A different way of eating
¨Beef vs. Chicken¨

Master´s Thesis

Dynamic simulation approach exploring the benefits to the environment of eating chicken vs beef in the USA, to reduce the climate change.

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Abstract

The wellbeing of the environment is one of the most important topics now a days because all the different problems we are facing as the population continues to grow, in this case to be more specific we are talking about the climate change and the impact our way of eating has on it.

When we talk about meat, is well known that the USA is one of the biggest meat consumers on the planet, mostly beef and chicken, they are also the biggest producers of the same, this meaning that their economy is also directly linked to this products in a certain degree.

Also the fast food industry is very important in the USA, and also mainly composed of beef and chicken, this leads the high consumption of beef and chicken they have.

To study this behavior a system dynamics approach is going to be used, considering real data regarding the consumption per capita, the breeding of the cows and chickens (broilers), and the impact all this generates to the environment in terms of emissions, water consumption and land use.

According to several experts and studies, the consumption of chicken meat generates less impact on the environment, so a switch to eat more chicken rather than beef will generate less emissions to the environment and that is what this is trying to test, this is not an easy task to do because the USA has a very big meat consumption but creating awareness and implementing policies will help to change this behavior.

With the proposal of using a system dynamics model, we will be able to test some policies and impact to the environment always considering that the food supply will be achieve as it is being achieved now a days.

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Chapter 1. Introduction

1.1 Background

The climate change affects the entire world, and it has several causes and consequences, one of the main causes is the greenhouse effect, which is compose of different gases like water vapor, carbon dioxide, nitrous oxide, methane and fluorinated gases.

According to (United States Enviromental Protection Agency , 2018) in the case of the methane gas which is the one this work is focused on, they say that the Agriculture sector is the largest source of this gas in the United States, this means that if there is a significant reduction of methane gas in this sector, it will have an important impact in the environment.

The mayor generator of this emissions in the agriculture sector is the cattle, the livestock in the United States (Quinton, 2019), and it also has other bigger impacts to the environment for example:

- It uses a lot of land that can be used instead as forests to fight the climate change in some cases, and if we compare the land use requirements, the Beef cattle requires much more than the chicken for example.

  The Beef cattle that is produced in a feedlot, uses 15m2 (Watts, et al., 2016, p. 4) which is the most efficient way of breeding rather than the grazing which uses much more land, and the chicken space is just a bit bigger than a sheet of letter size paper (Farmsanctuary, 2017).

  By having less land used for livestock we could have more trees to also lower the levels of carbon dioxide, this is a possibility to reduce the impact to the environment and also increasing the use of bioenergy (Bazilchuck, 2019).

- The water used for this animals is much higher than others used for slaughtering as mention in the water footprint network (2010) ¨ The water footprint of meat from beef cattle (15 400 m^3 /ton as a global average) is much larger than the footprints of meat from sheep (10 400 m^3 /ton), pig (6000 m^3 /ton), goat (5 500 m^3 /ton) or chicken (4 300 m^3 /ton).¨ In other words to produce beef, bigger amount of resources are needed and also the damage to the environment due to the emissions, land use and water use is much higher,

- Regarding the emissions generated per animal, the beef cattle is the one that generates the most, as we can see on the next figure (figure 1).

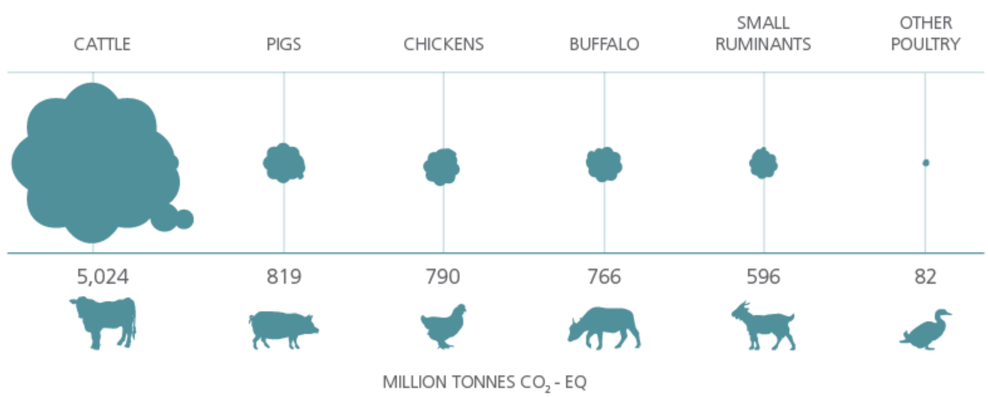

Figure 1. Global estimates of emissions by species.

(Food and Agriculture Organization of the United Nations, 2018) Food and Agriculture Organization of the United Nations. (2018). FAO. Retrieved from http://www.fao.org/gleam/results/en/

In order to find and test ways to reduce this emissions we need to try different ways to eat by switching types of meat, reducing the meat or find more efficient ways to produce the meat in the system because this is affecting the whole population in a direct way.

During 1990 and 2018 the emissions from the agricultural activities increased (United States Enviromental Protection Agency , 2018), this shows that as long as the production of food continues the same way, the emissions will just keep increasing at alarming rates.

In the case of the chicken, the emissions are so much less, ¨Replacing the carbon-heavy beef on your plate with carbon-light chicken will cut your dietary carbon footprint a shocking amount: in half. That’s according to a first-ever national study of U.S. eating habits and their carbon footprints¨ (Leahy, 2019)

The Enteric fermentation is the most important methane source from broilers (Dunkley, 2011), so in order to make further analysis we will use this emissions from the broilers to compare and test.

Another important way to try to reduce the emissions is switching from meat to a plant based diet, so instead of using calories from meat to satisfy our daily calorie intake people is having a plant based diet, which is healthier and has more benefits than consuming meat (Harvard Healt Publishing, 2018).

In order to be able to test and evaluate this behaviors, a system dynamics approach will be used, this because when talking about food systems and their correlation with the emissions, it’s possible to identify the feedback loops and accumulations that will be generated when testing for a switching from beef to another food like chicken or plant based, via policy or by simply making this change manually in order to also evaluate the impact on land use, and water consumption. This will be explain in deep on chapter 3.

1.2 Research challenges

Since the United States is the biggest producer of beef in the world (Buchholz, 2019), its impact to the world and to this country is the biggest due to this fact, so in order to find ways to reduce it, the best option to replace this type of meat or at least replace the majority of its consumption is the chicken.

The chicken and the beef are usually compared by several experts and researchers because of the protein content, and the way in which this products are sold as in fast food chains or super markets (same access).

The United States is also the biggest producer of broilers in the world (Shahbandeh, 2020), so they have the possibility and experience to increase or decrease the production of both types of meat, and regarding the emissions, several sources say that the ones coming from beef are much higher than the ones coming from chicken, some examples:

¨ Animal-based foods have a bigger carbon footprint than plant-based foods. Producing beef, for example, uses 20 times the land and emits 20 times the emissions as growing beans, per gram of protein, and requires more than 10 times more resources than producing chicken.¨ (Leahy, 2019)

¨ Compared with the other animal proteins, beef produces five times more heat-trapping gases per calorie, puts out six times as much water-polluting nitrogen, takes 11 times more water for irrigation and uses 28 times the land, according to the study published Monday in the journal Proceedings of the National Academy of Sciences.¨ (CBS NEWS, 2014)

¨ A vegetarian diet greatly reduces an individual's carbon footprint, but switching to less carbon intensive meats can have a major impact as well. For example, replacing all beef consumption with chicken for one year leads to an annual carbon footprint reduction of 882 pounds CO_2e.[7]¨ (University of Michigan , 2019)

This encourages the assumption that if the beef is replaced with the chicken or a plant based diet, the emissions will be reduced, but in order to make such dynamic tests, the data used for those assumptions needs to be accurate and according to the way in which this animals and crops are produced in the USA.

In order to make this replacement and evaluation, the demand of the beef is going to be changed and its deficit or surplus will be moving the feedback to the emissions and the general demand, changing also the demand for chicken and plant based diet, altering the amount of emissions, land use and water use which again needs to have the correct back up in data.

There is a lot of information about this issue in general, so in order to get good values for every variable, sometimes several sources are needed to get a ¨standard¨ data which has to make sense with the historical and real behavior in order to generate a good testing and manage the theoretical challenge.

Regarding the changes of the diet, which is the practical challenge, there are some countries for example Denmark, that consider the importance of change the way they eat in order to reduce the emissions, in specific reduce the beef consumption with a tax policy which will lead to the less consumption of eat and in consequence the reduction of the emissions (Bearak, 2016).

On the next figures 2a and 2b, it's shown the normal behavior form the food system or sectors (the food system or sector is composed by the beef sector, the chicken sector and the plant based which they all are correlated when talking about the impact to the emissions, land use, water consumption and demand) to the emissions considering only beef and chicken, the demand and the direct emissions to the environment (2a) and the introduction of feedback loops that lead to the reduction of the emissions by replacing beef for chicken (2b) further explanation on chapter 3 section 3.7.

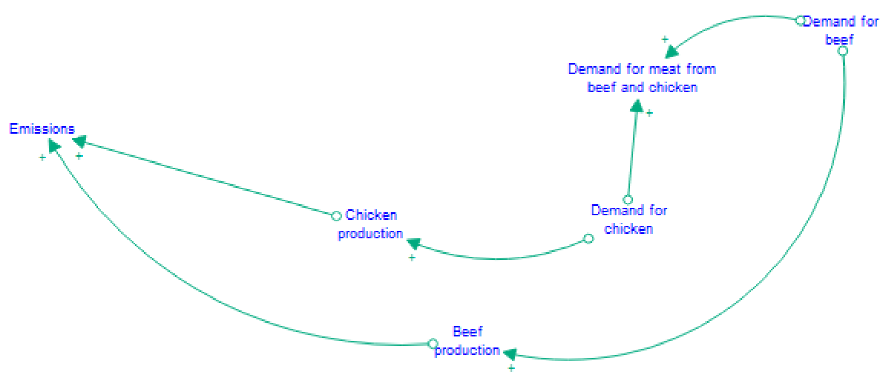

Figure 2a.

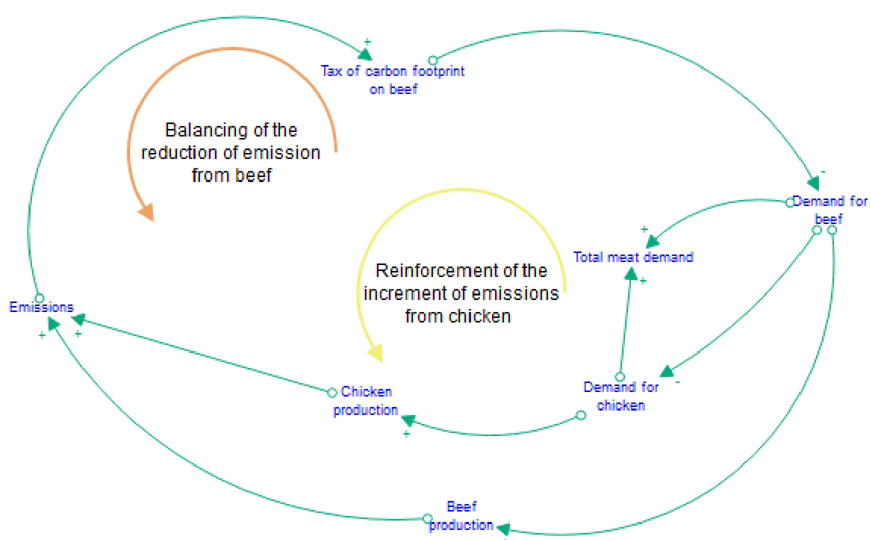

Figure 2b.

1.3 Research Objectives

The main objective of this research is to explore how much is it possible to reduce the emissions from beef through a change in the demand for it, mainly by consuming chicken or plant based instead, and with the dynamic model see the consequences that this will bring to the environment in terms of emissions, land use and water consumption.

The aim of this research has this specific objectives:

- Understand the processes that are responsible for the emissions generated by the food system in the United States.
- Test alternative policies in order to reduce the emissions.
- Identify the most effective policies.
- In addition to the emissions, evaluate the impact on water and land use related to the food production.

To meet this objectives, a development of a system dynamics model is generated considering the variables that are involved in every scenario and it is always a condition that the food demand is satisfy in order to have a correct research.

1.4 Research Questions

The next questions are linked to the objectives of this research, and based in the United States.

Questions:

1. Which behavior of emissions is expected until the year 2050?

2. How much would the emissions will reduce or increase if population demands less beef and compensate with chicken?

3. What would be the consequences of such changes on the water consumption and land use?

4. Which way of eating will be more efficient in reducing the emissions (more plant based, more chicken or more beef)?

5. In the overall picture of all the elements (emissions, land use and water consumption), which diet is the better choice?

6. What are the limitations in the system structure of making such changes in order to reduce the emissions?

Chapter 2. Methods

2.1. Research Strategy

In order to make a proper research regarding the emissions and how they are affecting our environment, a system dynamics approach was chosen as the research methodology to this case of study. ¨The field of systems thinking and the development of systems dynamics modeling were created to address the need to understand complex systems and their behavior over time and to enable decision-making.¨ (Ramjeawon, 2020, p. 88)

In this specific case the goal is to improve the environment through changing our diet, and with the system dynamics approach observe how beneficial it could be if changes are made on the demand for beef. ¨The System Dynamics approach is founded on the scientific method. The goal of a system dynamics project is sometimes to build theoretical understanding, sometimes to implement policies for improvement, and often both.¨ (System Dynamics Society, n.d.)

The use of system dynamics consists in a research made with the help of a mathematical model which is constructed from mental models and it’s composed of Feedback, which is one of the core concepts of system dynamics and helps us to understand the relationship between stocks and flows. Several diagramming tools are used to capture the structure of systems, including casual loop diagrams and stock and flow maps. (Sterman, 2000)

The Agriculture sector can play a very important role to assure the food security, it also may contribute on alternating the climate change (Food and Agriculture Organization of the United Nations, 2008), that's why is very important to investigate this matter by using the system dynamics approach which considers several components of the sector and can create a model which involves real data from the population diet behavior, agricultural data, and makes it possible to test ways in which by changing the diet composition the emissions may be reduced.

2.2 Data Collection

When it comes to the system dynamics methodology there are three types of data needed in order to the correct development of the structure and decision rules in the models, which are: numerical, written and mental data. The numerical data are the time series and cross-sectional records in various databases, the written data are records such as operating procedures, organizational charts, media reports, emails and any other archival materials, and the mental data concerns all the information in people´s mental models including their impressions, stories, understanding of the system and how decisions are made (Sterman, 2000, p. 853).

In order to collect the data for this research, the main tool used was the web, google scholar and official government sites from the United States. Also in some cases some private organizations had data in terms of numerical and written which helped a lot to develop the mental data in order to formulate and create an actual model which follows a pattern determined by the sources and generates the behavior needed in order to be able to test and investigate.

This numerical and written sources where mainly obtained from ¨National Chicken Council¨ which is a non-profit trade association conformed by producers, processors, distributors and industry firms, that has the objective of representing the U.S. broiler chicken industry at a national level, also several data from that site comes directly from the USDA ¨ U.S. department of agriculture¨, which is another very important source for this research in terms of numerical and written data.

Several quantitative and metal data was available on recognize international journals like national geographic, the Washington post, by Harvard University, by Penn State University, and also on sites that manage world data like ¨Our world in data¨ which its composed by a global community of scholars and their work is presented on this site, in some cases in order to have a more accurate validation we focus on the US government sites which in several cases matched the world data.

The data collected for this research involves several processes like the breeding and cycle of the broilers as well as for the beef and crops, how the population demand for this products is changing across time (historic data), data regarding the calories equivalences, how much meat you can get form each animal produces and the variation of this through time, this where some of the most important data collected in order to be able to produce a model which represent this food system, most of this data came from the USDA site.

2.3 Data analysis

The analysis of the data involving the modeling in this research was done following the guidelines by Sterman (Sterman, 2000), some of the things he mentions is the importance of the proper use of statistical methods to estimate parameters, in the case of this research the ¨mean¨ was used in order to estimate the future behavior for the meat from beef and chicken, the growth in the population, the meat consumption per capita and the weights of the beefs and chickens across time, the mean is basically referred as the average (Kenton, 2019).

Sterman also mentions the importance of assessing the ability of the model to replicate the historical data when the numerical data is available, which was the case, the numerical data was available in order to manage to replicate a very similar behavior as the historical one.

The focus was also on the validation of the data and the model, as mention by Barlas ¨ Model validation constitutes a very important step in system dynamics methodology.¨ (Barlas , 1996) Several tests where done on the model in order to validate the behavior generated and be sure that the results where coherent and that it made sense with the data collected and the way in which the system should present such behavior, more about the tests is described on chapter 4-Model analysis.

The main purpose of the data analysis is to validate the data collected and use the parameters established by Sterman in order to be able to test the different scenarios driven by the change in the demand for those products and by this be able to see all the effects in the rest of the sectors like: land use, calorie intake, water consumption and the most important one the emissions.

Chapter 3. Model description

This chapter consists on a detailed description of the model design for this study and takes into consideration variables needed in order to represent its functionality and all the processes involved in order to create behavior and be able to test the introduction of policies and comparisons which will be described on chapter 4-Model analysis.

The model overview consists of the following sectors:

- Demand: this structure represents the population demand for beef and chicken meat in the United States.
- Food sectors (plant based crops sector, beef sector and chicken sector): This structures represent the production of meat (chicken and beef) and crops needed to satisfy the demand of the population, each sector has different variables and calculations design to produce a behavior that matches the reality.
- Water consumption: This structure represents the level of water consumption used by the food sectors.
- Land use: This structure represents the land used by the food sectors in order for them to produce.
- Calorie intake: This structure represents the amount of calories generated by the food sectors and is used also to replace beef meat for plant based diet (crops instead of meat).
- Emissions: This structure represents the amount of emissions generated by the food sectors, involving the ones produced by animals and the ones produced by crops.

The next figure (figure 3) represents the model overview, it shows the interaction between the different sectors in a simplified way, and also it shows with the red lines the new relations generated by the adaptation of new structure en each sector in order to test and research to able to answer the objective questions in this study. This new relations which are also called feedbacks are explained in detail on chapter 3-Model description and 4-Model Analysis.

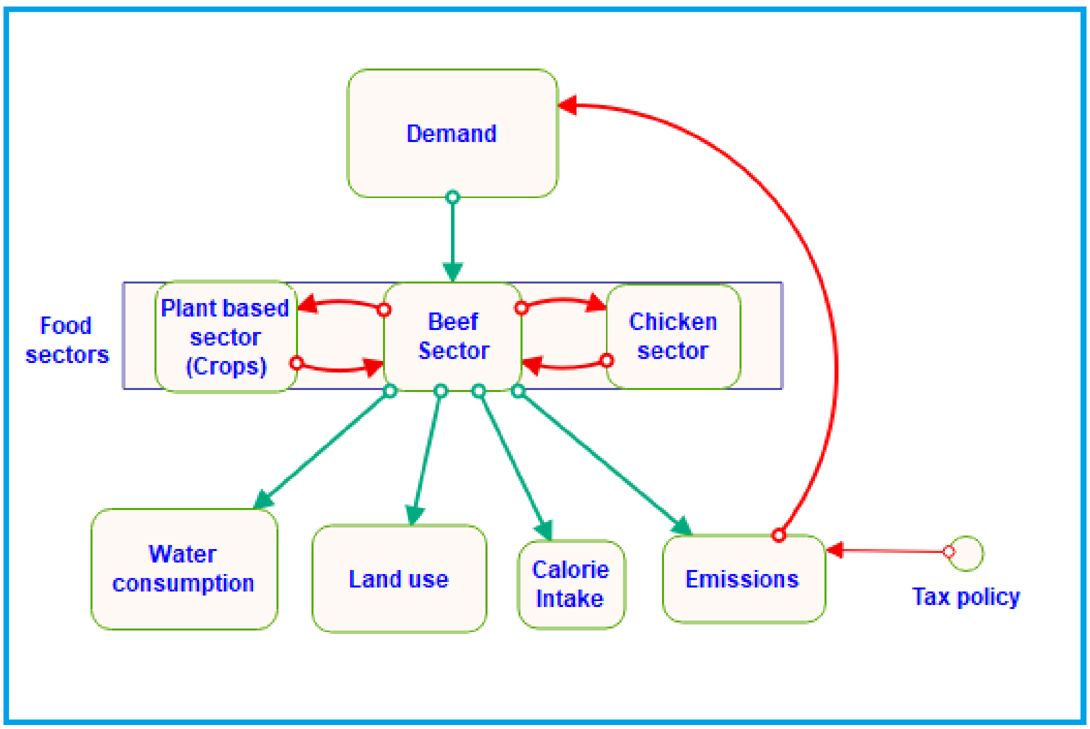

Figure 3. Model Overview

3.1 Demand

This sector has the objective to represent the demand generated by the population in the USA, the way it produces this behavior is by using the historical demand for beef and chicken per capita in the States (National Chicken Council , 2020) and with this an average is calculated to represent the possible future demand until the 2050.

In this sector you are able to control the entire demand of the meat (chicken and beef) by turning on ¨consumption percentage to beef¨ with switch 1, which allows the user to change the consumption of beef by manipulating the ¨manual consumption of beef per capita of the entire system¨ and with this decide how much of the meat demand is going for beef and the rest will be for chicken, this changes are applied starting from the year 2020 so the historic behavior is not modified.

All the formulas and sources of information are available when needed in the Apendix-Model documentation section of this research.

Another very important appliance that is introduced in this sector is the variable called ¨ Beef meat that will be replaced due to tax policy ¨, as it is stated on the name, is basically the amount of beef meat that will be switch by chicken meat, this converter needs to be activated with ¨switch 5¨ in order to function, this is because for the tax policy we have 3 variables that use switches:

- Beef meat that will be replaced due to tax policy - ¨Switch 5¨ (in this sector): when turned on, it means that when the tax policy switch is on (Beefs not going to be produced due to the tax policy), the reduction on the beef production will be substituted by the chicken, when turned off it means that you are not choosing the chicken for the switching.

- Beefs not going to be produced due to the tax policy - ¨Switch 3¨ (emissions sector): when turned on, the tax policy is activated, when turned off the normal behavior will occur.

Beefs not going to be produced due to the tax policy gives us the equivalent of beef meat that will stop being produced in order to switch it with another food (chicken or plant based (crops)).

To calculate the amount of meat that is going to be needed in order to produce the equivalent on chicken or plant based (crops), the converter called ¨ beefs not going to be produced due to the tax policy ¨ is calculating this data, it determines the amount of emissions desired on the beef sector and calculates how many cows are over this desire, this means that the amount of beef that needs to be reduced is being calculated by (tons of emissions/emissions per beef), this gives the desired reduction and with a smthn function, this number is dictating how much cows are not going to be produced across the timeline in order to achieve that goal, the purpose of the smthn function is to give a more real change to the system due to the fact that it takes time to adjust this kinds of behavior (United States Department of Agriculture, 2019), because the demand is being generated by the population choices and also in order to have a smoother change in the demand in the cases that the desire is too big, to the model wont react in an aggressive and not ¨real¨ way.

After the value is generated, it becomes tons of meat needed to still satisfy the demand and with the switch 5 and 4 you determine whether the substation will be with chicken or with crops (plant based diet).

- Crops instead of beef - ¨Switch 4¨ (Plant based sector): when turned on, the reduction on the beef production will be substituted by the crops, when turned off it means that you are not choosing the crops for the switching, more information will be shown on the plant based sector.

This converters generate the new loops that will increase the demand for the chicken and the plant based sector and will reduce the demand for the beef , this are shown on figure 3 with the red lines and will be a further explanation in the policy analysis.

Figure 4 shows the structure of demand in the model.

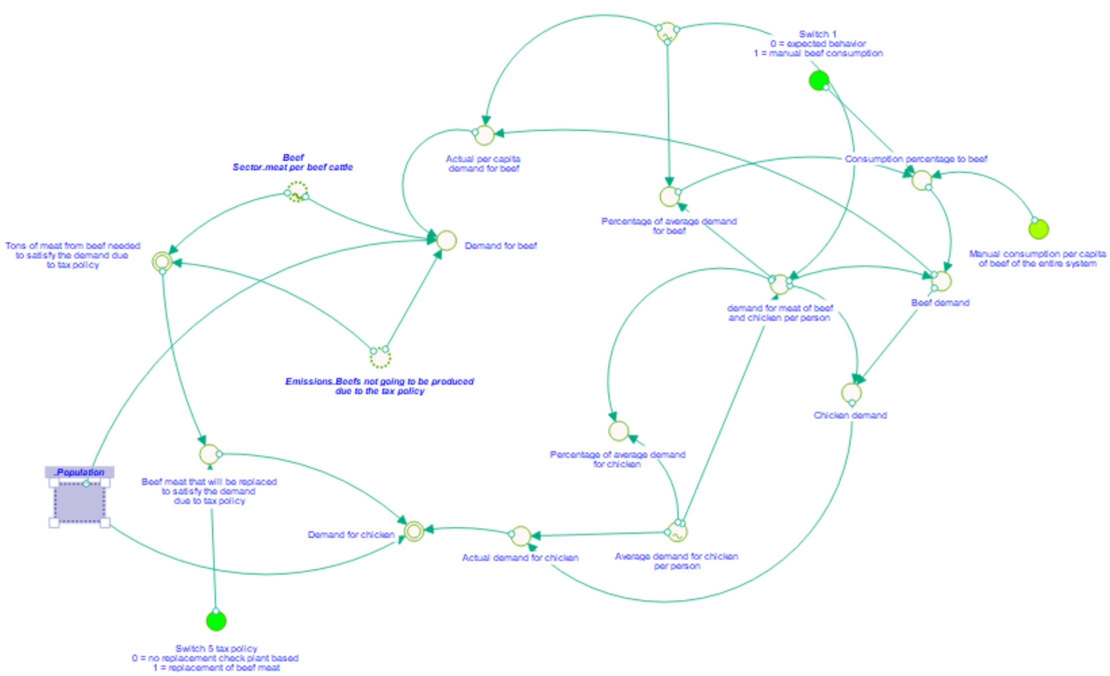

Figure 4. Demand sector

3.2. Food sectors

3.2.1 Chicken sector

This structure objective is to represent the behavior of the chicken production in the United States, and since the production of a broiler chicken takes about 47 days (compassion in world farming, 2019), this structure is very simple due to the fact that the production is very efficient and it doesn't take much time to produce a broiler for consumption.

The way in which this structure works is by using the historical chicken demand per capita and then an average to follows the future years, and with this we are able to reproduce how many chickens are needed in the system in order to satisfy this demand, and we also use the historical weight per chicken and again an average to estimate the future weight in order to know how much meat each broiler is producing.

The next figure shows the chicken system.

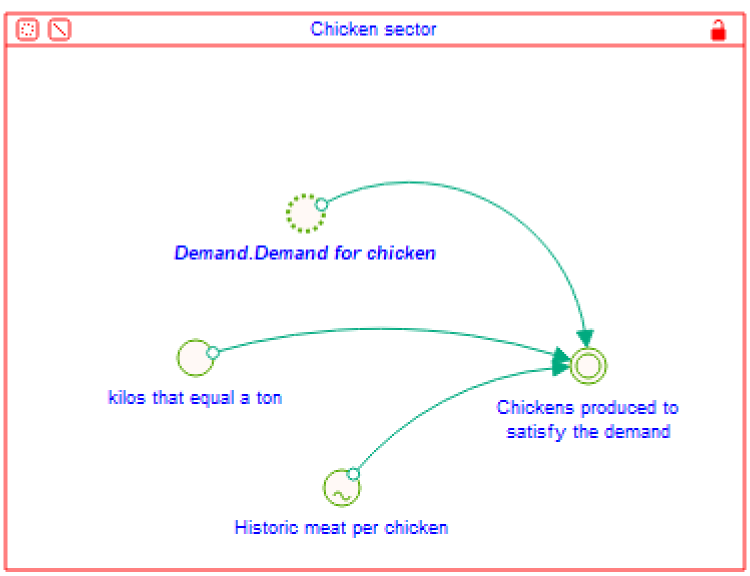

Figure 5. Chicken sector.

3.2.2 Beef Sector

This structure focus on the production of the beef cattle in order to produce meat to satisfy the demand from the population, its composed by 2 main stocks, the claves and the cows, and several flows and variables, this type of breeding is called cow/calve producer (Barkley, 2012).

The calves stock hast 3 flows, one is the breeding which is calculating how much claves are going to be needed in order to satisfy the demand, it considers the effect of change in demand on breeding which is the demand for beef over the normal breeding rate, which gives the value needed to increase or decrease depending on the demand and on the breeding capacity, when it increases in means that the capacity needs to increase and in the case of the United States they import when needed in order to be able to supply the demand (Drouillard, 2018).

When the demand increases, the structure considers the increase on the calves and cows stocks, in order to be able to supply, in the case of the calves they go to the ¨beef slaughtering rate¨ which is the responsible of the direct meat production and they also go to the ¨maturation to cows¨ which then goes to the ¨cows stock¨ and with this cows is how the ¨normal breeding rate¨ is formed.

Figure 6 shows the reinforcement loop that allows the increment in the breeding of the beef sector (green lopp), as well as the reinforcement loop for the ¨maturation to cows¨ which increase the number of cow on this sector and the reinforcement loop for the ¨beef slaughtering rate¨ which increase the beef production.

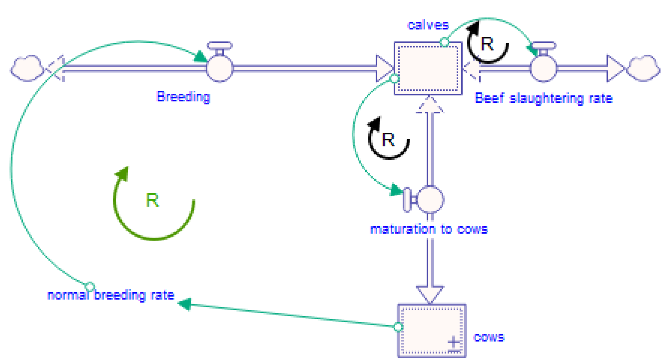

Figure 6. Reinforcement loop to the breeding.

The ¨cows stock¨ objective is to generate the breeding capacity of this structure, because this cows are the ones that are producing the calves, but they have a limited live time and after it's done they are also sent into the beef slaughtering rate to be a part of the supply as well (Drouillard, 2018). In order to determine their life time the structure considers an average life time converter as well as the one used of time to maturation which is the same for the claves to be ready to slaughter, this converter is called ¨time to mature in order to slaughter¨.

Figure 7 shows this structure and it also shows another 2 loops, R2 which is the responsible of the breeding capability and this means at a higher number of cows, more calves you may produce, and the R1which increase the beef meat production because of the slaughter of the cows.

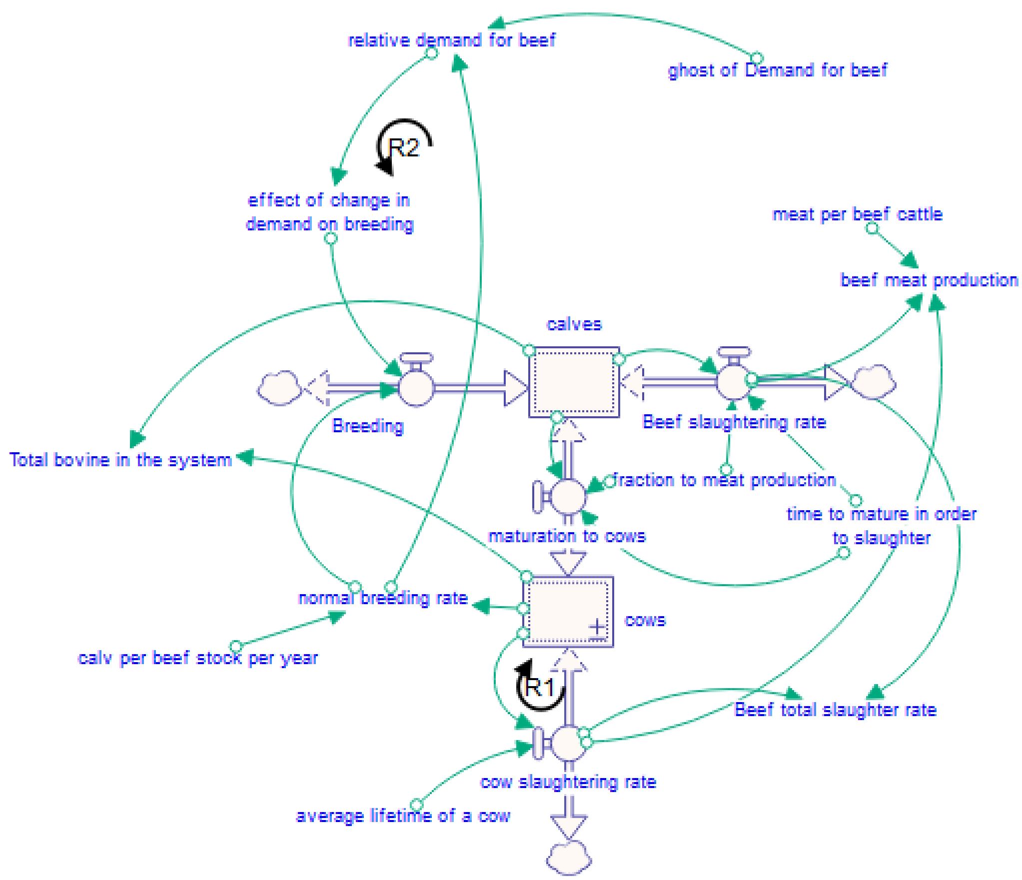

Figure 7. Beef sector

3.2.3 Plant based (crops) sector

This structure has the objective of producing the crops needed in order to satisfy the demand for plant based diet as a response of the switching from beef to plant based, also it considers the crops used for the animal consumption in this case chicken and beef, the production of crops varies depending on which sector is requesting the crops for consumption, this is mainly because the crops used for feed the beef sector are not the same as the ones used for the chicken sector because they use specific type of crops for example the beef uses hay silage and corn silage (Kime & Harper, 2014), and in the case of the chicken is corn and soybean (Determan, 2014).

This means that the production of the crops from chicken and the beef are different because of the type of crop, with this and the amount of broilers and beef being produced, the structure is calculating how much crops are needed in order to feed this animals.

The special application in this structure is the ¨crops instead of beef¨ which determines if the beef is going to be replaced for the plant based diet (crops), when the tax policy is on.

By turning on ¨crops instead of beef¨ with switch 4 the amount of crops needed in order to replace the beef is calculated, this calculation is based on the amount of calories that are not going to be produced from beef because of the tax policy and are transferred into the equivalence of the crops calories, with this the structure it's possible to determine how much crops are needed in order to make the replacement. This calculation starts with the converter ¨Beefs not going to be produced due to the tax policy¨ which indicates the number of cattle head that are no longer needed in the system and multiplied by the ¨meat per beef cattle¨ the amount in tons of meat is calculated. After this, the amount required is then multiplied by ¨calories per ton of beef¨ in order to determine now in terms of calories, the new requirement of crops to satisfy this demand ¨calories needed from beef to satisfy the demand¨.

This new demand is then divided over the calories per hectare of crops and the amount of hectares needed is generated and transferred into the total crops which will establish the new amount of crops being used in this structure in order to satisfy the demand.

In figure 8 this structure is represented.

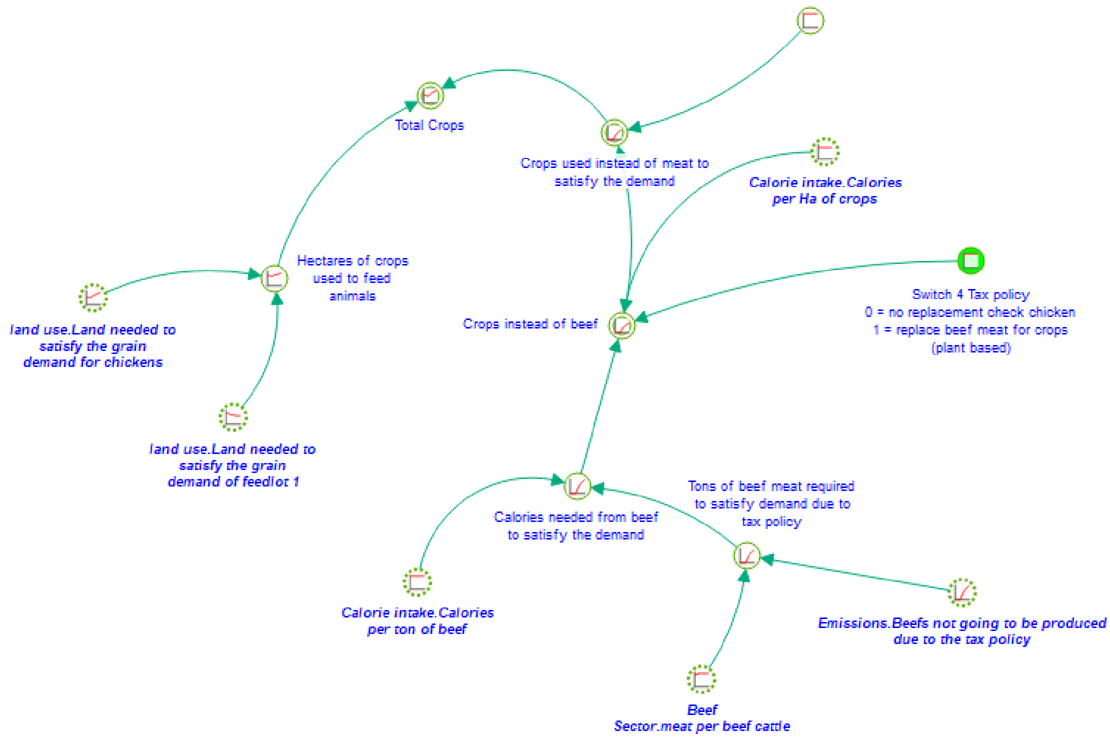

Figure 8. Planted based (crops) structure.

3.3 Water consumption

This sector has the objective on representing the amount of water consumed by the entire food sectors, in the case of the beef and the chickens, it considers the amount of animals and their water requirements.

In the case of the beef, it considers the consumption per year, and also it considers between calves and cows by stablishing and average, this because several factors affect the amount of water consumed by beef, such as climate and activity of the bovines (Lang, 2008).

In the case of the chickens, the average water consumption per chicken is being calculated, the main difference is that this value is being treated per year, the variable that is responsible for this calculations is called ¨water required per chicken (lifetime), this is because each chicken or broiler produced for meat consumption doesn’t live more than a year (United States Department of Agriculture, 2020)so in this system that justifies to consider this as just a yearly consumption per chicken. To calculate the water that the crops need, the system is considering an average water consumption per kilo of crop harvested, and the crops used to estimate this consumption are the converters:

7. kilos of gran needed to feed chickens: as it name states, this converter shows the amount of kilos of grain needed in order to produce the chickens in the chicken sector, its calculated by the number of chickens in the system times the kilos of grain needed per chicken.
8. kilos of grain needed to feed the feedlot: This kilos correspond to the bovine system that spends time on the feedlot in order to produce meat, calves spend time in this system in order to gain weight and then be sent to slaughter, when they are not sent to slaughter they become cows and are kept to produce calves (Barkley, 2012).
9. Water required from crops (plant based diet): this are the crops generated by the switching from beef to plant based diet.

Figure 9 represents the water consumption sector.

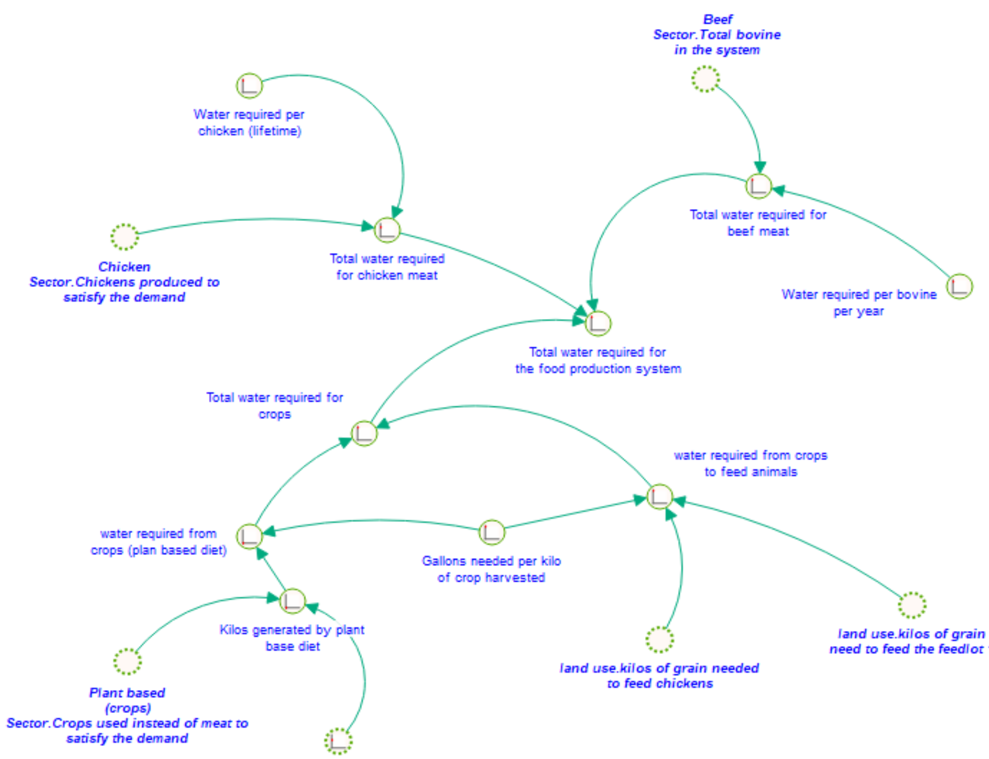

Figure 9. Water consumption sector.

3.4 Land use

The objective of this structure is to estimate how land is going to behave because of the demand from population to the food sector, in other words how much land is needed in order to produce the food, and it calculates the land needed for the plant based (crops), beef sector and chicken sector.

In the case of the plant based this system is considering the converter called ¨Total Crops¨, this because the value is already in hectares, so it just adds to the main converter of this system that's called ¨Total land use¨.

For the beef sector, first the system considers the number the number of bovines in the system, after it calculates the number of Ha needed in order to breed this cattle, the calculation I the number of bovine in the system times the average of Ha needed per bovine, this average is calculated based on the needs when in feedlot and when in grazing, in the appendix-model documentation all the sources for this average are available, the second calculation is based on the number of ha needed in order to satisfy the consumption for the feedlot, this is also an average of the consumption per bovine and the calculation is the number of bovine in the system times the year consumption per bovine. This gives us the amount in kilos for the beef sector and then this kilos are divided with the converter ¨kilos of grain produced per Ha of crops¨ and the system then generates the value for the Ha required to satisfy the feedlot supply.

For the chicken sector, the system uses the total number of chickens first to estimate the land use for the chicken production, and for this the system multiplies ¨average number of Ha needed per chicken¨ times the entire number of chickens, secondly in considers the feed for the chicken production which as in the beef sector, is the total number of chickens times the ¨yearly consumption of grain in kilos per chicken¨ and the same as in the beef sector is done in order to get the amount of Ha needed in order to satisfy the feed for the chicken sector.

The figure 10, shows the land use sector.

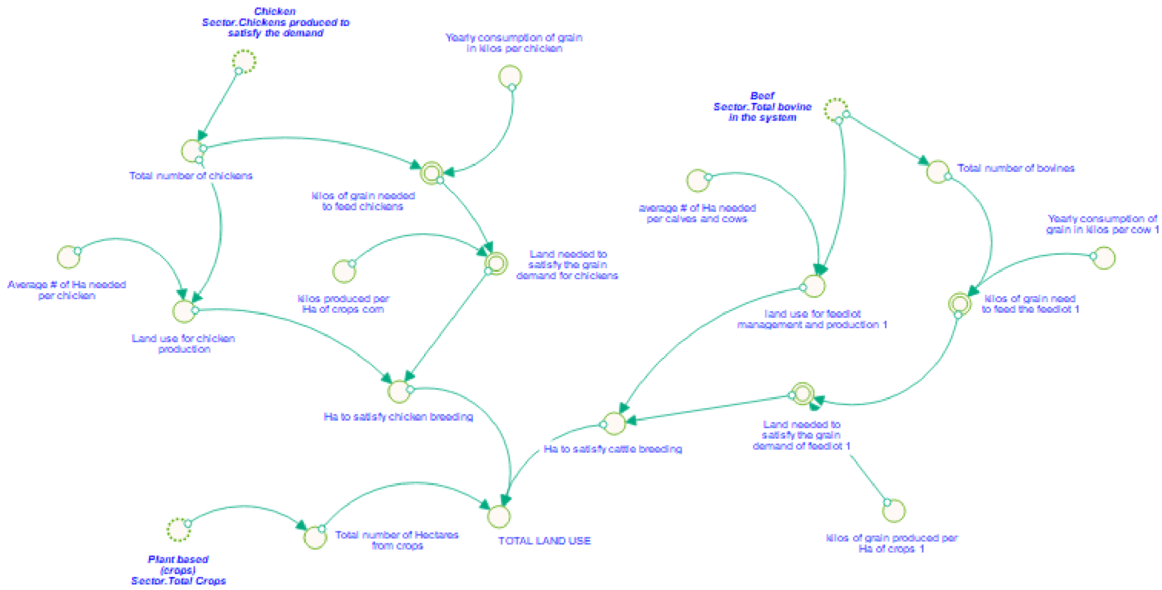

Figure 10. Land use sector

3.5 Calorie intake

This sector represents the calories generated by the food sectors, the main purposes of this sector is to validate the switch from beef to plant based, in other words to see if when this switch is being made the equivalent amount of calories are being replaced, in order to check this the converter ¨total calories production¨ represents the total amount of calories generated by this system and with this it's possible to validate if the system is meeting the demand or not after making the switch .

The other main purpose of this sector is to generate the value for the converter called ¨calories needed from plant based instead of beef – tax policy¨, the use for this converter is to compare it with the converter called ¨calories need from beef to satisfy the demand¨ located in the plant based sector, when the match is exactly the same, it means that the requested demand is being made and it represents the amount of calories needed in order to make the replacement.

Apart from this purposes the system also shows the normal amount of calories required by the population, the calories being generated from the beef sector, chicken sector and plant based sector, in the case of the plant based sector, it just takes into consideration those crops use to replace the consumption of meat, and not those ones used to feed the chickens and the beefs.

Figure 11 shows the calorie intake sector.

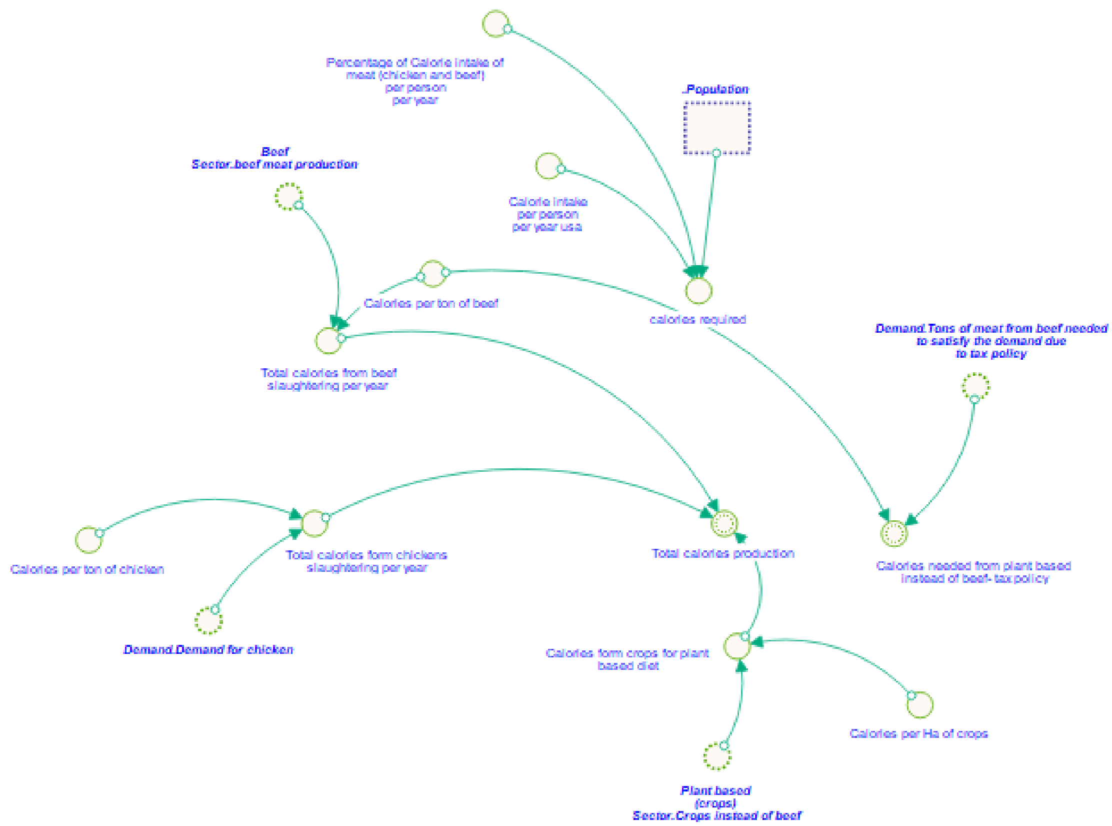

Figure 11. Calorie intake sector

3.6 Emissions sector

The emissions sector has the objective of representing the behavior of the emissions being generated by the food sectors, it considers the emissions from the beef sector, chicken sector and plant based sector.

In order to represent the emissions from the chicken sector an average per chicken is calculated on the converter called ¨emissions per chicken per year¨ and multiplied by the total amount of chickens in the system in order to get the emissions from this sector, is important to know that the chickens are one of the animals that generate less emissions when talking about methane (Dunkley, 2011).

The emissions from the plant based sector come from the ¨emissions from crops for cattle¨ which are the ones responsible to feed the cattle, and the way they are being calculated is the amount of Ha used for this feed times the emission per Ha of crops including fertilizers, the fertilizers are the responsible for the emissions from crops (FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS, 2017). This emissions also come from the hectares used to feed the chicken and the hectares used to replace the beef to plant based diet, the reason of making a distinction between hectares from beef and this ones is because depending of the crops is the level of emissions they will generate because of the fertilizers (FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS, 2017), and in the case of the chicken and human consumption the crop consider is mainly corn, and for the beef its being considered the silage and hay.

The emissions from the beef sector has two types, the ones coming from the calves and the ones coming from the cows, the reason the emissions are different is due to the fact that the feed consumptions of the animals is different and it influences the amount of methane emissions being generated by each type (Nikolov Hristov & Johnson, 2014), the calculation is emissions per type of animal times the number of the animal, in this case calves or cows.

Figure 12 shows the emissions sector.

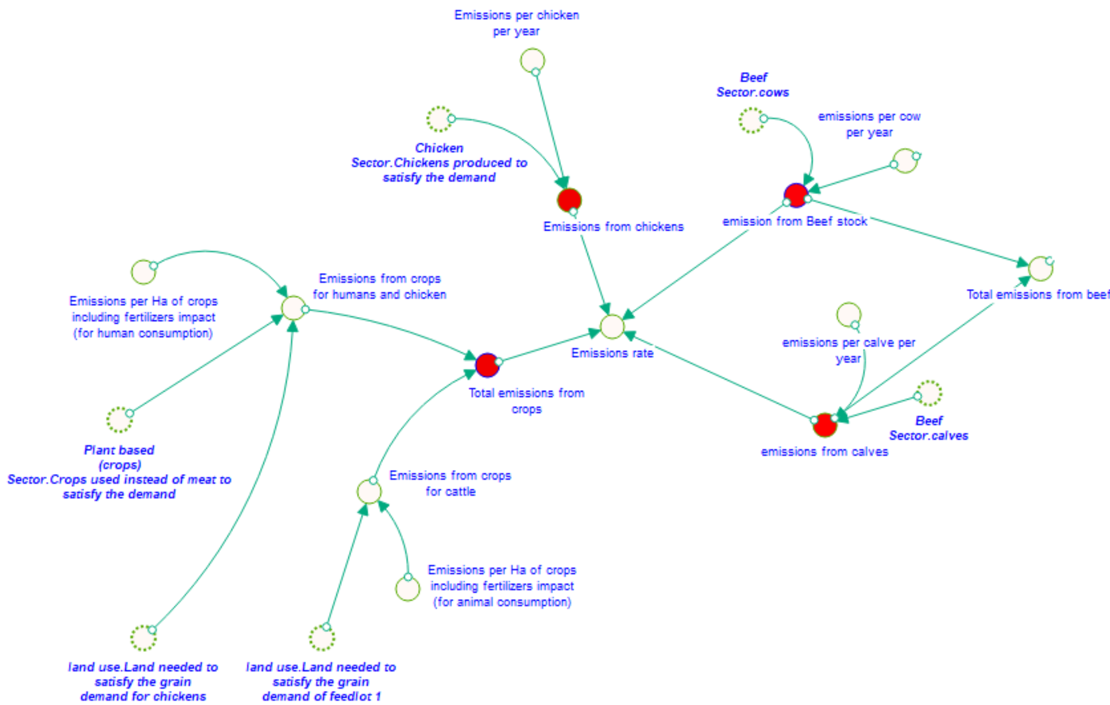

Figure 12. Emissions sector

This sector has an special appliance or strucutre added in order to test the tax policy on the beef described on the chapter 5 – Policy analisis.

The objective of this structure is to modify the demand for beef, in order to do this a desire level of emissions is set, the user is able to determine how much emissions he wants that the beef sector generates and this means that it will affect the production of the beef.

The ¨gap¨has the formula: (IF TIME > 2020 THEN (IF (Total_emissions_from_beef-Desired_level)> 0 THEN (Total_emissions_from_beef-Desired_level) ELSE 1) ELSE 0), the purpose of having the conditional IF, is to only make it work starting from 2020, in order to not affect the historic behavior of the system, then the calculation for the gap is the ¨total emissions from beef – Desired level¨ which creates the gap, this gap indicates the level of emissions needed to be reduced in order to reach the desired level.

After the gap is calculated, the next process is determining the number of beef that is not going to be required for the demand, to do this in the converter ¨emissions equivalence to beef¨, the gap is being divided by the ¨average emissions per bovine¨, in order to produce the number of beef that is not going to be produce on the demand for beef.

In order to make this structure modify the demand for beef, the converter ¨emissions equivalence to beef is being used on the next one called ¨beef´s not going to be produced due to the tax policy¨, that has the formula:
IF"Switch_3_tax_policy_0_=_normal_behavior_1_=_tax_policy_for_emissions_reduction" > 0 THEN (IF TIME > 2020 THEN SMTH1(emissions_equivalence_to_beef/adj_year, Time_do_adjust_the_the_demand_behavior) ELSE 0) ELSE 0, the purpose of the first conditional is to be able to have a switch that will activate or de-activate this policy when the value of the switch is 0 or 1, the second conditional is also ensuring that the system will just react to this policy from 2020. The equation that gives us the actual number of beefs not going to be slaughtered is: (SMTH1(emissions_equivalence_to_beef/adj_year, Time_do_adjust_the_the_demand_behavior)), this equation uses a smth function, considering the emissions equivalence to beef and the adjustment time to generate the change, and this function is being applied during the 30 years that this model is evaluating after the 2020, in other words until 2050, that's way the time to adjust the demand behavior is 30.

When this structure is activated, the new demand will be being modified across the entire period of time left, and will affect the behavior of the entire system, the variable ¨beefs not going to be produced due to the tax policy¨ is linked to the demand sector and is the responsible of the new feedback loops generated in the system, this loops are described on chapter 3, section 3.7.

Figure 13 represents the structure for the tax policy that is added to the emission sector.

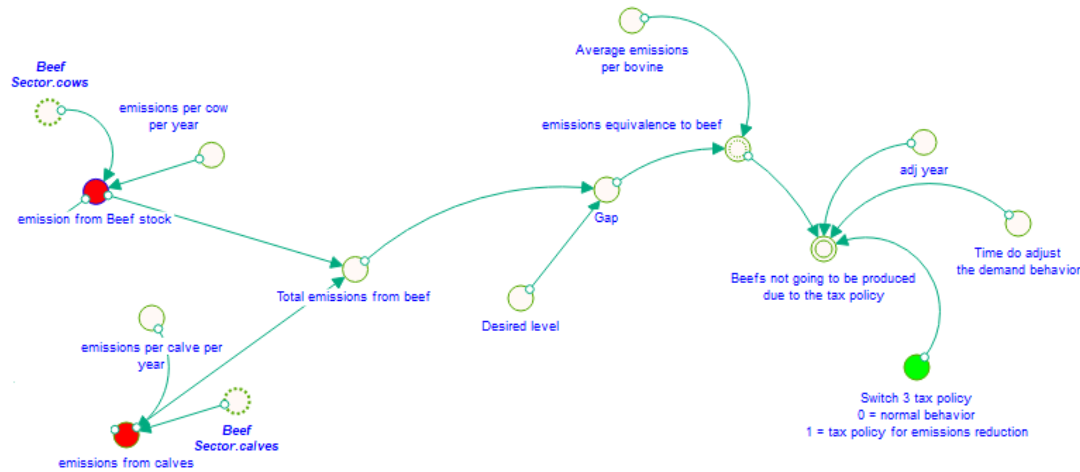

Figure 13. Tax policy structure on emissions sector.

3.7 Model overview: Feedback loops.

This section shows the feedback loops in the model, and describes the way in which they are affecting the system, apart from the feedback loops already described on the beef sector, when the tax policy is activated new loops are affecting the system due to the fact that the demand is now being controlled by the emissions generated by the beef sector and this makes the system switch that demand to the chicken sector or to the plant based (crops) depending on the decision of the user.

When the demand is switched because of the tax policy, the objective is to reduce the emissions form the beef sector by reducing the production, and replacing that demand for chicken or plant based, in order to still be able to satisfy the demand but at a lower emissions cost to the environment.

The figure 14 shows the feedback loops on an overview level.

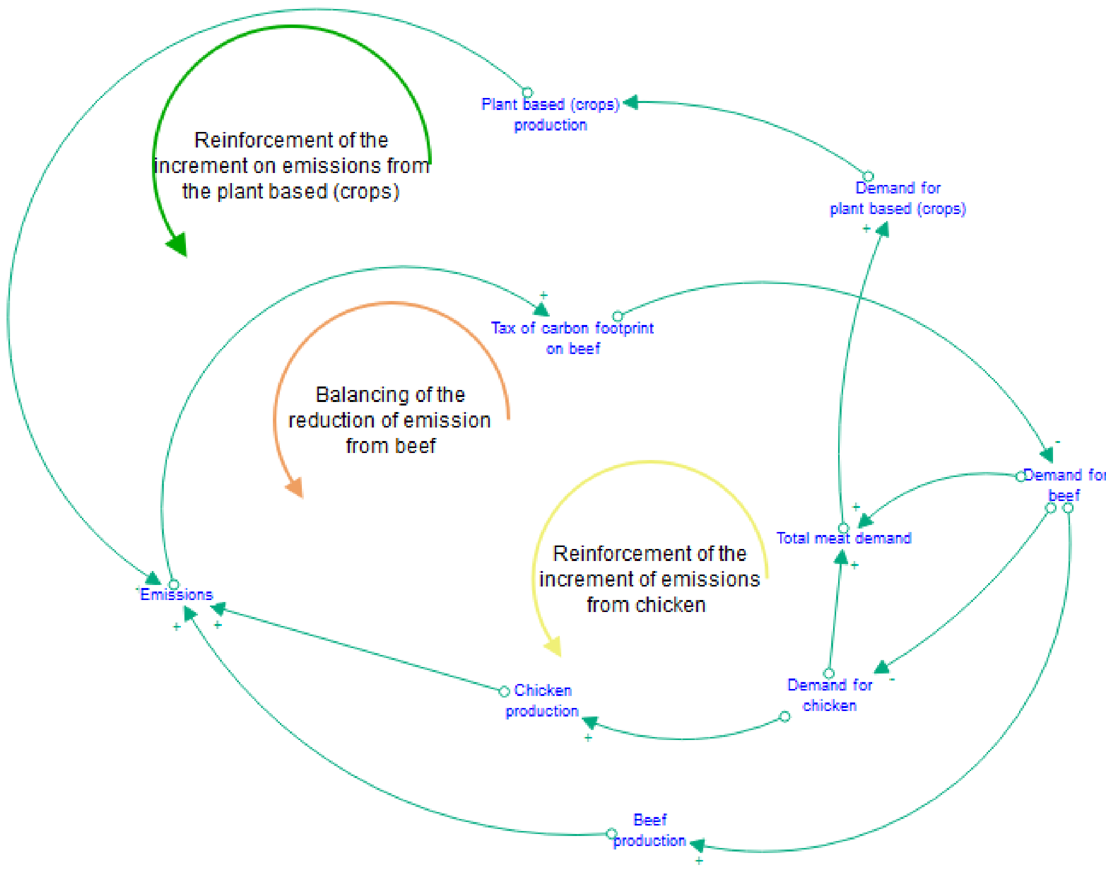

Figure 14. Mayor Feedback loops, overview of the model.

This feedback loops affect the entire system, the way in which they affect it is the next:

- (Green) Reinforcement of the increment on emissions from plant based (crops): This loop becomes active when the tax policy is on and when the user decides that the switching from meat will be with plan based diet, the first thing it does is creates a demand for the plant based diet, and by this the plant based (crops) sector is affecting the rest of the sectors by generating emissions, water consumption, land use and calories.

  Each year the demand is changing due to the policy, and the plant based sector is following this change across the loop, the objective for this loop is to test the impact on the environment and resources that the switching from beef to plant based will generate.

As shown on figure 14, the change on the new demand for the plant based (crops) sector will depend on how much emissions is the beef sector generating and on how big or small would be the desired level for the emissions from beef sector due to the tax policy, in other words, the bigger the desire of reduction for the emissions from the beef sector, the bigger the demand for the plant based sector in order to switch on product for another.

- (Yellow) Reinforcement of the increment on emissions from chicken: This loop works in the same way as the green loop, and has the same condition, the tax policy has to be activated in order to work and also the user needs to choose that the beef demand will be switched for the chicken demand, in this case the demand is going to be an addition to the already existing demand for the chicken and the objective is also to test how much will the environment will be affected if this switch is made.

- (Brown) Balancing of the reduction of the emissions from beef: This loop is reducing the emissions from the beef sector through the tax policy, when this policy is activated it means that the user has the decision of choosing a desired level for the emissions that are going to be generated from beef, based on a policy, and this will lead to a decrease on the beef production and to a switch from that production to another product, in this case chicken or plant based, this switch is considering a smthn function on the converter ¨Beefs not going to be produced due to the tax policy¨ in the emissions sector, the reason is that it considers the assumption that when the government needs the people to decrease the consumption of a certain product, with an introduction of a tax policy this will happen but gradually (Gupta, 2010).

  This loop is also affecting in a direct way the sectors such as, emissions, land use, calorie intake and water consumption.

3.8 Basic settings

The global settings for the model are shown next:

1. Start time: 2000
2. Stop time: 2050
3. Time units: years
4. Delta time (DT): ¼
5. Integration method: Euler

It's possible to change this settings in order to make validation testing, policy design, or other uses for the model in this thesis, this values are set to work for the purposes of the testing a policies implemented in this research.

The model is fully documented in the Apendix and the Stella ¨stmx¨ model file attached to this thesis.

Chapter 4. Model Analysis

4.1 Model behavior

The models aim is to represent the historical and tested behavior of the sectors mentioned on chapter 3, and uses historical data for some of the core variables of the model such as, consumption of beef and chicken meat per capita, weight of the animals and population, this consideration if for the period 2000-2019, the rest of the variables are averages based on literature, and the data is based on the United States. In order to be able to evaluate and analyze the behavior of this model, the base behavior considerate is the one that uses historical behavior, and as mentioned before is from the period 2000-2019, the rest of the running which is from 2020-2050, is considered as the testing period, the testing period has the aim to evaluate the behavior of the emissions, land use, water consumption and the changes of the beef, chicken and crops ¨population¨.

Figure 15 shows the base behavior of the variables which this research is investigating such as, Total emissions, Total Land use, Total water consumption, Beef meat production and Demand for chicken (tons of meat produced by the chicken sector).

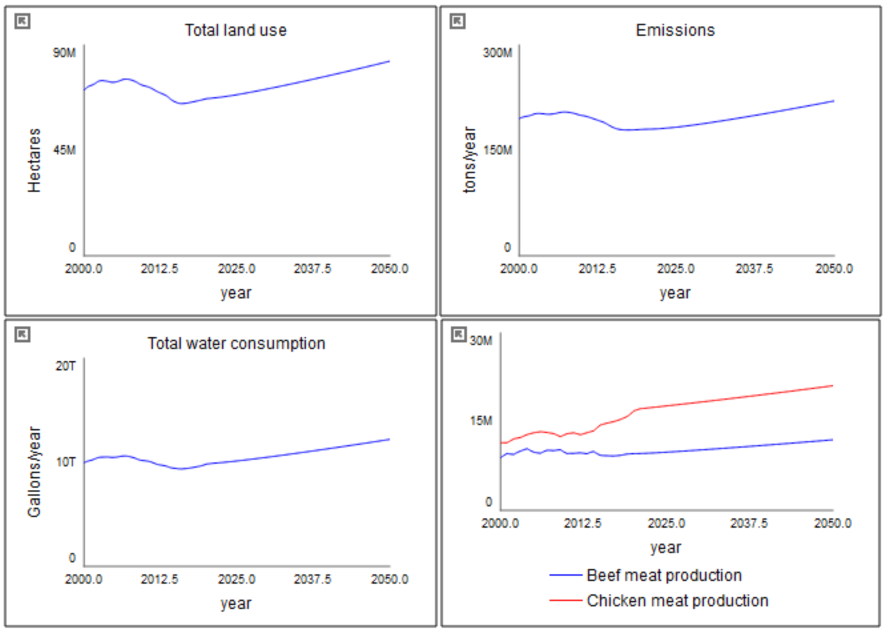

Figure 15. Graphs showing behavior for total land use, emissions, total water consumption, beef meat production, and chicken meat production.

4.2 Validation testing

For the validation test, this research will focus on a formal model validation, which is composed by a structure validity (Direct structure tests and structure-oriented behavior tests) and behavior validity, always following the guidelines by Barlas (Barlas , 1996).

The structure validity as mentioned before has two parts:

- Direct Structure tests: This tests analyze the validity of the model structure by comparing directly with the knowledge about the real system, involving mathematical and logical relationship (no simulation is involved at this stage). This tests consider an empirical part which involves the comparison of the model structure with the information obtained directly from the real system being modeled and the theoretical part which involves the comparison of the model structure with generalized knowledge about the system that is found on literature.

- Structure-oriented behavior tests: This tests focuses on the validity of the structure indirectly by applying behavior tests on model-generated behavior patterns, this tests involved simulation and can be applied to the entire model as well as to isolated sub-models in the system. An important part of this tests are related to the extreme condition evaluation, which involves assigning extreme values to selected parameters and comparing the behavior with the observed or anticipated behavior of the real system. In this part the sensitivity of the model is also evaluated to see if it reacts accordingly to the observed real behavior.

Behavior validity: Also known as behavior pattern tests, once enough confidence has been built due to the previous tests, the introduction of this tests are made, the reason is that this section of formal validation is related to the measurement of the accuracy of the model to reproduce the major behavior patterns exhibited by the real system, in order words this tests are related to work with the entire simulation in order to see if the results and behavior that the model is creating, matches the real system when something is altered, for example the demand for a product that will lead to a normal increase or decrease of that system, if the system reacts in a way that matches the real system it would mean that the system at least in that part is reacting in a good way.

4.2.1 Structure validity

- Direct structure tests: The formulas used in this model are based on the data collected from several sources, and they attempt to reproduce a behavior that reacts in the same way as the real system structure, in order to evaluate if this model is reproducing that kind of behavior, this part of the formal validation will evaluate the formulations and relations made in the model to see if they are valid when comparing with the real system structure.

In the case of the food sectors, according to the data collected, for the case of the beef, this sector is composed by two stocks, calves and cows, which by relation they are the responsible for the beef meat production as well as the production of the calves, this process is called cow/calve production (Barkley, 2012), the flow responsible for the production of calves is called ¨breeding¨, the formula used is (normal_breeding_rate*effect_of_change_in_demand_on_breeding), this process considers the capacity of production represented by the ¨normal breeding rate¨ which accounts for the cows available to produce calves, and the ¨effect of change in the demand on breeding¨ that accounts for the need to produce more or less based on the breeding capacity, in other words in order produce, the producers take into consideration the demand and the capacity to produce more or less calves in order to satisfy the demand, this relation is as in the real system.

After this calves are being produced on and accumulating on the stock ¨calves¨, a parte are sent directly to the ¨beef slaughtering rate¨ or ¨maturation to cows¨, in order to decide this, de model uses the flow ¨beef slaughtering rate (calves*fraction_to_meat_production/time_to_mature_in_order_to_slaughter), this formula considers how much calves are needed for the demand, and decides as well how many will be turned into cows to be able to satisfy the breeding for the future. The time considered, refers to the time in which calves are ready to be slaughter and also the time that takes it to mature and be sent to the ¨cows¨ stock. Also cows are sent to slaughter when they become of age and taking into account for the meat supply, that also is part of the decision of sending calves to this stock, in order to prevent the capacity gong below the levels needed to satisfy the future demand that in the real system is expected to be increasing (Drouillard, 2018). This representation, considers the cow/calve production, and follows the line for the beef meat production for the purposes of this study.

The chicken sector, it's a simplified structure which takes into consideration the demand for broilers mainly, and the historic weight for them, as shown in the formula for the variable ¨Chickens produced to satisfy the demand¨((Demand.Demand_for_chicken)*(kilos_that_equal_a_ton/Historic_meat_per_chicken))* , this represents the number of chickens required by the demand sector, and the outcome is based on the ¨historic meat per chicken¨ converted into tons by the division seen in the formula, since it's not possible to know the future weight on chickens an average was calculated for the next years, this formulation represents the breeding for chicken, the reason it's so simplified is because the chicken production is much faster than beef, it takes about 47 days in average to produce and harvest one broiler (compassion in world farming, 2019), for the purpose of this research this sector is considered like that, due to the producing time, and the efficiency of the real system.

In the case of the emissions, land use, calorie intake and water consumption, the formulas represented are multiplications considering averages per animal, all based on the literature and relations of the real system, this is sufficient to represent the impact generated for this sectors, for example: if one was trying to see the impact on land from the Beef sector, the system considers the beef population (calves and cows), and multiplies the necessity of land per animal on average, and the user will get how much land is needed to satisfy the beef sector, this is the same when talking about chicken or other sectors like emissions. This sectors (emissions, land use, calorie intake and water consumption) rely on the production from chicken and beef, and when the tax policy is introduced they also rely on the plant based (crops) sector. The sources used in order to make the averages are mentioned in the appendix – model documentation.

For the plant based sector, on part evaluates the necessity of crops from the beef and chicken sector, in other words how much crops they need in order to be feed, and uses estimations of crop production according to the crops needed, and considers the animal requirements, when the tax policy is on, this sector will make the proper conversions from beef to crops by using the calorie intake sector, in order to make the switch and consider the new amount of crops that will be needed in the system. For the purposes of this research, it is consider that the formulas and relations are appropriate in order to create behavior that will be related to the real system.

When evaluating the extreme condition testing for this chapter, the model considers the alteration on the demand sector by managing the entire demand, in order to do this, a variable called ¨demand for meat of beef and chicken per person¨, this variable sums this 2 demands and the use for this is to manual manage the entire meat demand, the user can decide how much from that demand will be for the beef sector and the rest will be for the chicken sector.

To do this, an structure on the demand sector is the responsible for controlling this values, as described con chapter 3 section 3.1, by turning on consumption percentage to beef with switch 1, the user can use the variable ¨Manual consumption per capita of beef of the entire system¨ and determine how much demand will go to beef and the rest to chicken, on figure 17 its shown this part of the demand sector.

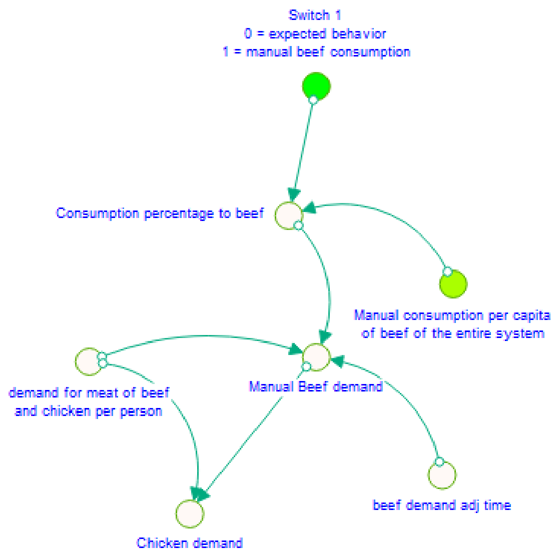

Figure 17. Part of the demand sector that controls the manual consumption for beef.

- Structure-oriented behavior:

It can be seen on figure 15, the big impact that the beef and chicken meat production has on the other sectors when the testing period is being evaluated, the co-relation across sectors is visible on this graphs.

The most sensitive variable when the production of both types of meat is being increased is the total land use as also shown in this graphs, the reason for this aggressive change is the beef population needed in order to produce the meat, on figure 16 its shown the behavior for the chicken sector and beef sector in terms of land use, and it's clear that the total land use follows the behavior of the beef sector´s population due to the fact that in order to produce meat, a great more deal of land needed in comparison to chicken (Flachowsky, Meyer, & Südekum, 2017).

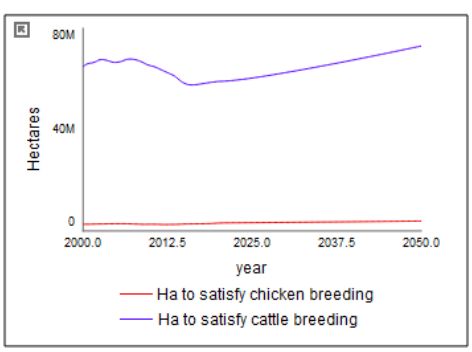

Figure 16. Graph that shows the hectares needed to satisfy the breeding of the beef and chicken sector.

Regarding the emissions from the system, the behavior is also responding more to the beef sector, again the reason is that the beef cattle generates more emissions to the environment than the chicken sector (Solly, 2019), in other words it cost more to produce a ton of beef meat than a ton of chicken meat when talking about the emissions generated to the environment, that's why a slight change on the way we eat may improve the conditions for the environment.

In the case of the water consumption we also see the correlation with the meat production and this is also in a big measure because of the increase of the population that at the same time is demanding more food, this means more animals and more water consumption.

In the case of the beef sector, according to the historic data, the number of cattle has maintain an average of 93 million heads across the base behavior period (2000-2019) (statista, 2019) , and regarding the beefs slaughtered the average per year on the base behavior period is around 32 million heads (United States Department of Agriculture, 2020), the actual behavior of the base period gives less than the historical data, this is due to the fact that in the United States there is an overproduction of beef each year, which leads to this difference (Resnick & Zarracina , 2018).

In order to make the assumption of how much does the United States is overproducing, an estimate based on data about the billions of pounds produced per year was used (Our world in data, 2019), in order to add a value on the demand based on this number to see if the model will create a similar behavior to the real data, and when considering an overproduction of 4 million heads per year, the model gives us results very close to the real behavior, but for purposes of testing the model will remain the same, this meaning that the production is being considered just for the amount required for the people and not considering the overproduction.

A new converter was added on the demand sector called ¨normal overproduction on the United States¨ for the previous purpose and it's available for the user.

For the chicken sector, the model is also evaluating the consumption for the United States without considering the exports (National Chicken Council, 2020) and the overproduction (Bunge, 2018) being produced each year, in order to test and evaluate if the model is creating the appropriate behavior for this research the estimates of broilers being produced for export was calculated as an average for the base period taking the value of 17% added to the demand due to exports, and an increment for the over production, when this value is being added to the demand it also creates a very similar behavior to the historic one, and again in order to evaluate and use this model for research and testing purposes we will use it without considering this factors.

The rest of the sectors are based on data from literature and depend on the production from beef and chicken, in other words the system will test the reduction or increment in this sectors considering the production generated from the food sectors.

In order to evaluate the reaction of the model when values are being altered, the use of extreme condition tests is applied, the results are shown on figure 18.

Extreme condition test		
Stock or variable used	**Value assigned**	**Result**
Population (stock)	0	Positive, the behavior goes to value ¨0¨ after the stocks are empty due to the lack on population that generates the demand.
Calves (stock)	0	Positive, the system adjust by breeding the calves needed to satisfy the demand at the same level as before on year (2008), due to the fact that there are cows to breed and supply the deficit of claves until reaching the amount needed.
Cows (stock)	100	Positive, the stock starts accumulating until reaching the base behavior on year 2025, the emissions, total land use and water consumption are also affected due to the less amount of cows.
Demand for beef	0	Positive, the behavior on the beef sector goes to 0.
Time to mature in order to slaughter	15	Positive, they beef sector still performs, but it produces much more calves in order to satisfy the demand
Demand for chicken	0	Positive, the chicken sector goes to value 0, and reduce the emissions, land use, and water consumption
Manual consumption of beef of the entire system (switch 1 on)	0	Positive, the system still performs and after the base behavior period, all the demand is switched to the chicken demand.

Figure 18. Table - Extreme condition tests (structure-behavior oriented)

4.2.2 Behavior Validity

The next tests will show the change on behavior for the beef and chicken production, as well as the emissions, land use and water consumption to test if it matches what is being mentioned by the literature (the average demand for beef is 36.9% for the base period).

- Test 1 (demand for beef 20%):

Figure 19 shows the results on graphs when the demand for beef is at 20%, the blue line represents the base behavior and the red dotted the application of the manual demand for beef.

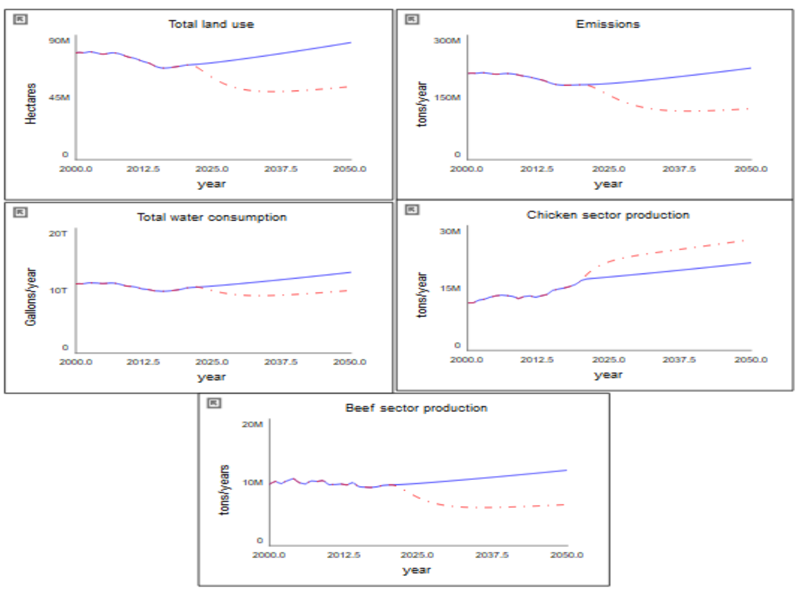

Figure 19. Graphs showing results from test 1 – Direct structure tests.

As shown in the results from figure 19, when the beef demand is lowered to a 20% and the chicken to an 80%, the land use, emissions, water consumption and beef sector production decrease, and in the case of the chicken it has an increasingly increased behavior, this results matches with the literature.

- Test 2 (demand for beef 80%)

Figure 20 shows the results on graphs when the demand for beef is at 80%, the blue line represents the base behavior and the red dotted the application of the manual demand for beef.

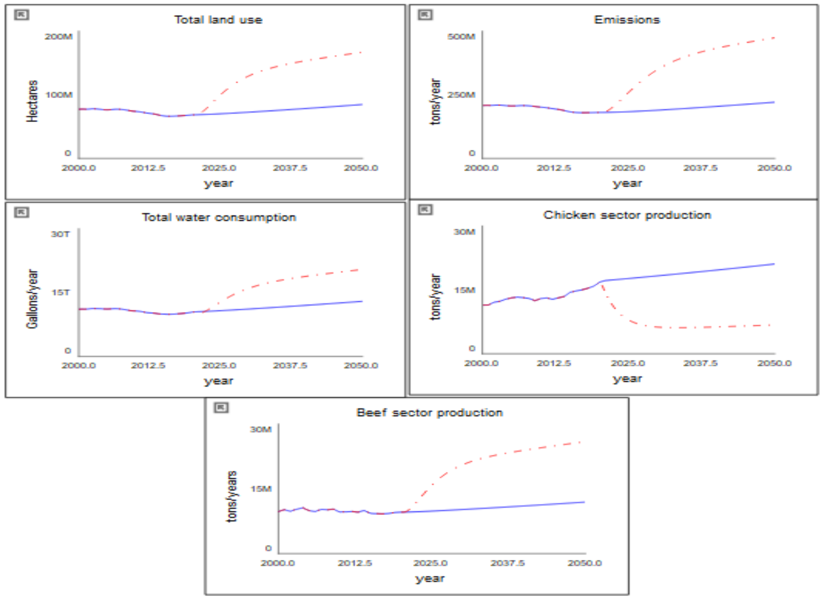

Figure 20. Graphs showing results from test 2 – Direct structure tests.

As shown in the results on figure 20, then the manual consumption for beef is 80% and chicken 20%, the effect on the emissions, land use, total water consumption and beef sector production makes all of this behavior increase increasingly and the chicken production decrease which also matches the literature.

For test 3 and 4, the used structure is now the one related to the tax policy introduction, which is mentioned on chapter 3 section 3.6, it also affects the demand of the model, and creates demand for the plant based (crops) sector. In this case the variable that defines how much would the demand be changed is the variable called ¨Desired level¨ on the emissions sector, this has to do with the desired level for the beef sector, considering the introduction of the tax policy and switching that demand for chicken or plant based (crops).

- Test 3 (switching from beef meat to chicken meat):

For this test, 3 runs were made, blue line shows the base run, the green dotted shows the desired level (DL) value of 1 million, and red dotted shows the DL value of 500 million. Figure 21 shows the behavior results for this runs.

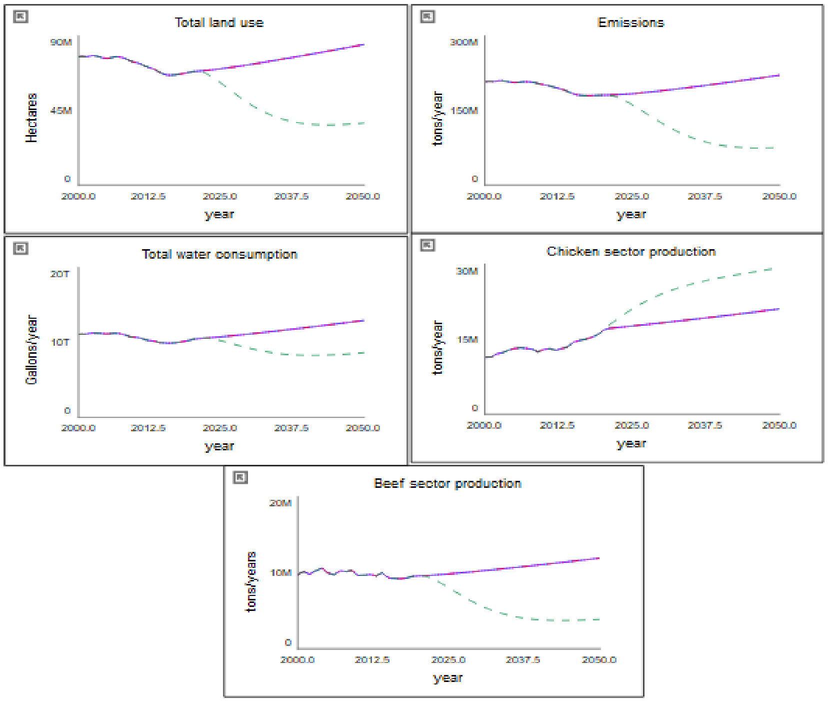

Figure 21. Graphs showing results from test 3 – Direct structure tests.

As shown on figure 21, when the DL is 1 million, the total land use, emissions, water consumption and beef production are drastically reduced, in the case of the chicken, the behavior is increasingly increased all this due to the fact that the system is requiring less emissions from beef and the response matches the literature. When the DL is 500 million, the system remains the same, due to the fact that this value is bigger than the actual emissions generation from the beef, so this policy is not doing any changes.

- Test 4 (Switching from beef meat to plant based (crops))

For this test, also 3 runs were made, blue line shows the base run, the green dotted shows the desired level (DL) value of 1 million, and red dotted shows the DL value of 500 million. Figure 22 shows the behavior results for this runs and also adds the plant based (crops) production.

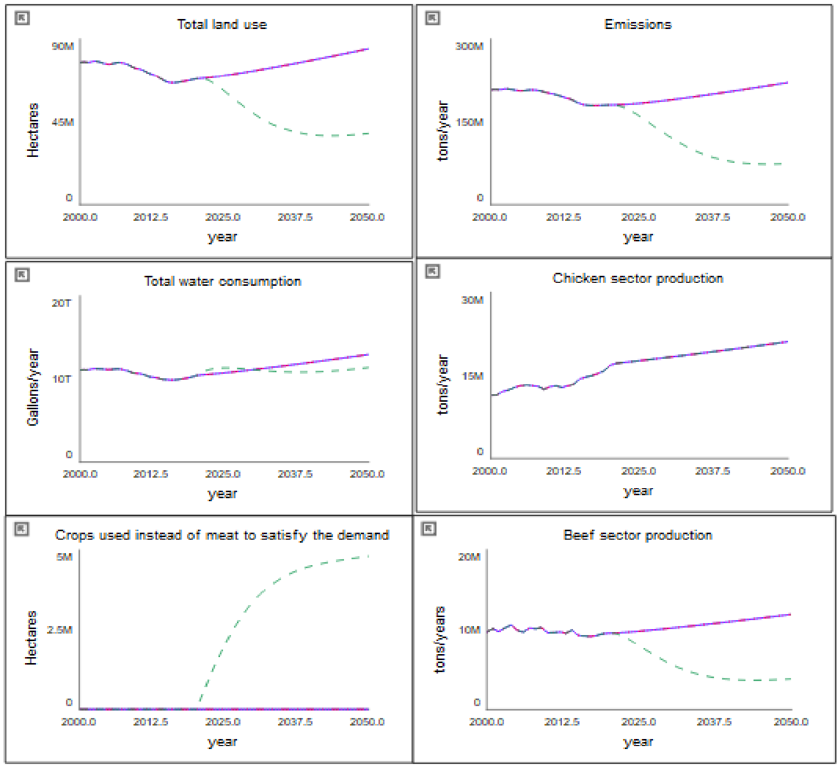

Figure 22. Graphs showing results from test 4 – Direct structure tests

As shown on figure 22, when the value of DL is 1 million (green line), the behavior of the plant based (crops) production increase increasingly, the beef production, emissions, total land use decrease, the chicken sector remains the same because no beef meat is being replaced for it and for the water consumption it slightly increases after the bas behavior period, but on year 2027 in starts decreasing. In the case that the DL is 500 million, the entire system remains the same due to the fact that the tax policy is not valid for this DL because is bigger than the actual one.

4.3 Main insights from behavior analysis and validity testing.

This chapter shows the main insights from the previous model validation testing in relation to the questions number 1, 2 and 3 from the research questions of this thesis.

1. Which behavior of emissions is expected until the year 2050?

On figure 15, from chapter 4 – section 4.1, the expected behavior until 2050 is shown, this by using the historic data until 2019, and after using averages to test and estimate a future behavior, the result is an increase of all the sectors due to the increase on population, and a necessity to control in this case the emissions and land use. This model behavior portraits the assumption that the demand would keep the same levels, and by this that behavior is being generated, so according to the data and this assumptions, that could be the expected behavior.

What is shown is basically, the increase on chicken and beef production, which leads to the increment on emissions, land use and water consumption, which is a reinforcement of the relation this sectors have to each other, and according to the real system, that is what happens when the production on the beef and chicken sector is increased.

The purpose then for this research is also reinforced by the fact that, by testing different ways of eating, in this case beef or chicken, it could be a way in which the environment is going to be less or more affected, depending on the choices of the population, further on chapter 5 the consideration of the plant base diet is being included.

2. How much would the emissions will reduce or increase if population demands less beef and compensate with chicken?

On chapter 4 section 4.2 for the behavior validity, the tests 1 and 2 address this question in specific, the results from test one show that when the total demand of meat from beef and chicken is consolidated, and the beef demand turns into 20% of this consolidation, the emissions are being reduce by switching beef meat for chicken meat.

In the case of test 2, the demand for beef turns into 80% from the total meat demand, and the results show that the emissions are increasing more than the base behavior, in this case the answer to the question is that, when the demand for beef is reduced and switch for chicken, the emissions will reduce, and in the case of this testing, the emissions are being reduce by 40% approximately if compared with the base behavior.

3. What would be the consequences of such changes on the water consumption and land use?

If the demand was to increase for the chicken and decrease for the beef, as shown on test 1, it can be appreciated on figure 19, from chapter 4 - section 4.2.2, that in both cases, the changes are on less water consumption and less land use, which according to the literature, matches on what would be expected to happen if this would happen on the real system, this shows that on this sectors it is also beneficial that the switching is made in order to reduce the impact on the environment.

Chapter 5. Policy Analysis

5.1 Policy aims

The main objective for the policies in this research is to test ways related to the way we eat to reduce the emissions to the environment, since the climate change is becoming more and more important, the way we are eating may help in reducing this (Fanzo & Herrero, 2019).

In order to do that an introduction of policies is needed, in order to change the consumption for products that damage the environment in a bigger way, in this case the policy considers a switching of products, in other words change the beef meat for chicken meat or plant based (crops) instead, in order to reduce the environmental impact being generated by this sectors.

The policy considers an introduction of a tax on carbon foot-print, which is applied to the beef sector, by adding a desired level for emissions from this sector, and by this creating a limitation for the production of beef meat, this limitation represents a switching for the farmers, so that instead of being encouraged to produce beef meat, they will consider options like chicken or crops, to replace the demand that by the tax will be decreasing due to the higher cost on beef meat (United States Department of Agriculture, 2019).

The policy A further analyze on section 5.2, focus on testing this policy by switching beef meat for chicken meat, the policy B further analyze on section 5.3, focus on testing the same policy but in this case the switching is for plant based (crops) instead of beef meat.

5.2 Policy A

As mention before, this policy aims to reduce the emissions by switching beef meat to chicken meat, in order to do this, the assumption is that when a tax on carbon foot-print is installed, the behavior on the demand for beef meat will be reduced, due to the higher price on the beef, and this will lead to a decrease on the demand, and by consequence a requirement for a substitute in order to satisfy the demand for food, this policy considers that the substitute selected is chicken, and shows results for such a change in behavior.

In order to represent this change on behavior, the feedback loop called ¨balancing of the reduction of the emissions form beef¨ is activated (feedback loop shown on figure 14), this means that the tax policy is on, in order to do this the converter ¨beefs not going to be produced due to tax policy¨ is activated with switch 3 (demand sector).

After the tax policy is on, the feedback loop ¨reinforcement of the increment of emissions from chicken ¨is also activated by turning on the converter called ¨beef meat that will be replaced to satisfy the demand due to tax policy¨ with switch 5 (demand sector).

When this 2 converters are on, the policy is working, and the reduction on production of beef meat will be replaced by the increment on production for chicken meat, influencing the behavior of the rest of the sectors such as, demand, land use, water consumption and emissions.

This policy tests 3 values for the desired emissions (converter called ¨desired level¨ on the emissions sector), the values represent how aggressive the tax policy will be, and the values selected for this policy are, A: 54.25 million, B: 108.5 million, C: 162.75 million. The emissions estimated by the base behavior are 217 million on the year 2050, this represents a wanted reduction for the case A: 75%, B: 50%, C: 25%.

Figure 23 shows the behavior results of such tests, the color correspondence is as follows:

- Blue: Base behavior

- Red dotted: Policy A
- Pink dotted: Policy B
- Green dotted: Policy C

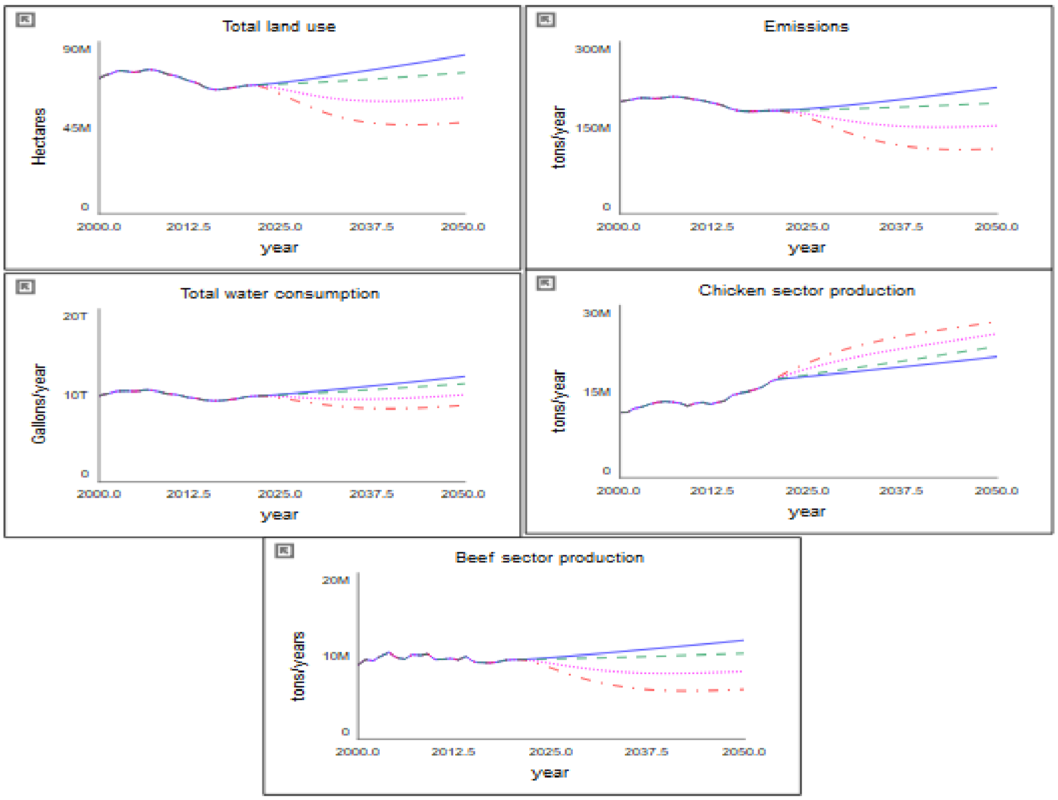

Figure 23. Graphs showing results from policy A testing.

As shown on figure 23, when making the switch for chicken and applying the policy, the environmental impact is reduced, and when the policy increases the aggressiveness, it shows that with more switching, the more beneficial it is to the environment. This means that a change of this type has a high sensitive response from the sectors involved.

On figure 24, the values for the emissions from policy A are shown.

Desired level	Emissions on 2050	Emissions accumulated 2000-2019	Difference from base behavior
Base behavior	221 millions	9.8 billions	-
A	114 millions	7.94 billions	1.86 billions
B	154 millions	8.69 billions	1.11 billions
C	193 millions	9.45 billions	0.35 billions

Figure 24. Results for the emissions behavior on policy A (values are in tones of emissions).

According to figure 24, the best decision when it comes to the emissions, is to take the value A for the policy due to the fact that has the mayor reduction on emissions.

5.3 Policy B

This policy has the same aim as policy A, but instead of making a switch for chicken, the switch is made for plant based (crops), in order to do this, the feedback loop ¨balancing of the reduction of emission from beef¨ (figure 14) is activated again, and now the activation of the feedback loop ¨Reinforcement of the increment on emissions form the plant based (crops)¨ is made by turning on the converter called ¨crops instead of beef¨ with switch 4 on the plant based (crops) sector.

This policy is then evaluating the impact to the environment when using plant based diet instead of beef meat.

Figure 25 shows the behavior results of such tests, the color correspondence is as follows:

- Blue: Base behavior
- Red dotted: Policy A
- Pink dotted: Policy B
- Green dotted: Policy C

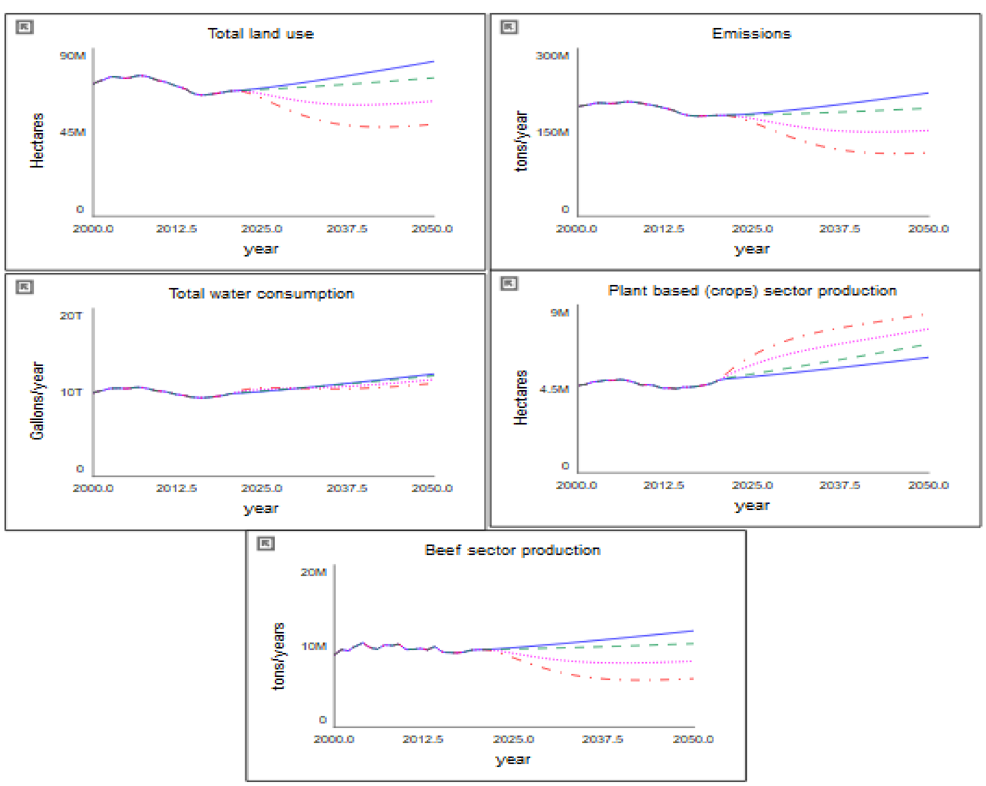

Figure 25. Graphs showing results from policy B testing

After performing the tests for policy B, on figure 25 it's shown that it also has a beneficial impact for the environment to make this switch. There is a decreasing behavior representing less land use, less water consumption and less emissions, this due to the balancing loop ¨balancing of the reduction of emission from beef¨ (lees beef production) and the reinforcement loop ¨Reinforcement of the increment on emissions form the plant based (crops)¨ (more plant based production).

On figure 26, the values for the emissions from policy B are shown.

Desired level	**Emissions on 2050**	**Emissions accumulated 2000-2019**	**Difference from base behavior**
Base behavior	221 millions	9.8 billions	-
A	113 millions	7.92 billions	1.88 billions
B	153 millions	8.68 billions	1.12 billions
C	193 millions	9.44 billions	0.36 billions

Figure 26. Results for the emissions behavior on policy B (values are in tones of emissions).

As shown on figure 26, the values for the emissions are very similar to policy A, this means that when talking about emissions considering the assumptions and data collected for this research, when switching for chicken or plant based (crops), the emissions are very similar. In this case the best desire level is the most aggressive one, option a, because it has a major impact on the reduction of emissions.

5.4 Main insights from policy analysis and testing.

The main insights from the policy analysis and testing are discussed in this section in relations to the research questions 4 and 5.

4. Which way of eating will be more efficient in reducing the emissions (more plant based, more chicken or more beef)?

After performing the testing on both policies, the results show that in the case of the emission reduction, the best way to do it is to make a switch for a plant based diet, this because according to the assumptions and data collected, after changing beef meat for a plant based (crops) option, the emission are reduced meaning that to have a plant based diet is more beneficial to the environment than one that involves beef meat.

5. In the overall picture of all the elements (emissions, land use and water consumption), which diet is the better choice?

In the overall picture the best option is the chicken, this because on the land use and emissions the behavior is very similar to the plant based and much better than the beef, but on the water consumption there is a big difference, the chicken water consumption is much lower than plant based or beef. This means that in the overall of the environmental impact, the chicken generates less impact than beef and plant based, this based on the assumptions and data collected for this model.

Chapter 6. Conclusions and limitations

After analyzing the different policies and testing the behavior of the model in several scenarios, it's clear that in order to reduce the emissions a change in the way in which people eats needs to be done.

In this case, the chicken proves to be an efficient way to reduce the emissions but also to reduce the land use and water consumption. The positive side of it is that if people find it hard to change a meat diet for a plant based diet this is a viable option to do that.

The results also show that the plant based diet is also beneficial to the environment in terms of emissions, land use and water consumption when compared to the beef, this represents another viable option to switch the beef meat which has a higher level of emissions (Ritchie, 2020).

Regarding the limitations of implementing this kind of policies, first of all is the effect on the farmers that produce beef.

They would need to change their type of business in relation to chicken or plant based food production, or producing less beef at a higher sale price in order to try to maintain the same levels of profit. In order to evaluate an implementation of these policies, this is one of the next steps needed for further evaluation.

Another important factor is the approval of the population, due to the fact that the United States is the biggest producer of beef and has a high consumption of it (Ritchie & Roser, Our world in data, 2017); it would take some time to change this behavior and validate its viability.

In regards to question 6; what are the limitations in the system structure of making such changes in order to reduce the emissions?

The need of a structure that validates and evaluates the consequences and changes on the farmers is needed, as well as the validation of the behavior on the population choices based on their preferences and needs regarding the beef meat vs chicken or plant based diet, the model structure used for this thesis could be utilize to be improved in order to make further analysis and adding of structures that will lead to a further research and evaluation of limitations and implications.

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Appendix: model documentation

Two electronic Stella files are attached to this thesis:

- ¨Dif. Way of eating FINAL.stmx¨ which is the complete model built used for this thesis. (all policies and switches are off)
- ¨Dif. Way of eating FINAL.isdb¨

The next pages of this thesis are the remaining model documentation which are arranged in alphabetical order based on the names of the sectors in the model file.

Model documentation:

Top-Level Model:

Population(t) = Population(t - dt) + (Population_growth) * dt {NON-NEGATIVE}

INIT Population = 329064917

UNITS: People

INFLOWS:

Population_growth = Population*Net_fractional_population_growth_rate

UNITS: People/year

Net_fractional_population_growth_rate = .006

UNITS: 1/year

Beef_Sector:

calves(t) = calves(t - dt) + (Breeding - Beef_slaughtering_rate - maturation_to_cows) * dt {NON-NEGATIVE}

INIT calves = 55000000

UNITS: animal

INFLOWS:

Breeding = normal_breeding_rate*effect_of_change_in_demand_on_breeding

UNITS: animal/Years

DOCUMENT: This flow represents the new requirement for breeding for the beef sector, it considers the effect of change in demand times the normal breeding rate (capacity of production)

OUTFLOWS:

Beef_slaughtering_rate =
calves*fraction_to_meat_production/time_to_mature_in_order_to_slaughter

UNITS: animal/Years

maturation_to_cows = calves*(1-
fraction_to_meat_production)/time_to_mature_in_order_to_slaughter

UNITS: animal/Years

DOCUMENT: This flows determines how much calves from the calves stock are going to mature in order to become cows.

cows(t) = cows(t - dt) + (maturation_to_cows - cow_slaughtering_rate) * dt

INIT cows = 29000000

UNITS: animal

INFLOWS:

maturation_to_cows = calves*(1-
fraction_to_meat_production)/time_to_mature_in_order_to_slaughter

UNITS: animal/Years

DOCUMENT: This flows determines how much calves from the calves stock are going to mature in order to become cows.

OUTFLOWS:

cow_slaughtering_rate = cows/average_lifetime_of_a_cow

UNITS: animal/Years

average_lifetime_of_a_cow = 5

UNITS: year

DOCUMENT: This is the average time, a cow spends before being sent into the slaughter house. sourced from: https://www.ers.usda.gov/topics/animal-products/cattle-beef/sector-at-a-glance/

beef_meat_production = (Beef_slaughtering_rate+cow_slaughtering_rate)*meat_per_beef_cattle

UNITS: tons/years

Beef_total_slaughter_rate = Beef_slaughtering_rate+cow_slaughtering_rate

UNITS: animal/Years

calv_per_beef_stock_per_year = 1

UNITS: 1/year

effect_of_change_in_demand_on_breeding = relative_demand_for_beef

UNITS: dmnl

DOCUMENT: This effect represents how much does the breeding needs to increase or decrease according the demand

fraction_to_meat_production = .8

UNITS: 1

DOCUMENT: This converter represents the assumption made in order to satisfy the meat supply and the breeding capacity, it determines how much calves from the stock are being sent to slaughter and how many into the maturation process.

meat_per_beef_cattle = GRAPH(TIME)

(2000.00, 0.3197), (2001.00, 0.3334), (2002.00, 0.3216), (2003.00, 0.3362), (2004.00, 0.3539), (2005.00, 0.3356), (2006.00, 0.325), (2007.00, 0.3383), (2008.00, 0.3389), (2009.00, 0.351), (2010.00, 0.335), (2011.00, 0.3411), (2012.00, 0.3519), (2013.00, 0.3535), (2014.00, 0.3791), (2015.00, 0.3676), (2016.00, 0.3678), (2017.00, 0.3628), (2018.00, 0.3626), (2019.00, 0.3679), (2020.00, 0.3679), (2021.00, 0.3679), (2022.00, 0.3679), (2023.00, 0.3679), (2024.00, 0.3679), (2025.00, 0.3679), (2026.00, 0.3679), (2027.00, 0.3679), (2028.00, 0.3679), (2029.00, 0.3679), (2030.00, 0.3679), (2031.00, 0.3679), (2032.00, 0.3679), (2033.00, 0.3679), (2034.00, 0.3679), (2035.00, 0.3679), (2036.00, 0.3679), (2037.00, 0.3679), (2038.00, 0.3679), (2039.00, 0.3679), (2040.00, 0.3679), (2041.00, 0.3679), (2042.00, 0.3679), (2043.00, 0.3679), (2044.00, 0.3679), (2045.00, 0.3679), (2046.00, 0.3679), (2047.00, 0.3679), (2048.00, 0.3679), (2049.00, 0.3679), (2050.00, 0.3679)

UNITS: ton/animal

DOCUMENT: this is an average from the last 5 years of information 2014-2018, sourced from: https://www.nationalchickencouncil.org/about-the-industry/statistics/per-capita-consumption-of-poultry-and-livestock-1965-to-estimated-2012-in-pounds/

normal_breeding_rate = cows*calv_per_beef_stock_per_year

UNITS: animal/Years

DOCUMENT: This converter represents the capacity for breeding for the beef sector

relative_demand_for_beef = Demand.Demand_for_beef/normal_breeding_rate

UNITS: dmnl

DOCUMENT: This converter considers the actual demand from beef and the normal breeding rate in order to calculate the necessity to increase or decrease the breading, based on the breeding capacity (normal breeding rate)

time_to_mature_in_order_to_slaughter = 2

UNITS: Years

DOCUMENT: This converter is the time a calve spends before being slaughter or going into the maturation process.

sourced from: https://www.pabeef.org/raising-beef/beef-lifecycle

https://foodprint.org/issues/factory-farming-and-animal-life-cycles/

Total_bovine_in_the_system = cows+calves

UNITS: animal

Calorie_intake:

Calorie_intake_per_person_per_year_usa = 839500

UNITS: calories/people/year

DOCUMENT: This is the average considering sex population, age and physical activity. sourced from:

https://health.gov/our-work/food-nutrition/2015-2020-dietary-guidelines/guidelines/appendix-2/

Calories_form_crops_for_plant_based_diet =

"Plant_based_(crops)_Sector".Crops_instead_of_beef*Calories_per_Ha_of_crops

UNITS: Calories/years

"Calories_needed_from_plant_based_instead_of_beef-_tax_policy" =

Demand.Tons_of_meat_from_beef_needed_to_satisfy_the_demand_due_to_tax_policy*Calories_per_ton_of_beef

UNITS: calories/year

Calories_per_Ha_of_crops = 3237485.138

UNITS: calories/Hectare

DOCUMENT: this is based on corn crops, sourced from:

Foods & Nutrition Encyclopedia, 2nd Edition, Volumen 1, page 1104

Calories_per_ton_of_beef = 1890000

UNITS: calories/ton

DOCUMENT: this value is transformed into tones and is obtained from this source:
http://bisoncouncil.com/health-and-nutrition#the-better-meat
Calories_per_ton_of_chicken = 1190000
UNITS: calories/ton
DOCUMENT: this value is transformed into tones and is obtained from this source:
http://bisoncouncil.com/health-and-nutrition#the-better-meat
calories_required =
(Calorie_intake_per_person_per_year_usa*"Percentage_of_Calorie_intake_of_meat_(chicken_and_beef)_per_person_per_year")*.Population
UNITS: calories/year
DOCUMENT: This converter represents the normal calories required by the population, the purpose is for the user to compare and see if the calorie intake requirements are being satisfied.
"Percentage_of_Calorie_intake_of_meat_(chicken_and_beef)_per_person_per_year" = .14
UNITS: dmnl
DOCUMENT: The average percentage of meat form chicken and beef of the entire calories intake, sourced from:
https://www.ers.usda.gov/amber-waves/2016/december/a-look-at-calorie-sources-in-the-american-diet/
https://www.businessinsider.com/daily-calories-americans-eat-increase-2016-07?r=US&IR=T#daily-meat-intake-has-risen-by-almost-100-calories-per-day-per-person-2
Total_calories_form_chickens_slaughtering_per_year =
Demand.Demand_for_chicken*Calories_per_ton_of_chicken
UNITS: calories/year
Total_calories_from_beef_slaughtering_per_year =
Beef_Sector.beef_meat_production*Calories_per_ton_of_beef
UNITS: Calories/years
Total_calories_production =
Total_calories_from_beef_slaughtering_per_year+Total_calories_form_chickens_slaughtering_per_year+Calories_form_crops_for_plant_based_diet
UNITS: calories/year

Chicken_Sector:

Chickens_produced_to_satisfy_the_demand =
((Demand.Demand_for_chicken)*(kilos_that_equal_a_ton/Historic_meat_per_chicken))*testing_overproduction
UNITS: Chicken
DOCUMENT: This converter represents the number of chickens produced in order to satisfy the demand, it consider the historic meat per chicken calculated as per ton, per the number of tons of meat needed in order to satisfy the demand, this gives the number of chickens needed.
Historic_meat_per_chicken = GRAPH(TIME)
(2000.00, 1.9003), (2001.00, 1.9076), (2002.00, 1.9438), (2003.00, 1.9718), (2004.00, 1.9847), (2005.00, 2.0302), (2006.00, 2.0504), (2007.00, 2.0783), (2008.00, 2.1216), (2009.00, 2.1231), (2010.00, 2.1624), (2011.00, 2.2102), (2012.00, 2.2367), (2013.00, 2.2535), (2014.00, 2.2837), (2015.00, 2.314), (2016.00, 2.3403), (2017.00, 2.3516), (2018.00, 2.3658), (2019.00, 2.38), (2020.00, 2.38), (2021.00, 2.38), (2022.00, 2.38), (2023.00, 2.38), (2024.00, 2.38), (2025.00, 2.38), (2026.00, 2.38), (2027.00, 2.38), (2028.00, 2.38), (2029.00, 2.38), (2030.00, 2.38), (2031.00, 2.38), (2032.00, 2.38), (2033.00, 2.38), (2034.00, 2.38), (2035.00, 2.38), (2036.00, 2.38), (2037.00, 2.38), (2038.00, 2.38), (2039.00, 2.38), (2040.00, 2.38), (2041.00, 2.38), (2042.00, 2.38), (2043.00, 2.38), (2044.00, 2.38), (2045.00, 2.38), (2046.00, 2.38), (2047.00, 2.38), (2048.00, 2.38), (2049.00, 2.38), (2050.00, 2.38)
UNITS: kg/chicken/year
DOCUMENT: After the base period (2000-2019), an average is calculated to represent the future behavior.
Sourced from https://ourworldindata.org/meat-production
kilos_that_equal_a_ton = 1000
UNITS: kg/ton
testing_overproduction = 1
UNITS: dmnl
DOCUMENT: This variable is used only for testing the behavior with an over production and exports from the chicken sector.

Demand:
Actual_demand_for_chicken = IF TIME < 2020 THEN (Average_demand_for_chicken_per_person) ELSE Chicken_demand

UNITS: ton/person/year

Actual_per_capita_demand_for_beef = IF TIME <2020 THEN Average_demand_for_beef_per_person ELSE Manual_Beef_demand

UNITS: ton/person/year

Average_demand_for_beef_per_person = GRAPH(TIME)

(2000.00, 0.03061), (2001.00, 0.02994), (2002.00, 0.03062), (2003.00, 0.02939), (2004.00, 0.02989), (2005.00, 0.02966), (2006.00, 0.0298), (2007.00, 0.02948), (2008.00, 0.02817), (2009.00, 0.02758), (2010.00, 0.0268), (2011.00, 0.02581), (2012.00, 0.0259), (2013.00, 0.0254), (2014.00, 0.02445), (2015.00, 0.0244), (2016.00, 0.02563), (2017.00, 0.02581), (2018.00, 0.02595), (2019.00, 0.02631), (2020.00, 0.02626), (2021.00, 0.02621), (2022.00, 0.02626), (2023.00, 0.02631), (2024.00, 0.02636), (2025.00, 0.02641), (2026.00, 0.02646), (2027.00, 0.02651), (2028.00, 0.02656), (2029.00, 0.02661), (2030.00, 0.02666), (2031.00, 0.02671), (2032.00, 0.02676), (2033.00, 0.02681), (2034.00, 0.02686), (2035.00, 0.02691), (2036.00, 0.02696), (2037.00, 0.02701), (2038.00, 0.02706), (2039.00, 0.02711), (2040.00, 0.02716), (2041.00, 0.02721), (2042.00, 0.02726), (2043.00, 0.02731), (2044.00, 0.02736), (2045.00, 0.02741), (2046.00, 0.02746), (2047.00, 0.02751), (2048.00, 0.02756), (2049.00, 0.02761), (2050.00, 0.02766)

UNITS: ton/person/year

DOCUMENT: sourced from: https://ourworldindata.org/meat-production

Average_demand_for_chicken_per_person = GRAPH(TIME)

(2000.00, 0.03474), (2001.00, 0.0346), (2002.00, 0.03633), (2003.00, 0.03678), (2004.00, 0.03805), (2005.00, 0.03873), (2006.00, 0.039), (2007.00, 0.03841), (2008.00, 0.0376), (2009.00, 0.03592), (2010.00, 0.0371), (2011.00, 0.03733), (2012.00, 0.03619), (2013.00, 0.03692), (2014.00, 0.0376), (2015.00, 0.04009), (2016.00, 0.04073), (2017.00, 0.04118), (2018.00, 0.04191), (2019.00, 0.043), (2020.00, 0.04499), (2021.00, 0.04588), (2022.00, 0.04593), (2023.00, 0.04598), (2024.00, 0.04603), (2025.00, 0.04608), (2026.00, 0.04613), (2027.00, 0.04618), (2028.00, 0.04623), (2029.00, 0.04628), (2030.00, 0.04633), (2031.00, 0.04638), (2032.00, 0.04643), (2033.00, 0.04648), (2034.00, 0.04653), (2035.00, 0.04658), (2036.00, 0.04663), (2037.00, 0.04668), (2038.00, 0.04673), (2039.00, 0.04678), (2040.00, 0.04683), (2041.00, 0.04688), (2042.00, 0.04693), (2043.00, 0.04698), (2044.00, 0.04703), (2045.00, 0.04708), (2046.00, 0.04713), (2047.00, 0.04718), (2048.00, 0.04723), (2049.00, 0.04728), (2050.00, 0.04733)

UNITS: ton/person/year

DOCUMENT: sourced from https://www.nationalchickencouncil.org/about-the-industry/statistics/per-capita-consumption-of-poultry-and-livestock-1965-to-estimated-2012-in-pounds/

beef_demand_adj_time = 3

UNITS: years

Beef_meat_that_will_be_replaced_to_satisfy_the_demand_due_to_tax_policy = IF "Switch_5_tax_policy_0_=_no_replacement_check_plant_based_1_=_replacement_of_beef_meat" > 0 THEN Tons_of_meat_from_beef_needed_to_satisfy_the_demand_due_to_tax_policy ELSE 0

UNITS: tons/year

DOCUMENT: This variable is determining the number of beef that would be replaced in order to use chicken instead, due to the tax policy converter.

Chicken_demand = demand_for_meat_of_beef_and_chicken_per_person-Manual_Beef_demand

UNITS: ton/person/year

Consumption_percentage_to_beef = IF TIME > 2020 THEN (IF "Switch_1_0_=_expected_behavior_1_=_manual_beef_consumption" = 0 THEN Percentage_of_average_demand_for_beef ELSE Manual_consumption_per_capita_of_beef_of_the_entire_system) ELSE Percentage_of_average_demand_for_beef

UNITS: dmnl

DOCUMENT: After this converter is on with the switch 1, the condition makes it so that it only operate after the base behavior period (2000-2019), and it considers how much percentage of the total meat demand would be for beef.

Demand_for_beef = ((((.Population*Actual_per_capita_demand_for_beef)/Beef_Sector.meat_per_beef_cattle)-Emissions.Beefs_not_going_to_be_produced_due_to_the_tax_policy)+Test_Normal_overproduction_on_the_United_Sates)

UNITS: animal/Years

Demand_for_chicken = ((Actual_demand_for_chicken*.Population)+Beef_meat_that_will_be_replaced_to_satisfy_the_demand_due_to_tax_policy)

UNITS: tons/year

demand_for_meat_of_beef_and_chicken_per_person =
Average_demand_for_chicken_per_person+Average_demand_for_beef_per_person
UNITS: ton/person/year
Manual_Beef_demand =
SMTH1((demand_for_meat_of_beef_and_chicken_per_person*Consumption_percentage_to_beef), beef_demand_adj_time)
UNITS: ton/person/year
DOCUMENT: This calculation represents the new beef demand, and considers the assumption of a smthn function which represents the delay on the switching for this demand due to the fact that it takes time to change the behavior of the populaiton, this based on the literature, the assumption is if the reason was a new tax policy or something that makes this change to keep it realistic. source: https://economics21.org/html/tax-increases-and-behavioral-responses-298.html
Manual_consumption_per_capita_of_beef_of_the_entire_system = 0
UNITS: dmnl
DOCUMENT: This converter determines the percentage of meat desired for the system after the base behavior period.
Percentage_of_average_demand_for_beef =
Average_demand_for_beef_per_person/demand_for_meat_of_beef_and_chicken_per_person
UNITS: dmnl
Percentage_of_average_demand_for_chicken =
Average_demand_for_chicken_per_person/demand_for_meat_of_beef_and_chicken_per_person
UNITS: dmnl
"Switch_1_0_=_expected_behavior_1_=_manual_beef_consumption" = 0
UNITS: dmnl
"Switch_5_tax_policy_0_=_no_replacement_check_plant_based_1_=_replacement_of_beef_meat" = 0
UNITS: dmnl
Test_Normal_overproduction_on_the_United_Sates = 0
UNITS: animal/years
Tons_of_meat_from_beef_needed_to_satisfy_the_demand_due_to_tax_policy =
Beef_Sector.meat_per_beef_cattle*Emissions.Beefs_not_going_to_be_produced_due_to_the_tax_policy

UNITS: tons/year

DOCUMENT: This calculation represents the tons of meat needed to satisfy the demand due to the tax policy, the calculation is the multiplication of the cattle needed and the weight per cattle.

Emissions:

adj_year = 1

UNITS: year

DOCUMENT: Time to adjust the tax policy implementation

Average_emissions_per_bovine_per_year = 2.7

UNITS: tons/animal/year

DOCUMENT: this is the average emissions coming from cows and calves

sourced from:

https://extension.psu.edu/livestock-methane-emissions-in-the-united-states

Beefs_not_going_to_be_produced_due_to_the_tax_policy = IF

"Switch_3_tax_policy_0_=_normal_behavior_1_=_tax_policy_for_emissions_reduction" > 0 THEN

(IF TIME > 2020 THEN SMTH1(emissions_equivalence_to_beef/adj_year,

Time_do_adjust_the_demand_behavior) ELSE 0) ELSE 0

UNITS: animal/Years

DOCUMENT: When activated, this converter represents the number of beefs not going to be produced due to the tax policy, it considers a smthn function in order to make a delay on the system on the 30 year period, due to the fact that according to the literature it takes to to the population to adapt to such changes.

Source: https://economics21.org/html/tax-increases-and-behavioral-responses-298.html

Desired_level = 162750000

UNITS: tons/year

DOCUMENT: This converter determines the desired level of emissions from the beef sector.

emission_from_Cows_stock = ((Beef_Sector.cows)*emissions_per_cow_per_year)

UNITS: tons/year

DOCUMENT: This calculation represents the emissions generated from cows on the beef sector.

emissions_equivalence_to_beef = Gap/Average_emissions_per_bovine_per_year

UNITS: animal

emissions_from_calves = (Beef_Sector.calves*emissions_per_calve_per_year)

UNITS: tons/year

DOCUMENT: This calculation represents the emissions from calves on the beef sector.

Emissions_from_chickens =

Chicken_Sector.Chickens_produced_to_satisfy_the_demand*Emissions_per_chicken_per_year

UNITS: tons/year

Emissions_from_crops_for_cattle =

"Emissions_per_Ha_of_crops_including_fertilizers_impact_(for_animal_consumption)"*land_use.Land_needed_to_satisfy_the_grain_demand_of_feedlot_1

UNITS: tons/year

DOCUMENT: This calculation represents the emissions from the crops used to feed beef cattle.

Emissions_from_crops_for_humans_and_chicken =

("Plant_based_(crops)_Sector".Crops_used_instead_of_meat_to_satisfy_the_demand+land_use.Land_needed_to_satisfy_the_grain_demand_for_chickens)*"Emissions_per_Ha_of_crops_including_fertilizers_impact_(for_human_consumption)"

UNITS: tons/year

DOCUMENT: This converter calculates the emissions from crops used to replace meat and to feed chickens, the reason is that the type of crop can be the same.

emissions_per_calve_per_year = 1.39

UNITS: tons/animal/year

DOCUMENT: This is the average yearly value of tons of emissions for the calves according to the literature

https://extension.psu.edu/livestock-methane-emissions-in-the-united-states

Emissions_per_chicken_per_year = 0.000285

UNITS: tons/chicken/year

DOCUMENT: Data obtained from an article made by the University Of Georgia

https://extension.uga.edu/publications/detail.html?number=B1382&title=Global%20Warming:%20How%20Does%20It%20Relate%20to%20Poultry?

emissions_per_cow_per_year = 4.01

UNITS: tons/animal/year

DOCUMENT: This is the average yearly value of tons of emissions for the cows on grazing according to the literature

https://extension.psu.edu/livestock-methane-emissions-in-the-united-states

"Emissions_per_Ha_of_crops_including_fertilizers_impact_(for_animal_consumption)" = .335

UNITS: tons/Hectares/year

DOCUMENT: this is based on the crops used for feeding cattle, soybeans in this case, and it shows the impact of emissions considering the fertilizers per Ha, sourced from: http://www.fao.org/3/a-i8275e.pdf

"Emissions_per_Ha_of_crops_including_fertilizers_impact_(for_human_consumption)" = .023

UNITS: tons/hectares/year

DOCUMENT: this is based on the crops used for feeding humans and chicken, corn in this case, and it shows the impact of emissions considering the fertilizers per Ha, sourced from: http://www.fao.org/3/a-i8275e.pdf

Emissions_rate = emissions_from_calves+emission_from_Cows_stock+Emissions_from_chickens+Total_emissions_from_crops

UNITS: tons/year

Gap = IF TIME > 2020 THEN (IF (Total_emissions_from_beef-Desired_level)> 0 THEN (Total_emissions_from_beef-Desired_level) ELSE 1) ELSE 0

UNITS: tons/year

DOCUMENT: Difference form the actual emissions and the desired level of emissions

"Switch_3_tax_policy_0_=_normal_behavior_1_=_tax_policy_for_emissions_reduction" = 1

UNITS: dmnl

Time_do_adjust_the_demand_behavior = 30

UNITS: years

DOCUMENT: This converter represents the 30 years used as the period for the tax policy to make the reduction for the emissions

Total_emissions_from_beef = emissions_from_calves+emission_from_Cows_stock

UNITS: tons/year

Total_emissions_from_crops = Emissions_from_crops_for_cattle+Emissions_from_crops_for_humans_and_chicken

UNITS: tons/year

land_use:

Cows_in_feedlot(t) = Cows_in_feedlot(t - dt)

INIT Cows_in_feedlot = 100000000

UNITS: cows

Ha_to_satisfy_the_feedlot =

land_use_for_feedlot_management_and_production+Land_needed_to_satisfy_the_grain_deman d_of_feedlot

UNITS: ha/years

average_#_of_Ha_needed_per_calves_and_cows = .7284

UNITS: ha/animal

DOCUMENT: This is the average amount of Ha needed to have a cow grazzing. (This number was calculated using this different sources)

https://rethinkrural.raydientplaces.com/blog/how-many-acres-do-you-need-to-raise-cattle

https://ourworldindata.org/land-use

http://www.fao.org/3/ar591e/ar591e.pdf

https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb1167344.pdf

Average_#_of_Ha_needed_per_chicken = 2.25e-5

UNITS: ha/chicken

DOCUMENT: http://www.fao.org/3/y5169e/y5169e05.htm

https://medium.com/new-farmer/square-feet-per-broiler-chicken-f17d47e75bd#:~:text=For%20square%20footage%20required%20per,a%20square%20foot%20per%20bird.

According to the source, it is being consider 4 birds per meter, this to take into consideration the extra space needed for supplies, etc.

average_#_of_Ha_needed_per_cow_to_satisfy_the_feed_lot = .0045

UNITS: ha/cows/year

DOCUMENT: This is the average Ha of land needed to satisfy each cow in a feedlot

https://www.mla.com.au/globalassets/mla-corporate/research-AND-development/documents/beef-cattle-feedlots---design-AND-construction---web2.pdf

Ha_to_satisfy_cattle_breeding =

Land_needed_to_satisfy_the_grain_demand_of_feedlot_1+land_use_for_feedlot_management_a nd_production_1

UNITS: Hectares

Ha_to_satisfy_chicken_breeding =

Land_use_for_chicken_production+Land_needed_to_satisfy_the_grain_demand_for_chickens

UNITS: Hectares

kilos_of_grain_need_to_feed_the_feedlot =

Cows_in_feedlot*Yearly_consumption_of_grain_in_kilos_per_cow

UNITS: kilograms/year

DOCUMENT: This is the amount of kilos of grain needed to feed the feedlot.

kilos_of_grain_need_to_feed_the_feedlot_1 =

Total_number_of_bovines*Yearly_consumption_of_grain_in_kilos_per_cow_1

UNITS: kilograms

DOCUMENT: This is the amount of kilos of grain needed to feed the feedlot.

kilos_of_grain_needed_to_feed_chickens =

Total_number_of_chickens*Yearly_consumption_of_grain_in_kilos_per_chicken

UNITS: kilograms

DOCUMENT: This calculation let us know how much kilos of grans are needed to feed the chickens in the system

kilos_of_grain_produced_per_Ha_of_crops = 45000

UNITS: kilograms/ha

DOCUMENT: The average between crop and hay yearly production per ha

https://www.agry.purdue.edu/ext/forages/rotational/articles/PDFs-articles/calculating-hay-yields.pdf

kilos_of_grain_produced_per_Ha_of_crops_1 = 45000

UNITS: kilograms/ha

DOCUMENT: The average between silage and hay yearly production per ha

https://www.agry.purdue.edu/ext/forages/rotational/articles/PDFs-articles/calculating-hay-yields.pdf

http://utbfc.utk.edu/Content%20Folders/Forages/Hay%20and%20Silage/Publications/sp434d.pdf

kilos_produced_per_Ha_of_crops_corn = 12000

UNITS: kilograms/ha

DOCUMENT: this is the average production of kilos per hectare considering corn needed for the feeding of the broilers.

http://www.fao.org/3/y3557e/y3557e08.htm https://farmdocdaily.illinois.edu/2015/11/international-benchmarks-for-corn-production.html#:~:text=Figure%201%20illustrates%20average%20corn,(159%20bushels%20per%20acre).

Land_needed_to_satisfy_the_grain_demand_for_chickens = kilos_of_grain_needed_to_feed_chickens/kilos_produced_per_Ha_of_crops_corn

UNITS: Hectares

Land_needed_to_satisfy_the_grain_demand_of_feedlot = kilos_of_grain_need_to_feed_the_feedlot/kilos_of_grain_produced_per_Ha_of_crops

UNITS: ha/years

Land_needed_to_satisfy_the_grain_demand_of_feedlot_1 = kilos_of_grain_need_to_feed_the_feedlot_1/kilos_of_grain_produced_per_Ha_of_crops_1

UNITS: Hectares

Land_use_for_chicken_production = Total_number_of_chickens*Average_#_of_Ha_needed_per_chicken

UNITS: Hectares

land_use_for_feedlot_management_and_production = Cows_in_feedlot*average_#_of_Ha_needed_per_cow_to_satisfy_the_feed_lot

UNITS: ha/years

DOCUMENT: This calculation represents the total land needed to satisfy the cow feedlot process

land_use_for_feedlot_management_and_production_1 = Beef_Sector.Total_bovine_in_the_system*average_#_of_Ha_needed_per_calves_and_cows

UNITS: Hectares

DOCUMENT: This calculation represents the total land needed to satisfy the cow feedlot process

TOTAL_LAND_USE = Ha_to_satisfy_cattle_breeding+Ha_to_satisfy_chicken_breeding+Total_number_of_Hectares_from_crops

UNITS: Hectares

DOCUMENT: The total land use that is needed to produce the chicken, beef and crops to satisfy the food demand from the population

Total_number_of_bovines = Beef_Sector.Total_bovine_in_the_system

UNITS: animal

Total_number_of_chickens = Chicken_Sector.Chickens_produced_to_satisfy_the_demand

UNITS: Chicken

Total_number_of_Hectares_from_crops = "Plant_based_(crops)_Sector".Total_Crops

UNITS: Hectares

Yearly_consumption_of_grain_in_kilos_per_chicken = 5.031

UNITS: kilograms/chicken

DOCUMENT: This is the average in kilos needed to produce a broiler, according to the source:

https://www.nationalchickencouncil.org/about-the-industry/statistics/u-s-broiler-performance/

Yearly_consumption_of_grain_in_kilos_per_cow = 1152

UNITS: kilograms/cows/year

DOCUMENT: this is an average calculated based on the daily consumption and converted into a yearly one

http://brandyaddison.blogspot.com/

https://www.mla.com.au/globalassets/mla-corporate/research-and-development/documents/beef-cattle-feedlots---design-and-construction---web2.pdf

Yearly_consumption_of_grain_in_kilos_per_cow_1 = 1152

UNITS: kilograms/animal

DOCUMENT: this is an average calculated based on the daily consumption and converted into a yearly one

http://brandyaddison.blogspot.com/

https://www.mla.com.au/globalassets/mla-corporate/research-and-development/documents/beef-cattle-feedlots---design-and-construction---web2.pdf

"Plant_based_(crops)_Sector":

Adj_time_to_produce_crops = 1

UNITS: year

DOCUMENT: this is based on corn crops, sourced from:

Foods & Nutrition Encyclopedia, 2nd Edition, Volumen 1, page 1104

Calories_needed_from_beef_to_satisfy_the_demand = Tons_of_beef_meat_required_to_satisfy_demand_due_to_tax_policy*Calorie_intake.Calories_per_ton_of_beef

UNITS: calories/year

Crops_instead_of_beef = (IF
"Switch_4_Tax_policy_0_=_no_replacement_check_chicken_1_=_replace_beef_meat_for_crops_(plant_based)" = 0 THEN 0 ELSE
(Calories_needed_from_beef_to_satisfy_the_demand/Calorie_intake.Calories_per_Ha_of_crops))
UNITS: ha/years
DOCUMENT: When activated this converter represents the number of Ha of crops needed in order to replace the beef meat for crops.
Crops_used_instead_of_meat_to_satisfy_the_demand =
(Crops_instead_of_beef)*Adj_time_to_produce_crops
UNITS: Hectares
Hectares_of_crops_used_to_feed_animals =
land_use.Land_needed_to_satisfy_the_grain_demand_for_chickens+land_use.Land_needed_to_satisfy_the_grain_demand_of_feedlot_1
UNITS: Hectares
"Switch_4_Tax_policy_0_=_no_replacement_check_chicken_1_=_replace_beef_meat_for_crops_(plant_based)" = 1
UNITS: dmnl
Tons_of_beef_meat_required_to_satisfy_demand_due_to_tax_policy =
Emissions.Beefs_not_going_to_be_produced_due_to_the_tax_policy*Beef_Sector.meat_per_beef_cattle
UNITS: tons/year
Total_Crops =
Hectares_of_crops_used_to_feed_animals+Crops_used_instead_of_meat_to_satisfy_the_demand
UNITS: Hectares

water_consumption:
Gallons_needed_per_kilo_of_crop_harvested = 75.81738
UNITS: gallons/kilogram/year
Kilos_generated_by_plant_base_diet =
"Plant_based_(crops)_Sector".Crops_used_instead_of_meat_to_satisfy_the_demand*land_use.kilos_produced_per_Ha_of_crops_corn

UNITS: kilograms

Total_water_required_for_beef_meat =

Beef_Sector.Total_bovine_in_the_system*Water_required_per_bovine_per_year

UNITS: Gallons/year

Total_water_required_for_chicken_meat =

"Water_required_per_chicken_(lifetime)"*Chicken_Sector.Chickens_produced_to_satisfy_the_de mand

UNITS: Gallons/year

Total_water_required_for_crops =

water_required_from_crops_to_feed_animals+"water_required_from_crops_(plan_based_diet)"

UNITS: Gallons/year

Total_water_required_for_the_food_production_system =

Total_water_required_for_beef_meat+Total_water_required_for_chicken_meat+Total_water_req uired_for_crops

UNITS: Gallons/year

"water_required_from_crops_(plan_based_diet)" =

Gallons_needed_per_kilo_of_crop_harvested*Kilos_generated_by_plant_base_diet

UNITS: Gallons/year

water_required_from_crops_to_feed_animals =

Gallons_needed_per_kilo_of_crop_harvested*(land_use.kilos_of_grain_need_to_feed_the_feedl ot_1+land_use.kilos_of_grain_needed_to_feed_chickens)

UNITS: Gallons/year

Water_required_per_bovine_per_year = 3500

UNITS: Gallons/animal/year

DOCUMENT: This is the average intake of water of calves and cows, considering weights and climate in the states.

sourced from:

http://www.omafra.gov.on.ca/english/livestock/beef/news/vbn0708a5.htm

https://www.grass-fed-solutions.com/cattle-water.html

"Water_required_per_chicken_(lifetime)" = 3.61

UNITS: Gallons/chicken/year

DOCUMENT: This is the average consumption of the entire life cycle of a broiler chicken, considering its daily water intake per week and per day, this the average of water need to produce one boiler.

sourced from: http://www.poultryhub.org/nutrition/nutrient-requirements/water-consumption-rates-for-chickens/

{ The model has 150 (150) variables (array expansion in parens).

In root model and 8 additional modules with 1 sectors.

Stocks: 4 (4) Flows: 6 (6) Converters: 140 (140)

Constants: 41 (41) Equations: 105 (105) Graphicals: 6 (6)

There are also 10 expanded macro variables.

}