form, food is exposed directly to the sun; some transparent material can be placed over them in order for preservation from the surrounding dust deposition and to reduce heat loss. As advantages, it can be mentioned low cost and almost no maintenance requirements. On the other hand, its main disadvantages are: the slowness of the process, its heterogeneity and the difficulty to control e ambient temperature.

The indirect form consists of two structures with specific well-differentiated functions. On the one hand the solar collector, whose main objective is to capture solar direct and diffuse radiation and to use this energy for increasing air temperature. This is achieved by circulating air between a transparent material and a sheet of absorbent material.

After the increase in temperature, air enters the second structure, the drying chamber, where it interacts with food, absorbs its water and returns to the environment. Air circulation can be by natural convection or through a blower in the entrance or exit of the drying chamber. One of the main advantages of this system is that it avoids exposure to direct solar radiation, so decreasing the possible for food degradation.

It is possible to control air flow and its maximum temperature, limiting the nutritional and gustatory degradation of some products sensitive to high temperatures. Among other advantages, we can mention the isolation of food products from possible environmental contamination (dust, acid rain, etc.), and the protection of food against rodents or other animals. Regarding to energy efficiency, indirect dehydration generally has a greater drying efficiency than direct dehydration. These advantages determined the present choice of the last type of solar dryer to be built and employed for apple dehydration in an experiment done at Rosario city.

Experimental wood solar dryer

We present two indirect solar dryers, designed and built with variations in construction material, size and purpose for which they were designed. Chronologically, the *Experimental wood solar dryer* (Figure 5) was the first one to be built, serving as a base and experience to another series of dryers built later. In particular, in the last one, the wood structure was replaced by a metallic one.

Construction goal

The main construction goal was to have a device that allows to experiment and test manufacture, operation and efficiency measures to be applied to the device. It was designed in such a way that it could be easily built, being able to be carried out in training courses or workshops with small farmers, students, etc. It is also intended to be of low cost, since common materials that can easily be obtained in the market were used. The dryer was built mainly with pine wood and painted black plate. This model of dryer was used as a basis to build others and also to perform measurements and experiments.

Dimensions and materials

The dryer has a solar collector plate through which the ambient air overpasses and absorbs energy. Then, it passes to the drying chamber, where the food is placed in slices to be dehydrated. The collector plate is mainly built with 0.02 m pine wood boards. The base size is 1 m long, 0.54 m wide and 0.12 m height. As lateral woods are 0,02 m thick each one, it results in 0.50 m^2 of effective solar collection area. The base layer is made of wood and over it, a thermal insulation of expanded polyethylene of 2 cm is placed.

A pre-painted black corrugated metal sheet is fixed above it and finally a UV resistant polycarbonate is placed as a cover. The distance between the polycarbonate and the sheet is 5 cm, space through which the air circulates, increasing its temperature and decreasing its relative humidity. Thanks to the corrugated form, the air can also flow behind the metal sheet.

The drying chamber is a wooden box of 58 cm wide, 70 cm high and 38 cm deep. It is at a height of 60 cm from the floor. The upper face is 45 degrees' slope, generating a height difference of 20 cm between the front and the bottom of the drying chamber. The front and the upper face are built with galvanized sheet painted black to increase the solar energy gain. The other faces are made with 0.02 m pine wood boards brushed on both sides.

Figure 5: Experimental wood dryer

2.8.1.1 *Experimental metallic solar dryer with photovoltaic electricity support*

Construction goal

The purpose of the construction of these types of metallic solar dryers was different from the motivations of the self-constructed wooden model. The metal dryer arises from a specific request by Eng. Raúl Terrile of the Municipality of Rosario, who was working in a project to promote Agro-ecology in small and medium farmers with their productive lands near the city.

Since the users were small farmers, the following requirements needed to be met:

- Resistance of materials and design against bad weather and wear,
- High level of dehydration capacity,
- High efficiency,
- Temperature control in order to preserve the products quality
- Off-grid energy self-generation
- Collector design to be easy to clean.

Consequently, it was decided to build metallic structure of iron structural pipes, covered with galvanized metal sheet and insulated with expanded polystyrene. Also, to limit the collector exit air temperature, in order to keep food properties, it was decided to put a temperature controller, used to measure and control temperature with a J thermocouple. The internal relay can directly switch a cooler with ON/OFF control. This increases air flow reducing thus its maximum temperature. The device is energized by a 30 W solar photovoltaic (PV) panel as can be seen in **Figure 6**.

Figure 6: Metallic dryer for small producers

Dimensions and materials

-Solar collector plate

The first layer is a plywood plate, of 0.94 cm wide by 1.16 cm long varnished on both sides. An expanded polystyrene plate 2 centimeters thick is mounted over it to isolate the collector plate and to reduce the lower face heat losses. The pre-painted galvanized metal sheet is then fixed with self-tapping screws. Then the polycarbonate sheet is mounted on the structure. A 4 cm space from the metal sheet to the polycarbonate allows air to flow and the "greenhouse effect" (heating of the air) occurs. The collector plate is finished with two pieces of folded metal sheet in a "C" shape that cover the side woods and protect the (**Figures 7-12**).

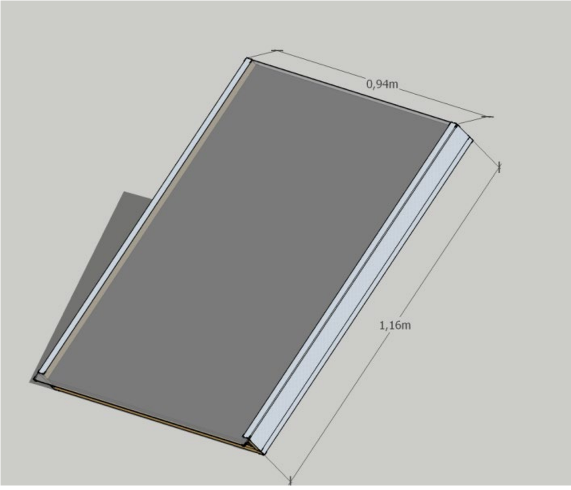

Figure 7: General image of solar collector plate with dimensions

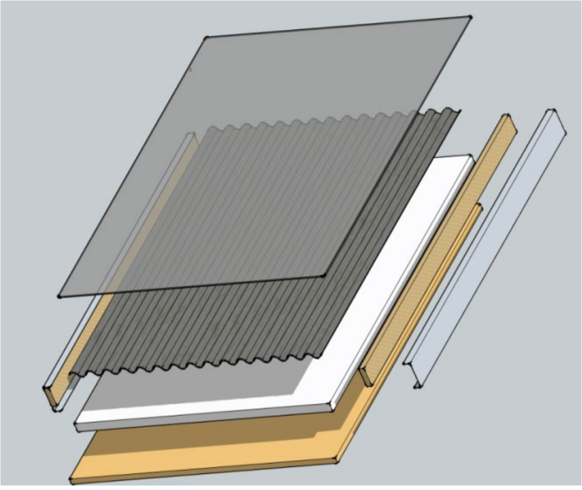

Figure 8: Different parts of the solar collector. From bottom to top, wood plywood, polystyrene insulation, pre-painted black metal sheet and polycarbonate

Figure 9: Solar collector plate

Figure 10: Construction detail

Figure 11: Construction detail of the dryer chamber

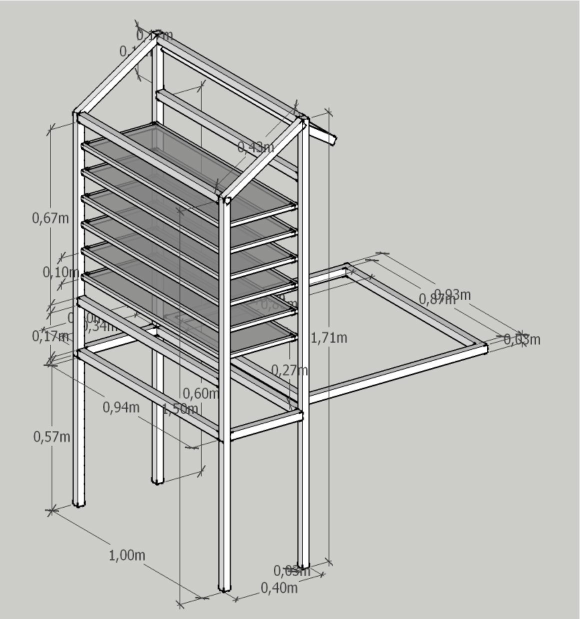

Figure 12: Dimensions of the chamber

Quantitative design study

- Measurements

The design goal of the solar dryers of this project is to dehydrate as many foods as possible, with the highest efficiency and at the lowest cost. Once the materials to be used in the design have been selected, the variable that will determine the cost of the dryer will be the size of the dryer.

To determine the dimensions of the dryer, two main variables must be taken into account. On one hand, the ratio between the size of the collector and the size of the drying chamber must be such that the collector has the capacity to absorb the energy necessary to dehydrate during the chosen time (1, 2, or more days) the moisture contained inside the food.

The total size can then be determined in two consecutive steps:

a) Determination of the specific drying chamber volume employed per time interval

We propose to obtain the specific volume of the dryer chamber that it is used in a given time interval (a day in the present case), as follows:

$$Specific\ dryer\ chamber\ size\ [m^3/day] = V_{sup} * Sup_{esp} * P$$

where:

- V_{sup}: Volume of chamber per surface of drying trays [m^3/m^2]

- S_{esp}: Specific surface: the surface occupied by each Kg of product in the drying chamber [m^2/Kg_{prod}]
- P: The daily rate food production to be dehydrated [Kg_{prod} /day]

V_{sup} and S_{esp} are constant characteristics of the chamber design and the type of product respectively, so the variable of the equation is the daily production to be dehydrated.

b) Determination of collector surface

On the other hand, it must be known the collector surface necessary to satisfy the energy demand. The surface will be determined by the following equation:

$$S_{colector} = \frac{P * H}{\eta * I}$$

where:

- I: daily solar irradiation, characteristic of the region and time of year [KWh/ (day.m²)]
- η: collector design performance [Kg_{water}/KWh]
- P: The daily rate production to be dehydrated [Kg_{prod} /day]
- H: the product moisture content [Kg_{water} /Kg_{prod}]

It must be noted that the only variable that can be optimized in a specific place, time interval, product and production rate is the performance of the collector, in other words, the ability of the collector to profit each KWh of energy received from the Sun, in evaporating water (Kg_{water}/KWh).

In order to optimize the design, it is necessary first to proceed by measuring and calculating its own characteristic constants: V_{sup} and η. Then, to start selecting food products whose properties and dehydration processes are widely known to determine: S_{esp} and H. So, knowledge of the initial situation of operation is obtained. This will allow recognizing the most easily variables to optimize and to have a quantitative starting point to analyze if the modifications introduced resulted in a better performance.

-Collector performance

The performance of the collector determines the mass of water to be dehydrated, according to the solar irradiance received during a given period of time and the surface of the collector. Therefore, the collector surface must be measured, the irradiance must be determined on a specific day, and the weight reduction of the product must also be measured throughout the day. We will also divide the measurement into hourly fractions to know the behavior of the collector in different conditions.

- Collector surface: 0.5 m^2
- Solar irradiance: Davis meteorological station, Vantage Pro2, of the Institute of Physics Rosario (CONICET – National University of Rosario, Argentina)
- Weight reduction sensor: Atma BC7103E electronic balance.

Figure 13: Left side, red apple before dray. Right side, red apple after dray

To determine the weight loss, we use the traditional method of measurement, which consists in removing the trays every certain period of time (1 hour). This form of measurement is quite good, but far from the optimal one, due to the need to open the chamber, with the consequent intervention in the drying process and the limitation in the frequency of measurements.

Measurement results

The solar dried food product was red apple (in pieces, **Figure 13**) and the measurements were taken on a particular clear day (24 July 2018), in the city of Rosario. The collector was located in a place where it received solar radiation throughout the day and also it was exposed to different wind directions, simulating normal field operating conditions.

Table 2: Total weight, net weight, weight reduction due to drying (water loss) and percentage reduction, for each of the two trays of red apples dried using the solar dryer, made in Rosario, Argentina, during a clear sky day (July 24, 2018)

	Lower tray (1)				Upper tray (2)			
	Total weight [g]	Weight without tray [g]	Weight reduction [g]	Per-centage reduction	Total weight [g]	Weight without tray [g]	Weight reduction [g]	Per-centage reduction
10:08	871	482	0	---	833	444	0	----
11:15	855	466	16	3.32%	820	431	13	2.93%
12:17	822	433	49	10.17%	799	410	34	7.66%
13:21	779	390	92	19.09%	770	381	63	14.19%

14:21	741	352	130	26.97%	746	357	87	19.59%
15:17	718	329	153	31.74%	725	336	108	24.32%
16:23	694	305	177	36.72%	700	311	133	29.95%
17:25	674	285	197	40.87%	682	293	151	34.01%
17:56	672	283	199	41.29%	676	287	157	35.36%

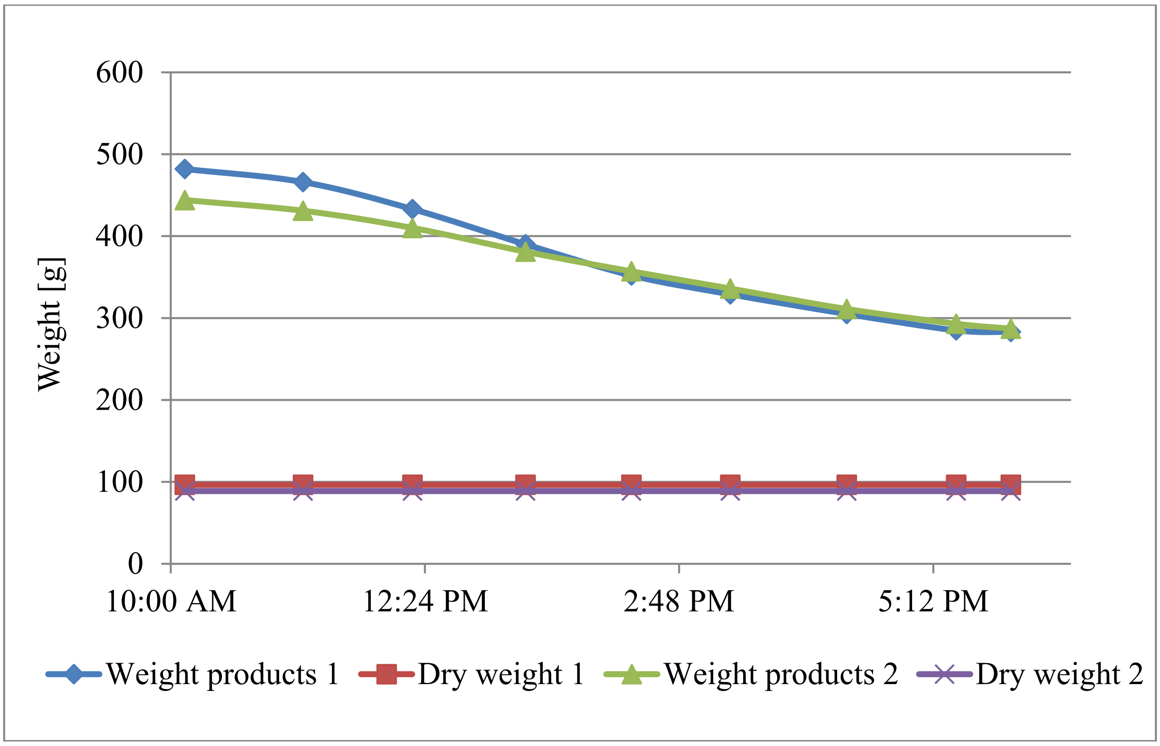

Figure 14: Weight reduction of red apple along the hours of the clear sky day (July 24, 2018), at Rosario, Argentina

Table 2 and **Figure 14** show the weight loss due to solar drying of red apple, along the hours of the clear sky day (July 24, 2018).

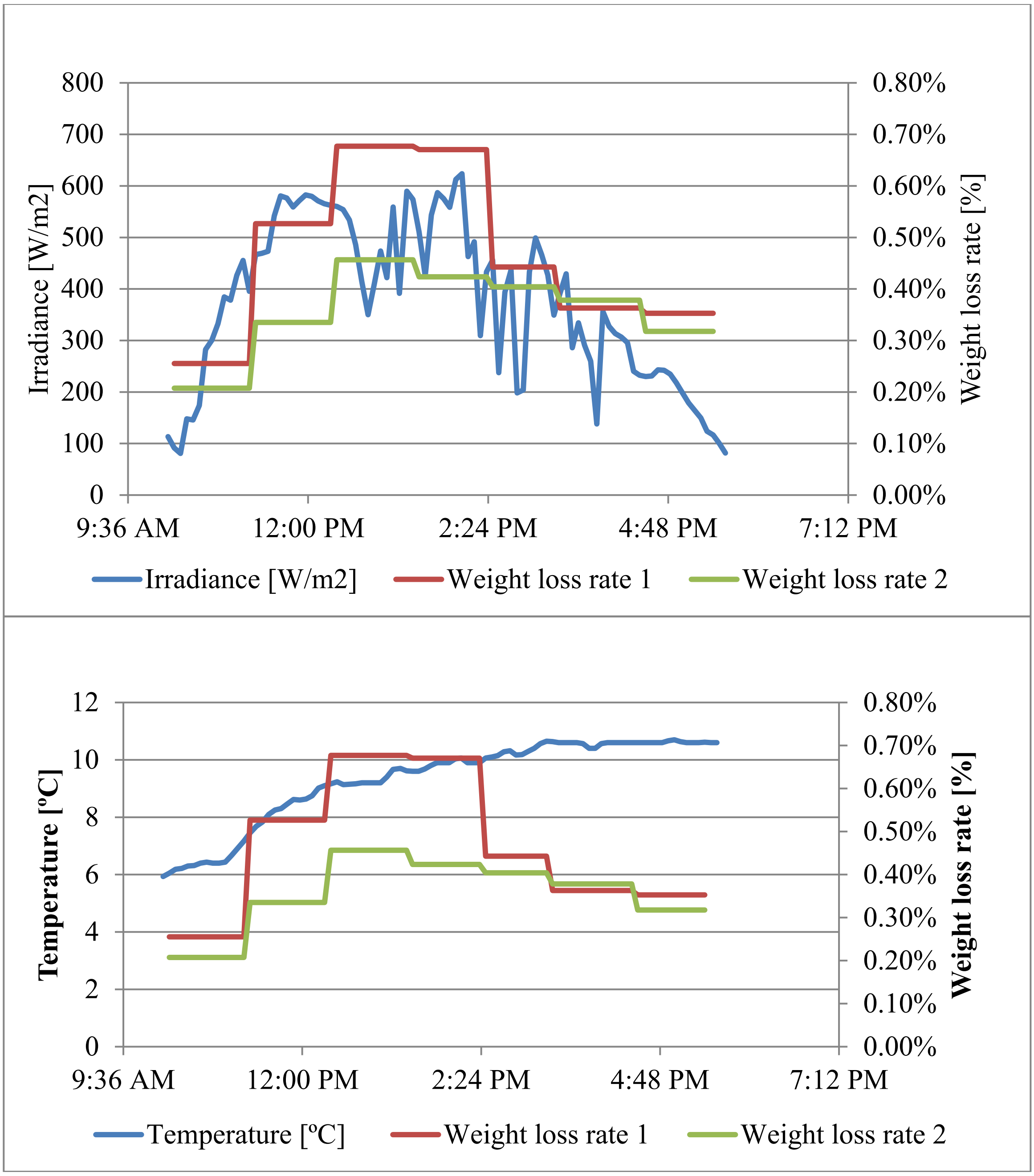

Figure 15: Solar irradiance (top figure) and ambient temperature (bottom figure) versus weight loss rate

The influence of solar radiation and of ambient temperature along the hours of the day is displayed in Figure 15. As expected, the weight loss rate is generally higher for tray 1 (due to its position in the dry chamber with respect to the incoming air) than for tray 2.

Table 3: Summary of the data giving rise to the total performance of the dryer.

Hour	Weight tray 1 [g]	Weight tray 2 [g]	Average solar irradiance [W/m2]	Daily solar energy [KWh/m²]	Area [m²]	Perfor-mance of Tray 1 [Kg/KWh]	Perfor-mance of Tray 2 [Kg/KWh]	Total perfor-mance of the dryer [Kg/KWh]
10:08	482	444						
11:13	466	431	254.88	276.12	0.50	0.116	0.094	0.210
12:18	433	410	533.28	577.72	0.50	0.114	0.073	0.187
13:23	390	381	485.13	525.55	0.50	0.164	0.110	0.274
14:22	352	357	522.78	522.77	0.50	0.160	0.102	0.262
15:16	329	336	380.48	348.77	0.50	0.164	0.141	0.305
16:25	305	311	308.54	359.95	0.50	0.124	0.129	0.252
17:23	285	293	203.89	203.88	0.50	0.196	0.189	0.386

We like to point out that, the total dryer performance does not depend only on the incident solar radiation, but on other factors such as the thermal inertia of the collector and the ambient temperature, among others. However, averaging the obtained values, assuming that these factors will maintain the relative daily variation, a main daily value of 0.268 Kg/KWh is determined, that is, for each KWh received by the designed solar collector, 0.268 Kg of water will be evaporated.

Comparison with a rather similar dryer tested in another climate

To evaluate the performance of the proposed design of the *Experimental wood solar dryer* (that it is named from now on as *Rosario solar dryer*), a comparison is made of this dryer with the solar dryer developed and tested by Bharadwaz et al. (2017), of the Mechanical Engineering University, RSET, Guwahati, Assam, India (that it is named *Assam solar dryer*). The publication was chosen because the product to be dried and the construction characteristics are similar to the present solar dryer.

The biggest difference between the studied designs is that in the present studied device the air circulation is produced by natural convection, on the other hand the one of the Indian Group worked with an air blower. Another significant difference lies in the size, the collector plate of the Assam solar dryer is 1.7 m^2 compared to the present one, which is only 0.5 m^2. It is also important to highlight the difference in the time of year that the measurements were made, in the Rosario case it was a full winter day, with an average ambient temperature of 9.3 ºC and in the Indian dryer it was a spring day with an average temperature of 33.0 ºC.

The similarities are in that the two were built with common low cost materials and both also dehydrate the same product (apple). In addition, both are relatively small and are designed for family production scales.

Table 4: Comparison between the Rosario solar dryer and the Assam solar dryer

	Average collector temp (Cº)	**Average ambient temp (Cº)**	**Initial weight (g)**	**Final weight (g)**	**Percentage weight loss**	**Solar collector area (m2)**	**Drying performance per solar collector area (g/m2)**
Rosario solar dryer	36.8	9.3	926	578	37.2%	0.5	696
Assam solar dryer	56.2	33.0	200	34	83%	1.7	97.6

From the results displayed in **Table 4**, one of the conclusions that can be reached is that both solar dryers reduce a significant amount of water, the Assam solar dryer is 83% superior to the Rosario dryer that only achieved 37.2% of water loss. This difference can be explained since in the first case, the total amount of product to be dried was higher and the ambient temperature and collector area were lower. Comparing the collectors, both reached a similar temperature variation: 27.4ºC in the Rosario solar dryer, against 23.1ºC in the Assam one.

Another interesting coefficient that was introduced by Piacentini and Combarnous (1977) is the ratio between the water removed per day (at the same initial, intermediate or final drying days) and the collector area. The values of this *Drying performance per solar collector area* are given in **Table 4**, last column. For the Rosario solar dryer is: 696 g/(m^2day), and for the Assam solar dryer it is lower: 97.6 g/(m^2day).

In conclusion, the proposed solar dryers can be a good option for the storage of food and consequently, for improving food security.

2.8.2 The design and test of a simple solar dryer for grains

Grains can also be dried employing solar energy. Drying in not as rapid as that with a conventional high temperature dryer (more than 30°C -50 °C), since this last one can dry tons of grains in an hour. The solar dryer increases the ambient temperature by only several centigrade degrees but reduces significantly the relative humidity, contributing to the extraction of water from the inner part of the grain.

The Solar grain dryer was developed in the 1980 decade by the Solar energy group of the Institute of Physics Rosario (CONICET – National University of

Rosario). It is still working at the Experimental Farm of the Faculty of Agricultural Sciences, National University of Rosario, Zavalla, Santa Fe province, Argentina. It is made of a simple (bare) solar collector to heat the air and a barn (with a capacity of dozen of tones of grains) to preserve the grains (**Figure 16**). It has a bottom surface with hole giving the possibility to the air with low humidity to enter in the silo and in this way to dry the grains during several days. It was dried different type of grains, typically produced in the nearby region (soybean, corn, wheat, sunflower and even rice).

The main advantages of the bean solar dryer are: greater flexibility in the harvest and commercialization of the grain, better quality of the product (less cracking, higher germination rates and absence of burnt or contaminated grains), possibility of conditioning the grain in the place of the harvest, fuel economy, greenhouse gas emission reduction. In addition, the silo solar dryer is simple to install, has low maintenance and great robustness, easily adaptable to existing systems, can be used for other agricultural applications that require the production of heat at low temperatures, such as: air conditioning of greenhouses, place for vegetable processing.

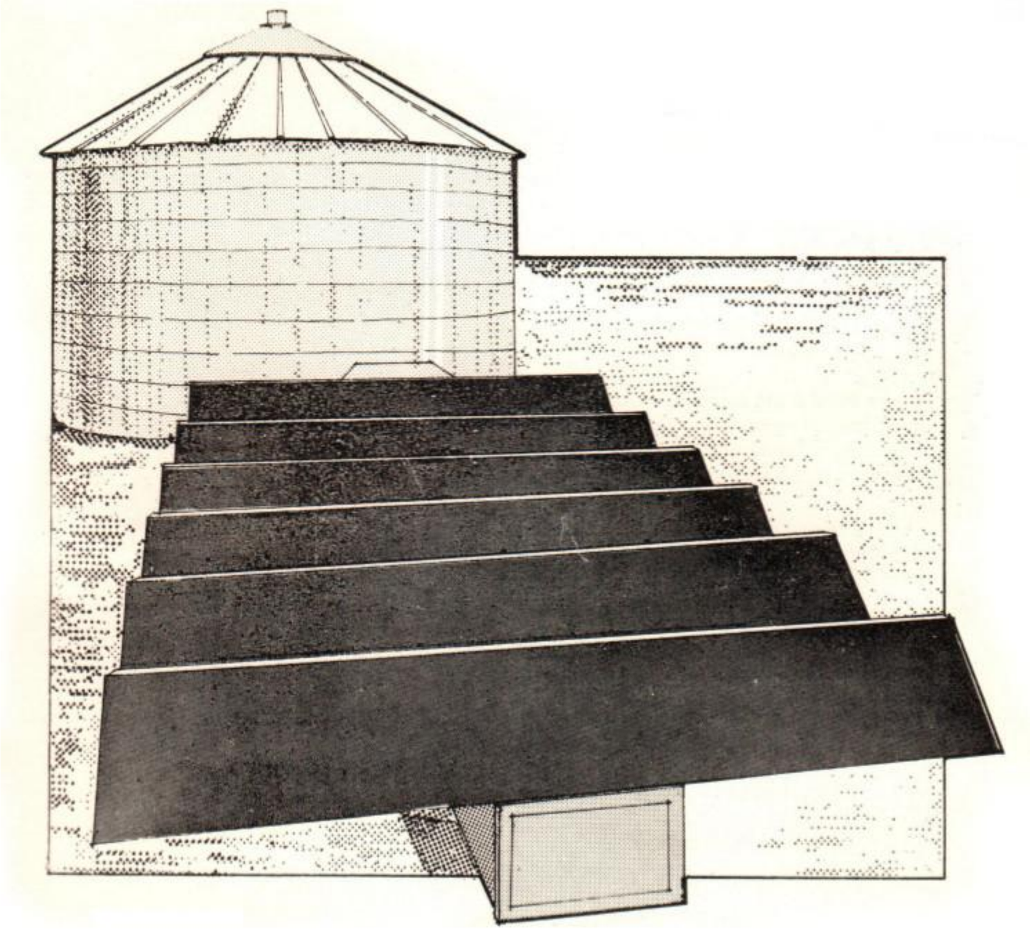

Figure 16: Schematic representation of the silo solar grain dryer developed by the Solar Energy Group of the Institute of Physics Rosario (CONICET – National University of Rosario) and placed at the Experimental Farm of the Faculty of Agronomical Sciences, National University of Rosario, in Zavalla, Santa Fe province, Argentina.

We like to emphasize that this solar dryer was built in years of the 1980 decade were Climate change and Sustainability were not considered as priorities. In an editorial guest in Drying Technology, Piacentini and Della Ceca (2017) proposed several sustainability criteria that would be needed to consider if a new silo solar dryer is to be built at present. Some of the criteria are the followings: i) materials to be used must be renewable or recyclable (mainly, steel and wood, but they need to be properly maintained, with periodic application of paint, avoiding in this way as much as possible, steel corrosion and wood degradation), ii) the electric motor that pumps the solar heated air into the silo must have the highest possible efficiency, iii) the solar collector and the air flow through the grains stored in the silo must be optimized, and iv) a life cycle analysis (commonly known as LCA) needs to be made, in particular, the *carbon* footprint needs to be evaluated and, eventually, the greenhouse gas emissions, compensated. As a conclusion, the possibility to dry grains employing a sustainable energy source (like solar) will improve food security, reducing grain degradation and at the same time contributing to the reduction of the emission of greenhouse gases.

2.9 COMPETITION BETWEEN FOOD AND ENERGY PRODUCTION USING PLANTS

Energy at affordable and stable cost over time is a basic requirement for the development of modern societies. Since the Industrial Revolution, there has been a steady increase in fossil fuels, mainly for industries during the early stages and for transportation from the first decades of the XXth. century on. Nevertheless, environmental concerns that started during the second half of that century soon became a major part of the development agendas due to the strong relation between greenhouse gases (GHG) released to the atmosphere by transportation and industries' fuels and climate change (IPCC, 2014). Therefore, the new arousing paradigm focused on using renewable energy sources, those that can be replenished during human lifetime scale, such as solar, eolic (wind power), geothermal, and biofuels. Anyway, it should be kept in mind that bioenergy, burning wood, is the oldest energy source of mankind.

Among these types of energies, biofuels, including liquid (derived from biomass for transportation uses), gaseous (methane gas), and solid (wood, charcoal) (FAO, 2010), offer a full range of possibilities. In accordance with feedstock and transformation processes involved in their production, biofuels can be classified in different types or generations. First generation includes bioethanol from sugarcane, *Saccharum officinarum*, corn, *Zea mays,* sweet potato, *Ipomea batatas,*and other minor species;and biodieselfrom soybean, *Glycine max*, oil palm,*Elaeisguineensis,*and canola, *Brassica napus*, among others.

Lignocellulosic feedstocks as woods (short rotation coppices *Populus*spp.,*Salix* spp.) or perennial grasses (*Panicum virgatum*; *Miscanthussinensis*, *Miscanthus x giganteus,* etc.) are second generation biofuels (bioethanol or pellets that can be used for heat and power), while H_2 and biodiesel obtained from algae comprise third generation ones.Third generation biofuels remain at lab or pilot stages, facing still a lot of technological and economic issues such as nutritional content of culture media and its aeration systems, how to achieve stable growth rates, biomass harvesting systems and lipid extraction (Enamala et al., 2018; Raheem et al., 2018; Verma et al., 2018).

In order to obtain second generation bioethanol, sequential procedures must be followed after harvesting and transporting low energy density feedstocks: mechanical or chemical pre-treatment for removing lignin and exposing cellulose fibers, cellulose hydrolysis (saccharification), glucose fermentation, and bioethanol distillation. Each of these steps has different options (Aditiya et al., 2016) being thermal and chemical pretreatments those with the highest energy, environmental concerns (GHG emissions, chemical pollution due to acids or alkalis used for delignification, etc.), and costs. Therefore, though many studies showing high energy efficiency and GHG reductions (Kumar et al., 2012; Karlsson et al., 2014; Morales et al., 2015; Pourhashem et al., 2016), there are very few true commercial lignocellulosic biofuel industries. These technological challenges to be fulfilled are been driven by positive aspects of lignocellulosic feedstocks that already had been established: (i) net reduction of GHG while using them; (ii) they can be grown on marginal lands with no competition for agricultural land; (iii) as most of the grasses for biofuel feedstock have C4 photosynthetic metabolism, there would be no effect on biomass production due to high atmospheric CO_2 and drought (Oliver et al., 2009) predicted by IPCC climate models (IPCC, 2014).

In spite of controversies due to the fact that first generation biofuels feedstocks are being used as food or for animal diets (Hill et al., 2006; Carroll &Sommerville, 2009, Rull et al., 2016), there are a lot of sugar or corn bioethanol production, as well as soybean, palm oil and canola biodiesel industries. Therefore, some people claim that biofuels are one of the factors responsible for the increase in food prices (Rosegrant et al., 2008) though according to the high complexity of the systems involved (crops and the technological events improving yields, land use change, population increase fostering food demand, and governments mandates and subsidies in biofuels and renewable energies), there is still a lot of controversy on the matter (Chakravorty et al., 2012; Hochman et al., 2014). Therefore, Tomei&Helliwell, (2016) highlighted the importance of focusing on the multi-functionality of agriculture, rather than in the food vs. fuel dichotomy.

Bioethanol was initially used as a biofuel when internal explosion engines were invented and only decades later it was displaced almost entirely by naphtha or diesel when oil exploitation began. Brazil developed the bioethanol industry from cane after the oil crisis of 1973 and persisted from there on. Argentina began also with such a project, but it was abandoned as soon as oil prices fell and remained with fossil fuels as the main energy matrix components, in spite of some hydroelectric plants and two nuclear ones. In USA, 10% corn bioethanol blended gasoline started early in the ’70 decade of last century, it increased up to 15% for special engines. USA is the largest corn bioethanol producer, consuming *circa* 1/3 of the total corn production.

The interest in biofuels resurfaced in Argentina in the XXIth century for three reasons: (i) oil prices increase during the early years of the XXIth. century; (ii) the idea that the reserves of fossil fuels were running out, which was later invalidated at least up to the present time and (iii) the international concerns on GHG. In 2006, a Law was passed in Argentina ruling the Regime of Regulation and Promotion for the Sustainable Production and Use of Biofuels, including bioethanol and biodiesel produced from of agricultural or agro-industrial raw materials (mainly based on sugarcane and soybean oil, respectively), and organic waste generated biogas. One of the regulatory aspects is the mandatory blending of fuels: gasoline with bioethanol and gasoil with biodiesel.

Though it was introduced in Argentina during the first decades of the last century, the cultivation of soybean started from the 60's on, in the most important agricultural area of the country, the Pampean region. In a few years, it became a major crop, increasing its cultivated area and production from 1970 onward (**Figure 17**) and competing with corn for the best lands in the area. Initially it was not considered a major oil crop, due to its relative low oil content (*circa* 18%). Symbiosis of soybean with nitrogen fixing bacteria (Rhyzobiaceae), high protein figures of the grain, full grain demand of different markets triggered and high prices the expansion of the crop (MAGyP, 2018), but the area of the other major crop, corn, was not affected (**Figure 17**). This soybean expansion diminished mostly pasture land for dairy and beef production, displacing cattle raising to other areas of the country and triggered land use change: from rangelands and woodlands to agriculture.

If the intention is to analyze the food-bioenergy controversy in the case of soybean and corn in Argentina, in spite of the high soybean biodiesel steady increase (**Figure 18**), the analysis is very complex due to: (i) there is no food deficit in the country, in fact the total production could feed a population 10 times higher; what exists are problems of economic access; (ii) direct consumption of soybean in the human diet is very low in the country, most of which is exported; (iii) according to the oil extraction system used (mechanical or solvent), different by-products are obtained that can be suitable for human consumption after industrialization (soybean meal, rich in proteins) or for animal consumption (these same flours), dietary or nutraceutical supplements (lecithin) and others for industrial use. Therefore, the problems that the intensification of cultivation can bring at the national level would not affect the food supply, but to other processes such as ecosystem services (biodiversity, storage of carbon in the soil, water retention in the soil, pollination, etc.) (Aizen et al., 2009), mostly due to land use change (passing from woods, shrubs or rangelands to crop land) than to cropping itself due to the improvement of management practices with lower environmental impact than Western Europe, USA, New Zealand, China, or Japan farmers (Viglizzo et al., 2011).

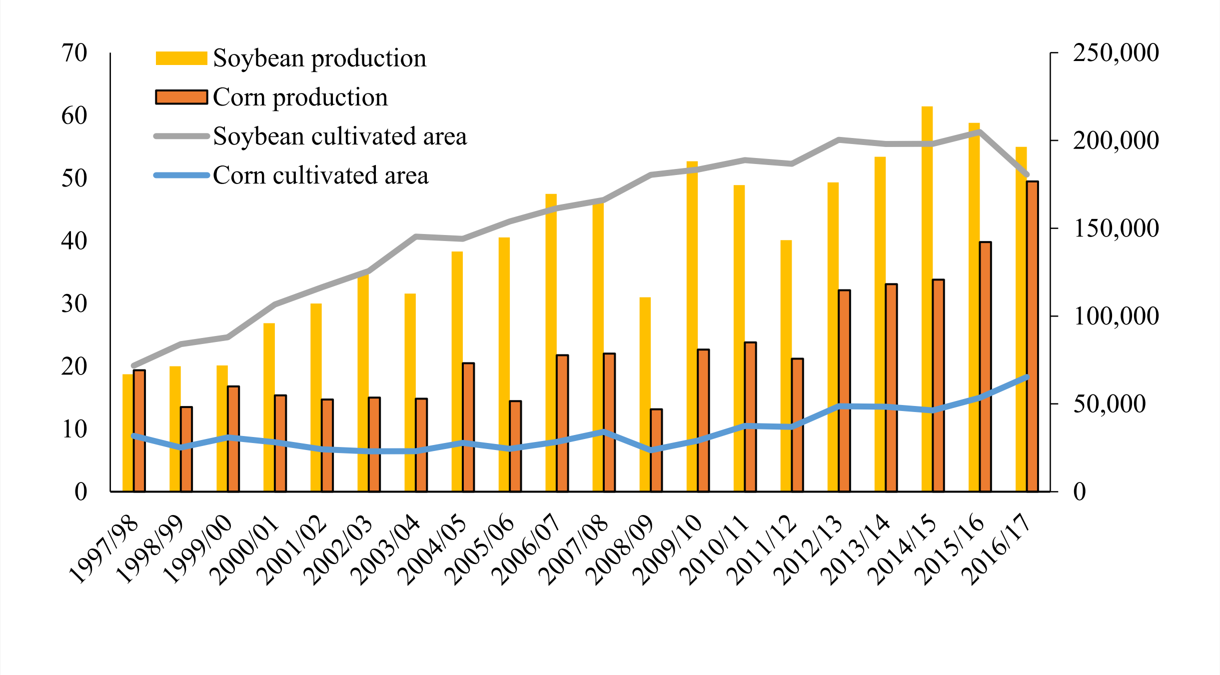

Figure 17: Soybean and corn production in Argentina: total production (Mg x 10^6) and cultivated area (km^2) (1997–2017). Source: MGAyP (2018).

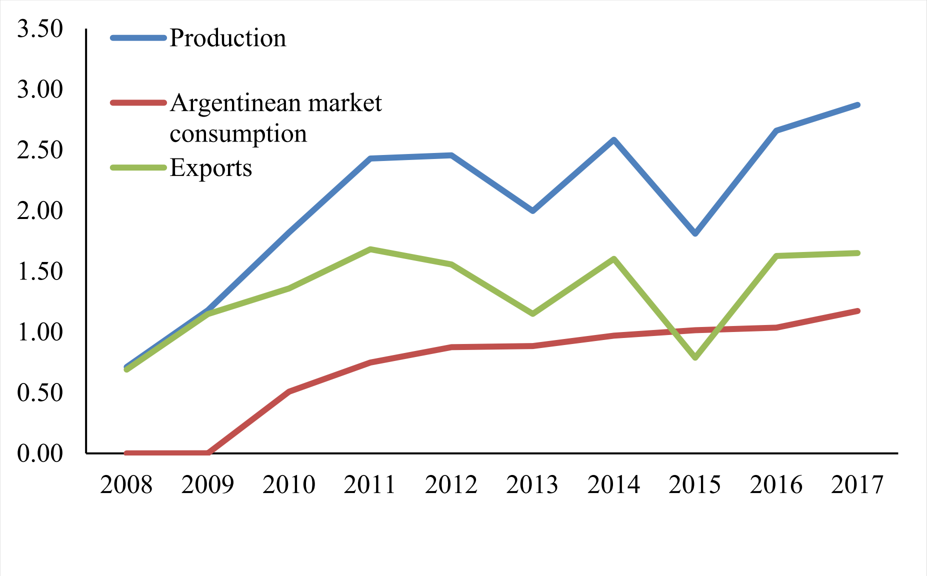

Figure 18: Total biodiesel production (Mg), Argentine market consumption, and exports. Source: INDEC (2018).

The same trend of no displacement of major crops (i.e., soybean vs. corn) is found in USA (**Figure 19**) as well as in Brazil (**Figure 20**). Nevertheless, though the data supports that on biomass basis the amount of crops being globally diverted to all industrial uses, including biofuels is not a significant amount (9% on biomass or calories basis, Cassidy et al., 2013), there are a lot of evidences suggesting a steady impact on food prices, with differences according to crops and countries (HLPE, 2013). An even in many countries, these figures of biomass diverted to biofuels can be higher than average (i.e.:

almost 40% calories in Brazil, Cassidy et al., 2013). Therefore, it can be concluded that considering the expected growth in human population and the increase in demand not only of food but of high energy demanding food (dairy, beef, fruits from distant markets), it should be convenient to increase funds in closing the technological gap for second generation biofuels and solar energy, which do not compete for land with food productions.

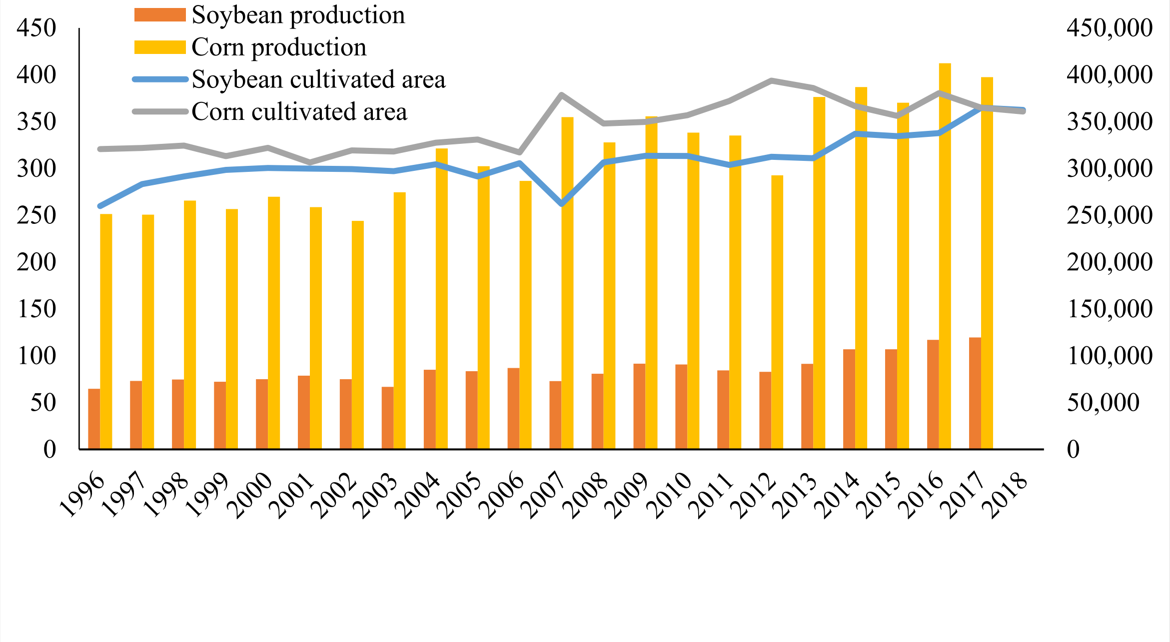

Figure 19: Soybean and corn production in USA: total production (Mg) and cultivated area (km^2) (1998–2017). Source: USDA (2018).

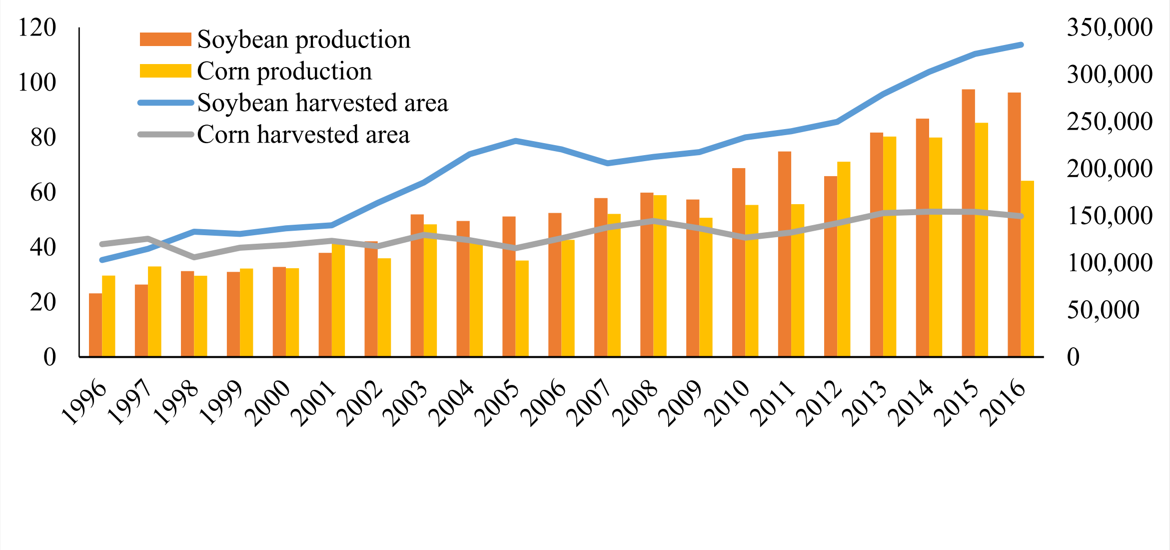

Figure 20: Soybean and corn production in Brazil: total production (Mg) and cultivated area (km^2) (1996–2016). Source: FAO (2018b).

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Food Security: Impact of Climate Change and Technology

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