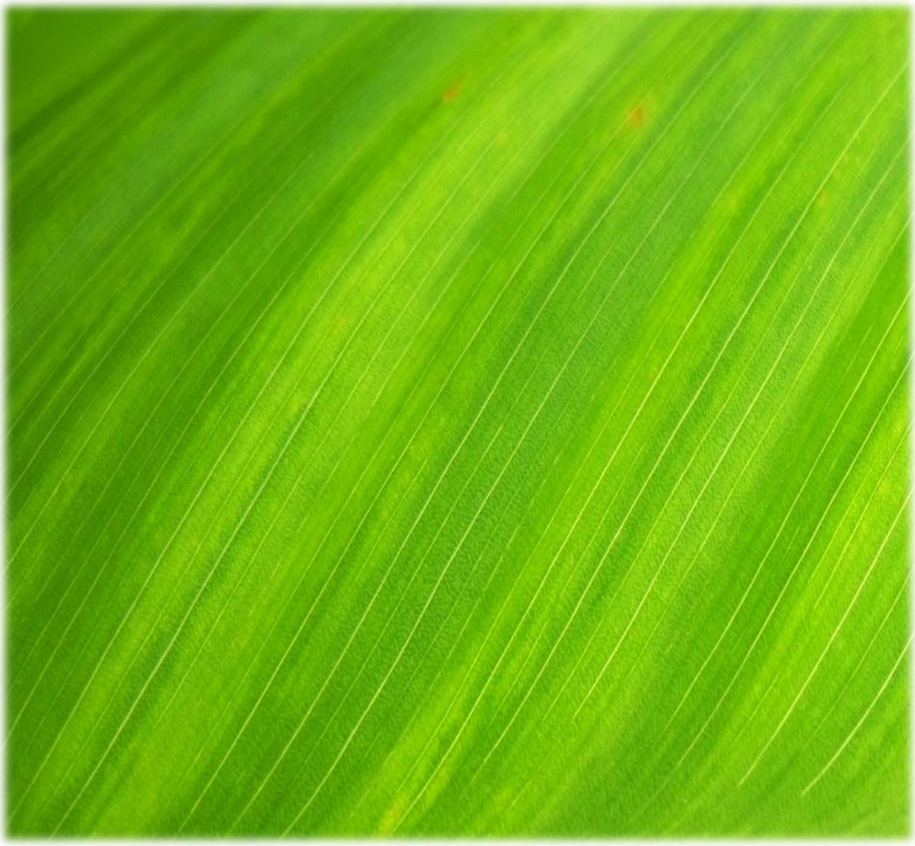
SDG LABS - Harnessing the potential of the social economy for green transformation through the establishment of socially oriented green labs at universities.
Project number 2021-1-PL01-KA220-HED-000032077



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SDG Labs Simulation Models

Thessaloniki & Poznań

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List of Figures

List of Tables

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Table of Contents

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1. Introduction

The purpose of the current document is to report on the development of the SDGLabs simulation models. The structure of the document follows the technical requirements as they were described in the project proposal. These tasks are:

- Design of conceptual and theoretical basis that will provide a firm foundation of how the simulation models work (Chapters 2 and 3 of the current document)
- Design an adapted SDG business model canvas (Chapter 4 of the current document)
- Define the technical specificities for the development of the business simulation models (Chapter 4 of the current document)
- Extract and classify data (best/worst cases) on factors affecting businesses decisions from the case studies and insights from representatives of the SE green business sector (Chapter 4 of the current document)
- Define the main variables of environmental sustainability business decisions in the SE sector that will be used in the models and validate those with the extracted data from the previous task (Chapter 4 of the current document)
- Develop the simulation business models (more than 20) and translation into Interactive Learning Environments (ILEs) (Chapter 4 of the current document)
- Teachers' testing in parallel with the piloting of the capacity building programme
- Finetuning the simulation models and upload them on the project's website (Chapter 4 of the current document)

2. Theoretical Background

The world that we live in is characterized by increasing complexity. Even in the last few years, events transpired that were considered unprecedented in the day we live; see for example the COVID-19 pandemic or the recent war in Ukraine. Thus, the act of designing and implementing policies (either for the public sector or for businesses) is becoming extremely difficult. On top of that there is the ongoing climate crisis, which has real consequences in various aspects of the daily lives of millions of citizens.
To assist policy-makers and managers reach better decisions in the face of such complexity, policy models are being used. Such models could be quantitative or qualitative and are used for various aspects of the policy lifecycle. The policy lifecycle itself consists of 5 steps:

- Identifying a problem
- Designing a policy
- Testing the policy
- Review (Tsaples, Papathanasiou, & Georgiou, 2022); (Tsoukias, Montibeller, Lucertini, & Belton, 2013)

Hence, there are models that are used to evaluate potential policies, to review policies and laws that are already in effect, models that help decision-makers to understand how the system/world really operates etc.
In a general sense, a model can be defined as a representation of part of the reality as seen and understood by policy-makers, analysts or stakeholders that is used to understand, manage or control that specific part of the reality (Pidd, 1997). However, in order for that model to be useful it must provide some insights on how that part of reality behaves or how it will behave in the future (Meadows, et al., 1974); (Duggan, 2016).
Nonetheless, a lot of these models rely on some assumptions that are not representative of the real world. For example, there are assumptions of linearity and equilibria, although it is clear that the world does not operate with such notions (Forrester, 2003). Moreover, the behavior of people more often than not affects how these systems work, hence it affects the potential for success or failure of any given policy. Finally, these complex problems (like the climate crisis) could have long-term consequences that are not easily visualized in the present, which hinders any policy targeted at reducing its effects (Tsaples & Armenia, 2016).
The consequence of all these limitations is that policies face resistance when applied and ultimately fail to deliver their potential. Moreover, there are unintended consequences that might appear and often they make the problem worse than it originally was.
For that reason, there is the need to think of systems (and design policy models in general) that are more holistic and are able to capture all the elements of a system and their interactions fully, while being able to represent in mathematical terms elements of human behavior that are not easily quantifiable.
One policy modeling approach that fulfils those criteria is Systems Thinking and System Dynamics. The purpose of the current document is to provide a description of the methodology with concrete examples and exercises.
Systems thinking is an intellectual approach that assists in looking occurrences/events from a systems and holistic approach. This holistic viewpoint involves the analysis of not only the elements the entity in object is composed of, but also of the relationships between those elements.
To better understand Systems Thinking, it is imperative to define what a system is.

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A system is an interconnected set of elements that is coherently organized in a way that achieves a purpose. Thus, from the definition, it can be assumed that the main characteristics of a system are three:

1) Elements: the entities which make up the system, they represent its fundamental constituents
2) Interconnections: the relationships that link elements between each other. The structure of relationships defines a system as well as its elements: the nature of the system football team doesn't vary even if all the members are changed. If instead interconnections are modified (for example rules are distorted), the nature of the football team changes.
3) Purpose: the objective which associates all the elements. Without a purpose, a system loses its identity (Meadows D. , 2008).

At its core, Systems Thinking is focused on studying systems and their behaviour. To do so, its operational branch was developed in the form of System Dynamics. System Dynamics is a computer-based methodology that facilitates the representation of systems in mathematical terms and assists in understanding the behaviour of systems over time (Sterman, 2000). The main assumption of System Dynamics is that the behavior of a system is largely dependent on its own structure and in order to improve the behavior the structure needs to change (Pruyt, 2013). System Dynamics as a modeling process, offers the opportunity investigate: how the system behaves, which elements can act as potential policy levers, and test these assumption in a consequence-free, virtual environment (Armenia, Tsaples, & Carlini, Critical events and critical infrastructures: A system dynamics approach, 2018).
System Dynamics has two main branches: The qualitative part with the development of Causal Loop Diagrams (CLDs) that serve to illustrate mental models and what are the elements and interconnections of a system and the quantitative part, where the CLD is translated in a series of equations and the model is simulated and experimented upon.

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3. System Dynamics

3.1 Qualitative System Dynamics

A Causal Loop Diagram (CLD) is a combination of causal links between elements of the system under study; it can be seen as a mapping diagram that visualises how the elements of the system interact with each other and how the behaviour of one elements affects the behavior of another. A CLD consists of variables (systemic elements) and arrows/edges (causal relations) that connect the various variables. For example, in Figure 1 below, variable A affects variable B.

Figure 1 Causal Link between two variables

The arrow/Edge that connects two variables does not only provide information about which variables affect other variables, but also what kind of impact this causal relationship represents. In typical System Dynamics notation, a causal link can be of two types:

- Positive. It is marked as + and it means that the two variables change in the same direction. For example, if variable A increases then variable B also increases. Or if variable A decreases then variable B also decreases.
- Negative. It is marked as – and it means that the two variables change in opposite directions. For example, if variable A increases then variable B decreases. Or if variable A decreases then variable B increases.

Apart from the polarity of the arrow (indication of the direction of change), the causal relationship can also illustrate if this change happens instantaneously or after a delay. Time delays are an important aspect of all real-life systems and of course of System Dynamics. At its core, a time delay indicates that the beginning of an action does not coincide with the time of the manifestation of the consequences of that action. For example, the action of turning on a fire to boil water is sooner than the event of the water boiling. Or if we consider governmental policies: if for example, a government increases the income tax of its citizens, the country's revenues will not increase instantly; rather an amount of time will pass before the effects of the increase are seen.
In CLDs, a time delay is indicated with two parallel lines, vertical to the causal link (Figure 2).

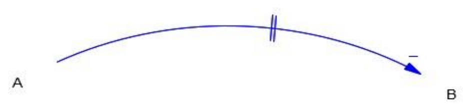

Figure 2 Causal Relationship with a time delay

In the specific example, if variable A increases, the variable B will decrease but after some time t.

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One of the most important aspects of System Dynamics (and Systems Thinking in general) are feedback loops. Feedback loops are closed cycles of interconnected variables (Figure 3).

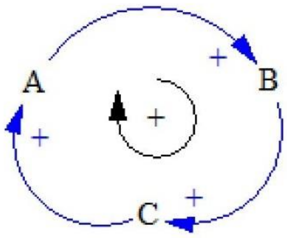

Figure 3 Example of feedback loop

Similar to causal links, feedback loops can be of two kinds: (a) positive and (b) negative. The feedback loop of Figure 3 is an example of a positive feedback loop.
Positive /Reinforcing Feedback Loops: Assume the positive feedback loop of Figure 3. If variable A increases, then variable B will also increase (positive causal link). The increase of variable B will cause an increase in variable C (positive causal link between B and C). The increase of variable C however will cause an increase in the variable A (positive link between C and A), which will enhance the initial increase of A.
Positive feedback loops can also be formed with negative causal links. For example, in Figure 4 assume an initial increase of variable A.

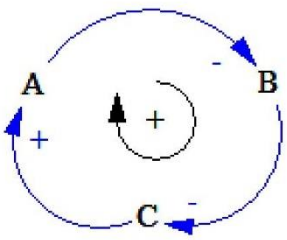

Figure 4 Positive feedback loop with negative links

The increase of variable A will cause a decrease of variable B (negative causal link, which means opposite directions of change). The decrease of variable B will cause an increase in variable C (negative causal link between B and C, which means opposite directions of change for the two variables). Finally, the increase of variable C will cause an increase in variable A (positive causal link, which means similar directions of change) which will enhance the initial increase of A, thus the feedback loop is positive.
The presence of positive feedback loops in systems means that there will probably be an exponential increase or exponential decrease of the behavior of the system, which is not always a good sign for the system's operation. For example, during the COVID-19 pandemic, the system of people who were infected with the virus during a wave increased exponentially.
Negative feedback loop
A negative/balancing feedback loop is form when all links are negative (or when their number is odd). For example, in Figure 5 there is an illustration of two potential negative feedback loops.

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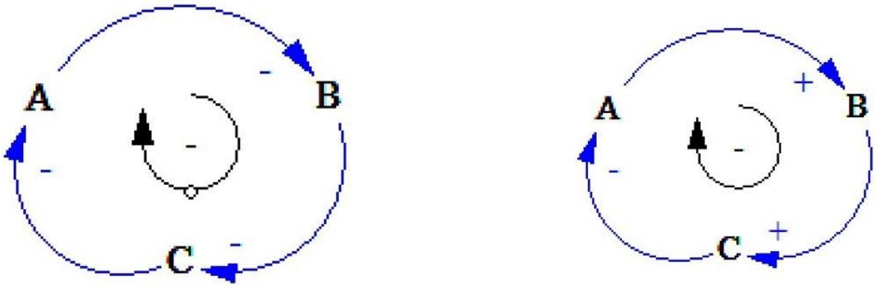

Figure 5 Examples of negative feedback loops

For example, the loop on the left has the following behavior: an initial increase in variable A will cause a decrease in variable B (negative causal link, opposite directions of change between the two variables). The decrease of B will cause an increase in variable C (negative causal link, opposite directions of change between the two variables), which will cause a decrease in variable A (negative causal link, opposite directions of change between the two variables). The final decrease of variable A might be bigger than the initial increase, thus canceling its original, intended effect.

Consequently, a negative feedback loop brings the system to an equilibrium and for that reason they are also called Balancing loops. One typical example of a negative loop is the interaction between a person and their thermostat: if they feel cold they will increase the temperature in the thermostat until the environment reaches a certain temperature. However, if the temperature goes above the desired limit, then the person will feel heat and will lower the temperature in the thermostat until an equilibrium is reached.

These simple structures have been used extensively in the literature to represent and model complex systems.

For example, during the cold war, USA and the Soviet Union proceeded to an arms race because they considered that each country was a threat to the other. Figure 6 below illustrates

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the system of arms race of the two countries.

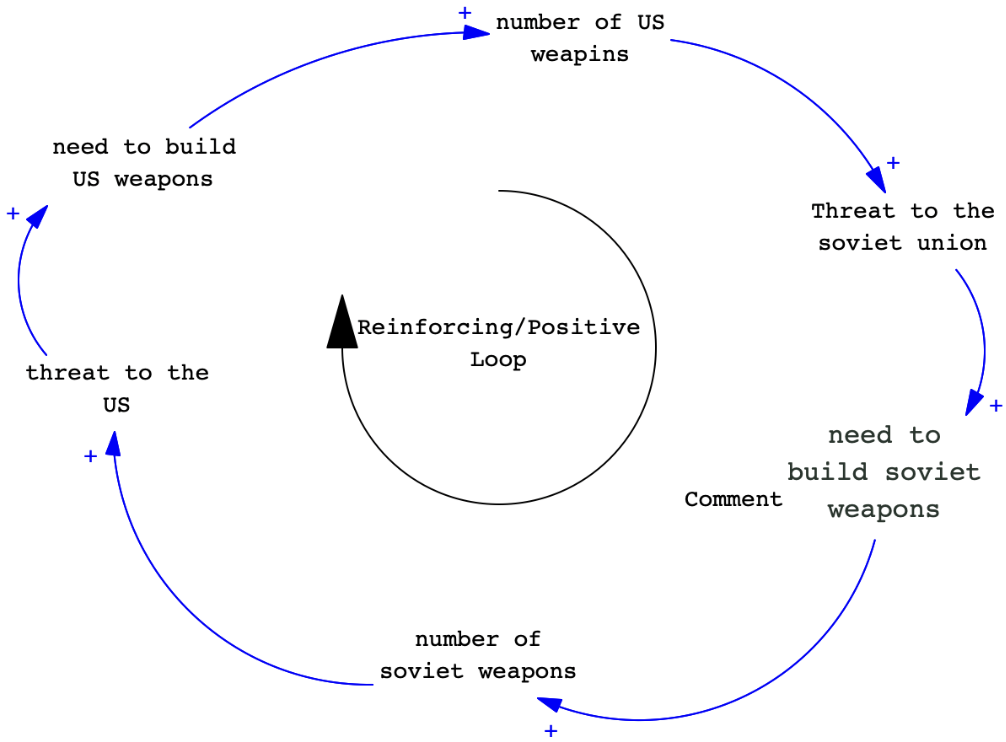

Figure 6 Arms Race positive feedback loop

As it can be observed, the number of US weapons increased the threat that the Soviet Union was feeling. This resulted in the need to construct more Soviet weapons which increased their number. However, the increased number of Soviet weapons increased the threat that the US was feeling, which resulted in their need to increase their weapons. Thus, a positive or reinforcing loop is formed.

Another example can be seen in the paper by Armenia et al. (Armenia, Arquitt, Pedercini, & Pompei, 2022). The authors illustrated how the climate crisis increases the number of forest wildfires, which in turn makes the climate crisis worse.

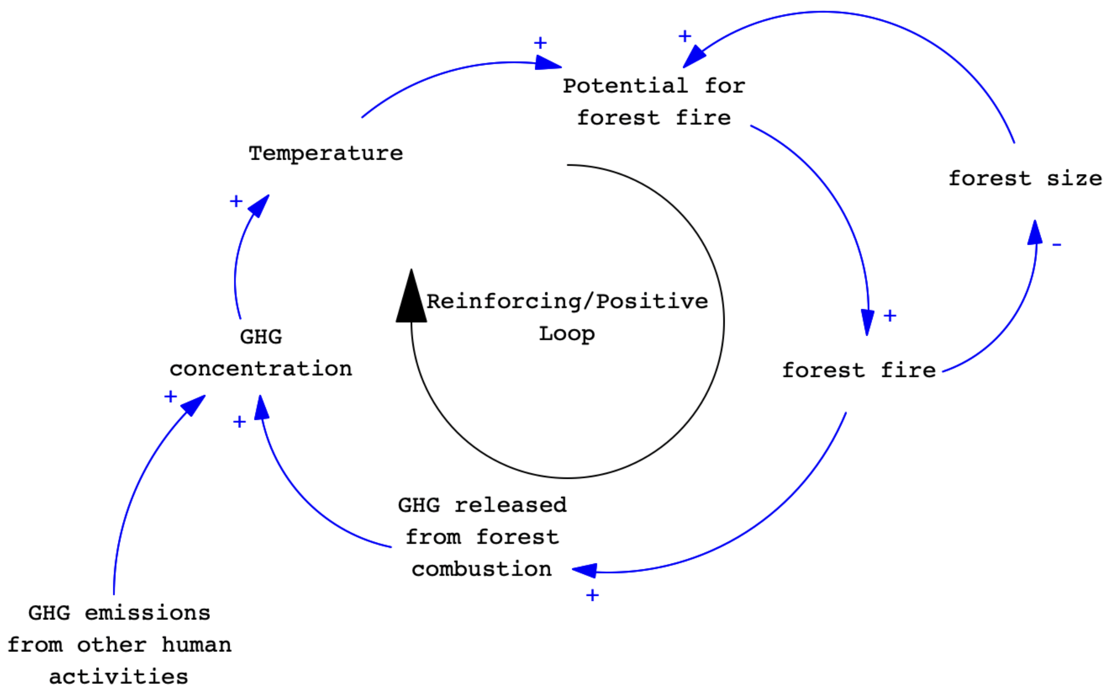

Figure 7 Causal Loop Diagram of forest fires and GHG emissions

The system/Causal Loop Diagram works as follows:

1) Higher temperatures increase the potential for fires
2) More fires increase the GHG emissions
3) More GHG emissions from fires increase the overall GHG concentration
4) More GHG concentration results in higher temperatures
5) Higher temperatures increase the potential for fires

Thus, the main loop is a reinforcing one. However, the Causal Loop Diagram contains another feedback loop which is a balancing one: The larger the number of forest fires decreases (in general) the size of forests, which decreases the potential for future forest fires (since they will not be as much forest).

Most real systems, especially the complex ones, contain more than one feedback loops. Those feedback loops interact with each other and generate complex behavior. Nonetheless, there are common structures and behaviors that are observed in various systems even if they deal with different issues. These are called Systemic Archetypes (Senge, 2006) and the following paragraphs will present the most common ones:

Oscillations

The problematic behavior that arises from a balancing (or negative) feedback loop with delay. It consists of repeated oscillations of a reference variable around a desired equililbrium level.

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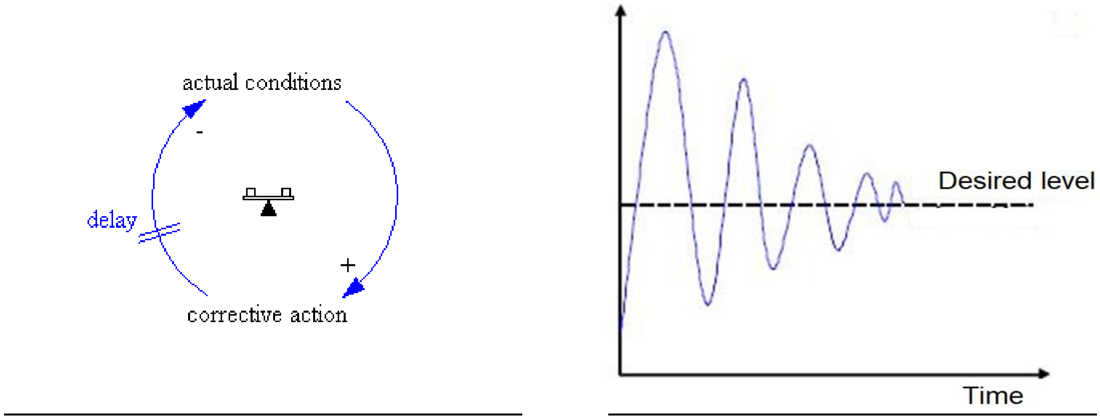

Figure 8 Oscillations Causal Loop Diagram (left) and potential behavior (right)

Limits to growth

The systemic archetype "Limits to growth" consists in the observation of an exponential development of a variable which, at a certain point, turns into an asymptotic growth, which stops and turns into stagnation from which, despite all possible efforts, it is difficult to get out. It is one of the most important systemic archetypes and is formed by the connection of a positive cycle with a negative cycle, on which a limiting condition acts. In particular, if the self-reinforcing cycle prevails first, growth seems to start towards an explosion when suddenly the self-balancing cycle is triggered, resulting in a reversal of the trend and the search for a goal

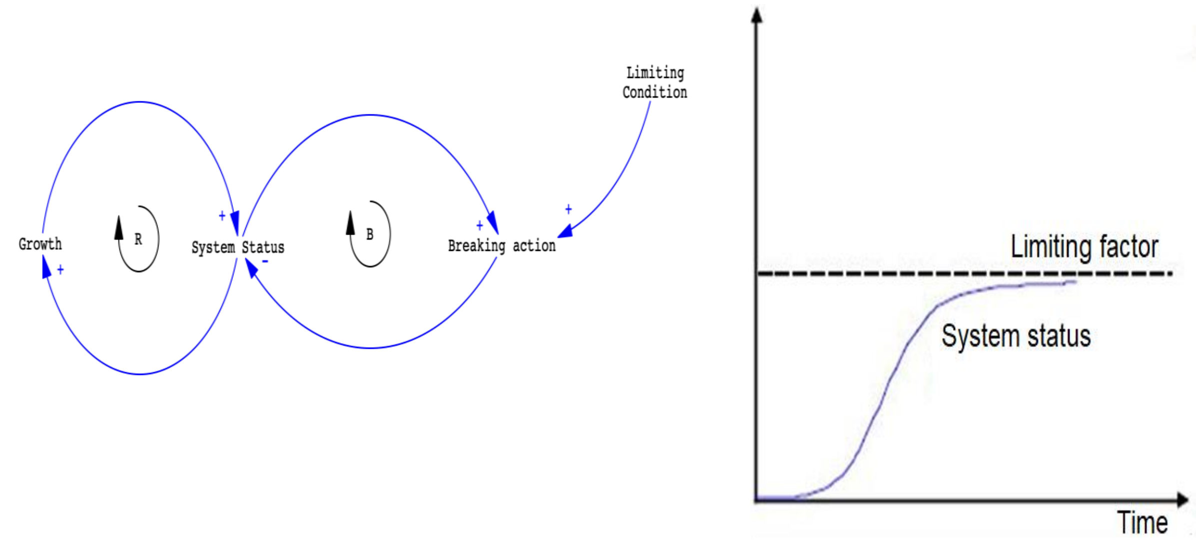

Figure 9 Limits to Growth Causal Loop Diagram (left) and potential behavior (right)

Solutions that fail

The systemic archetype "Solutions that fail" concerns the situations in which the manifestation of a problem is followed by an intervention that at first seems to alleviate the symptoms of the problem but, at a later time, results in a worsening of the situation.
The structure is composed of the aggregation of two feedback loops: a negative one, which represents the conscious adjustment process of the decision-making process aimed at

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eliminating the symptom of the problem; and a positive one, which represents the spontaneous and unwanted consequence that arises from the solution

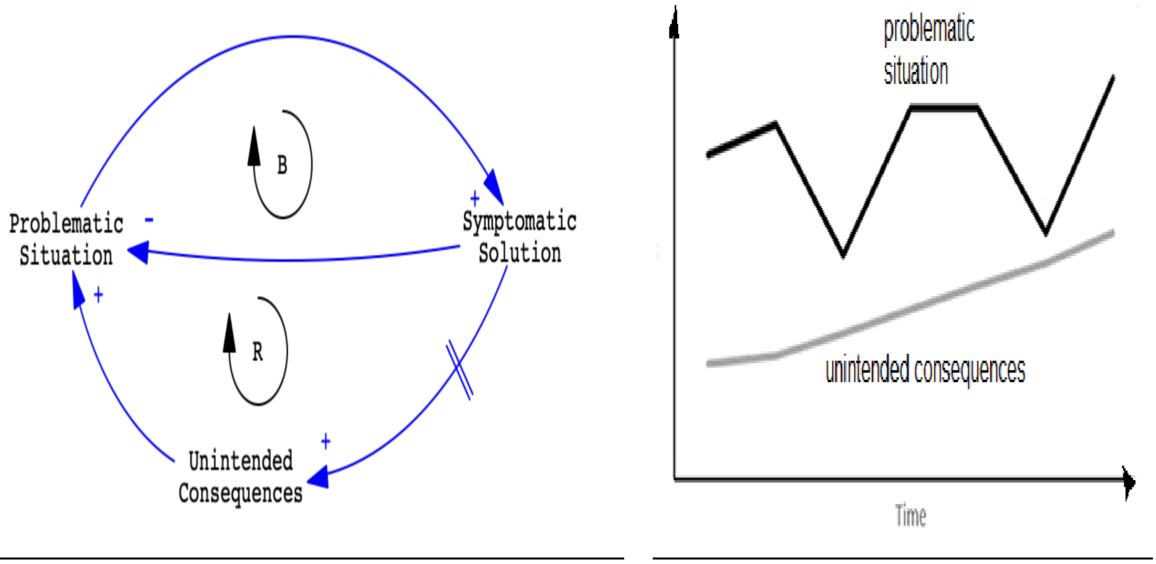

Figure 10 Solutions that fail Causal Loop Diagram (left) and potential behavior (right)

Overshoot and Collapse

The archetype "Overshoot and collapse" is focused on organizations that after growing very quickly, collide with a limit to their growth and the intervention to remove this limit is late and limited, generating, after an exponential growth, a series of oscillations of the observed variable

The structure is composed of the aggregation of 3 feedback loops: one positive, which constitutes the growth engine of the company, and two negative ones, which constitute the limit to growth.

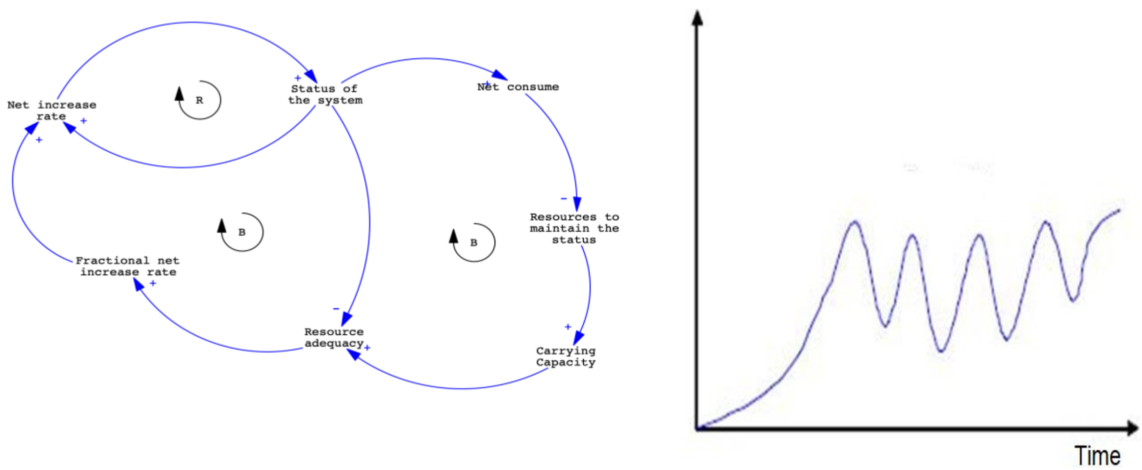

Figure 11 Overshoot and Collapse Causal Loop Diagram (left) and potential behavior (right)

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Success to the Successful

The systemic archetype "Success to the successful" appears when two competing parties fight for the same resources with a product or a service. An initial better position of one of the two results in continuous improvement of its overall position

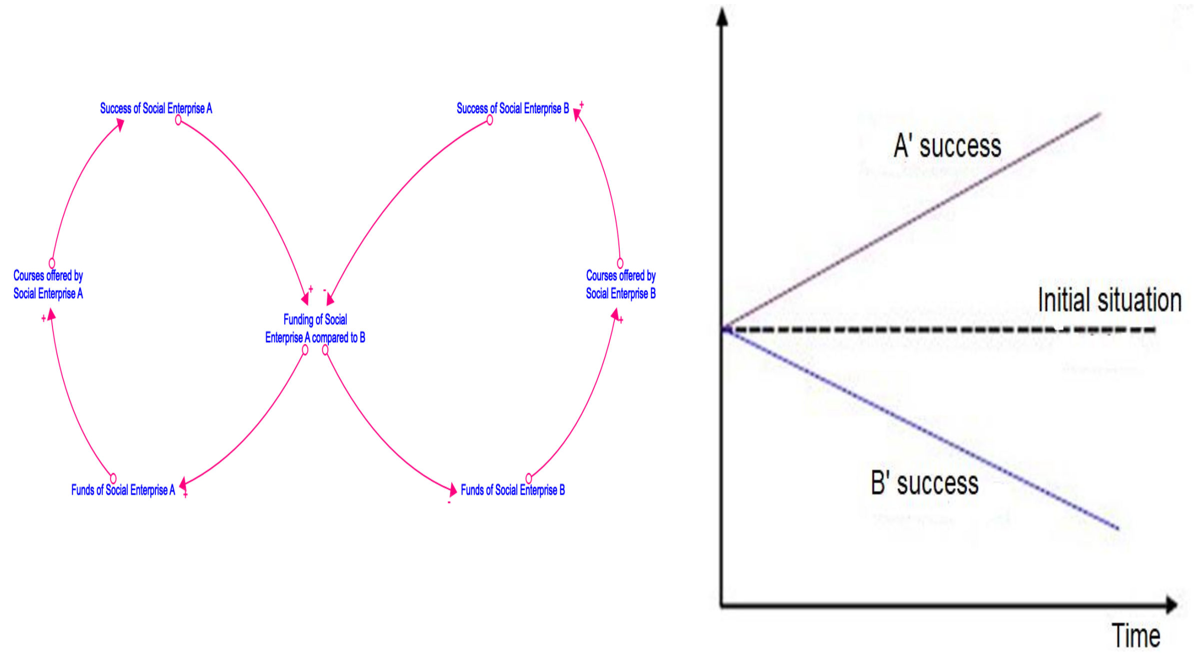

Figure 12 Success to the successful Causal Loop Diagram (left) and potential behavior (right)

For more information on Systemic Archetypes please check the book by Senge (The fifth discipline: The art and practice of the learning organization, 2006) along with the report by Daniel Kim (Kim, 1992).

3.2 Quantitative System Dynamics

However, as it was mentioned above, a Causal Loop Diagram is only a graphical representation of the system under study and cannot be simulated. To simulate such a model, there is the need to transform it in a quantitative System Dynamics model. The main elements of a quantitative model are stocks and flows (Figure 6).

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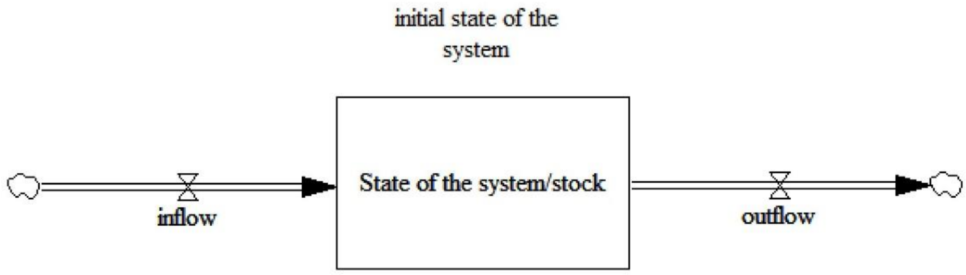

Figure 13 Typical Stock and Flow diagram

A stock represents the state of the system, which increases by the inflow and decreases by the outflow. A stock and its flows can be regarded as a bathtub: the water in a bathtub increases when we open the faucet and decreases when we open the drain. If for example we close the drain and open the faucet, the level of water in the bathtub will increase faster. If consequently, we close also the faucet, the water in the bathtub will not be zero; it will have the latest level (value) that reached before we closed the faucet.
This behavior is represented mathematically with the following equation:

$$State\ of\ the\ system(t) = initialstate\ of\ the\ system(t0) + \int_{t0}^{t} \big(inflow(s) - outflow(s)\big)ds$$

In the context of the current project, the end-users will not have to build quantitative models from the beginning, but could experiment with the SDG Labs simulation models gallery. In those models, there will be Graphical User Interfaces that allow the end-user to experiment with a model without having any mathematical knowledge, apart from an understanding of Systemic Thinking.
A well-known model that allows the user to see the future of climate change is the following: https://en-roads.climateinteractive.org/scenario.html

One famous model that has been modelled and studied extensively under System Dynamics is the Bass Model of diffusion (Bass, 1969). In this model, a simple differential equation explains how products are adopted in a population. In its basic form, the System Dynamics model is presented on figure 14 below[1].

[1] The model was developed in Vensim, and a free version of the software can be downloaded here: https://vensim.com/free-download/

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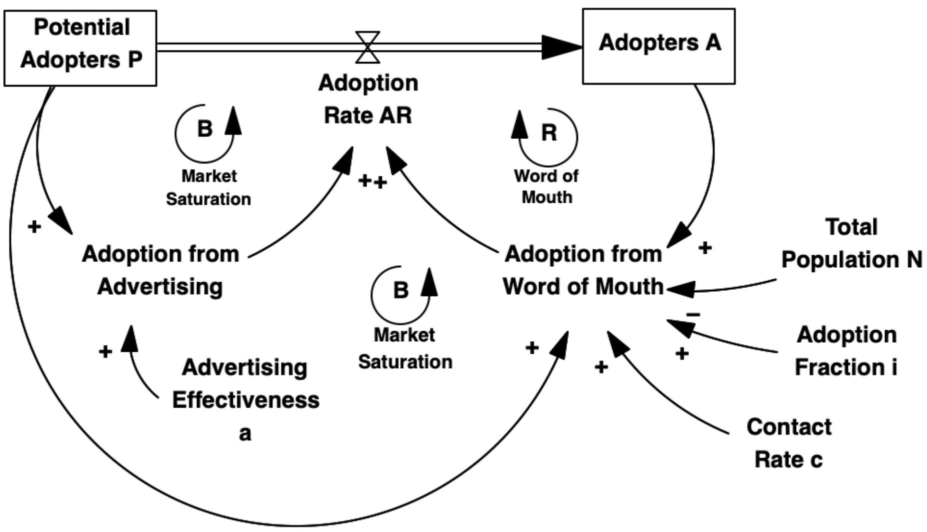

Figure 14 Bass Diffusion Model

There is an initial pool/stock of Potential Adopters (that equals the population under study). This stock empties by the flow Adoption Rate, which is determined by the variables Adoption from Advertising and Adoption from Word of Mouth.

The variable Adoption from Advertising, depends only on the Effectiveness of Advertising, while the variable of Adoption from Word of Mouth depends on the contact rate among the people in the population, the adoption fraction (how many of those contacted actually adopt the product/service) and of course the total population.

The results of this basic model are depicted on Figure 15.

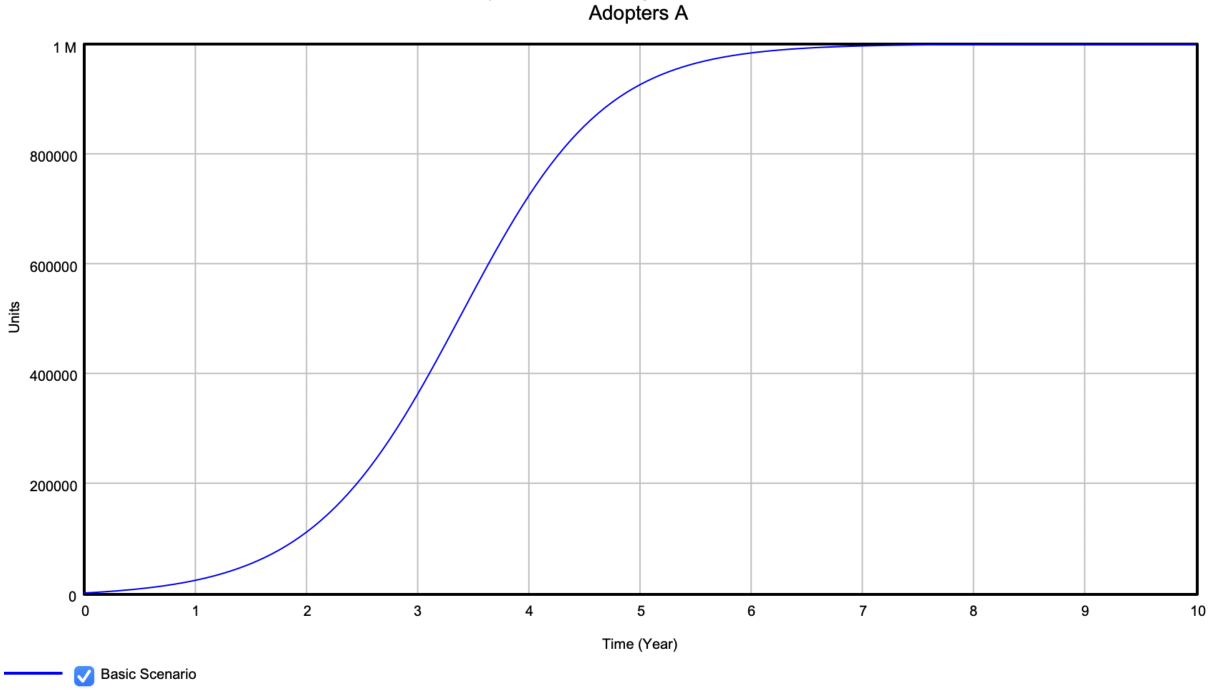

Figure 15 Adopters of the product/service over the entire simulation time

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As it can be observed, the total number of new adopters follows an S-shape: it is 0 at the start of the simulation time, it increases almost exponentially for 4 years, then the increase is slower until year 7 and finally for the last 3 years of the simulation time (7-10) the number remains constant. That means that there are no other potential adopters to adopt the product or service.

This simple model allow the experimentation with different scenarios. For example, we could increase or decrease the value of the variable Advertising Effectiveness and observe the results on Figure 16.

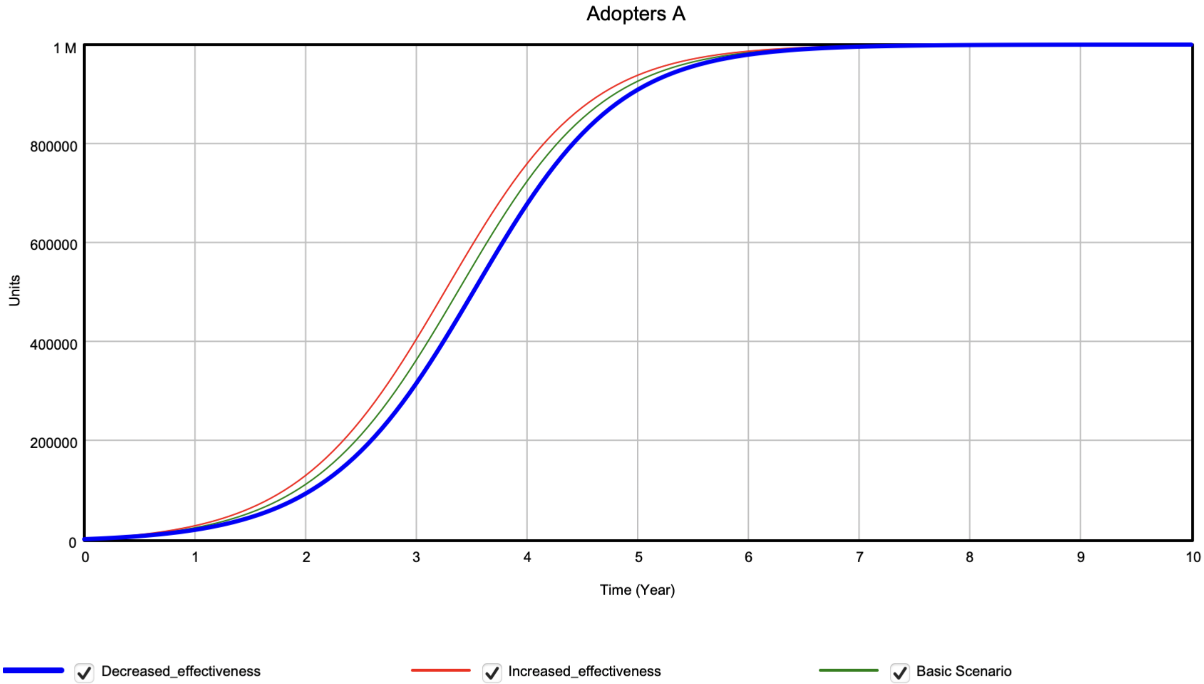

Figure 16 Results with different values of the advertising effectiveness

As it can be expected, the overall behavior does not change (S-shaped). However, with increased advertising effectiveness, the number of adopters is slightly higher at an earlier point in the simulation time, while with a decreased effectiveness the opposite occurs.

As it was stated before, this is the basic form of the Bass model. However, to make it more realistic other variables and structures could be added. For example, a variable could be added that associates cost with the advertising effectiveness. The logic would be that a company/organization could add more money into advertising with the hopes that it increases the adopters of its product/service. However, increasing advertising (and subsequently the cost) is not a linear relationship: constantly increasing the cost does not constantly increase the effectiveness. On the contrary, the relationship could take the form of Figure 17.

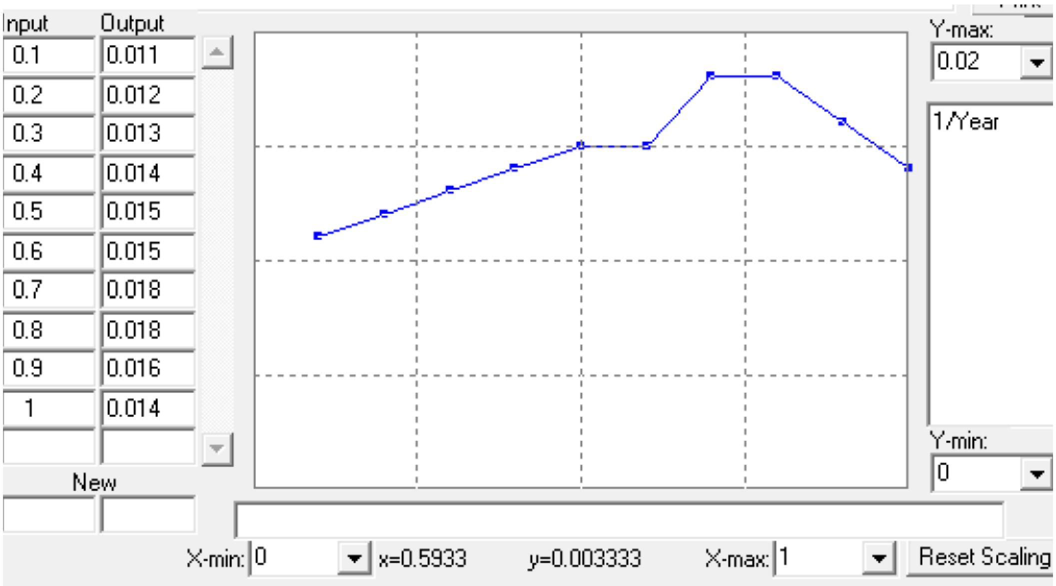

Figure 17 Non-linear relationship between cost and advertising effectiveness

As the cost increases (values from 0.1 to 1 indicating the level of cost), the advertising effectiveness increases, but there is a time when just increasing the cost has the opposite effect: it can be thought of as an oversaturation of advertisements that pushes back potential adopters of the product/service. Hence, the new results for a cost of 0.2, 0.6 and 0.9 are depicted on Figure 18 below.

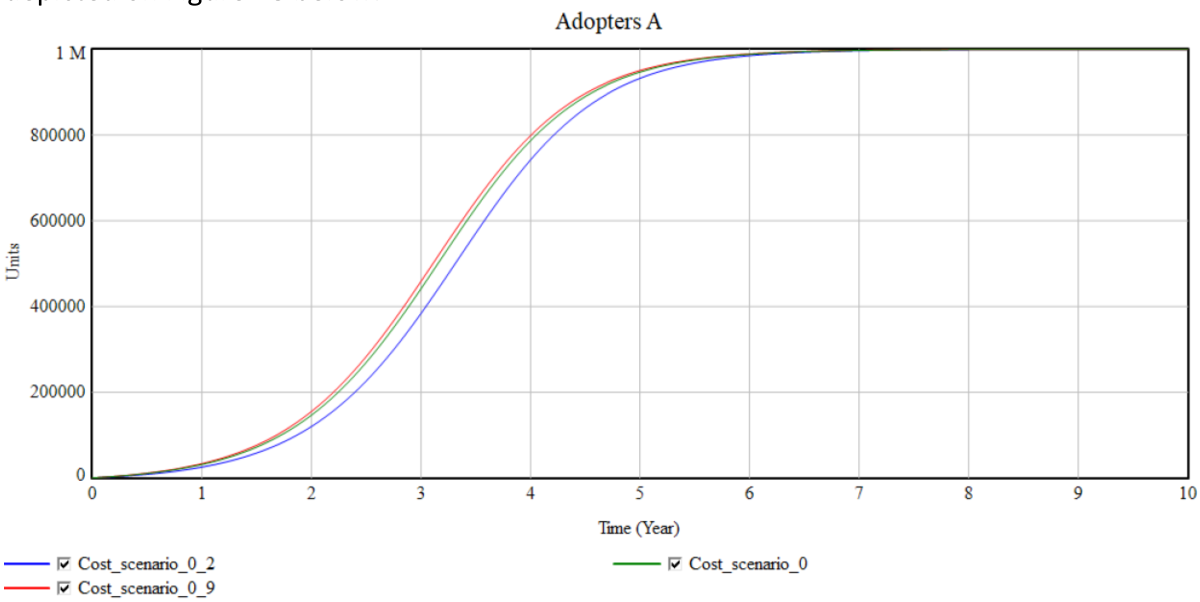

Figure 18 Results for different costs on advertising effectiveness

As it can be observed, increasing the cost for advertising does not alter the results, meaning that in the particular model the advertisement from the word of mouth might be a more powerful incentive to adopt the product/service.
Finally, the model could be expanded even more and take the form of figure 19.

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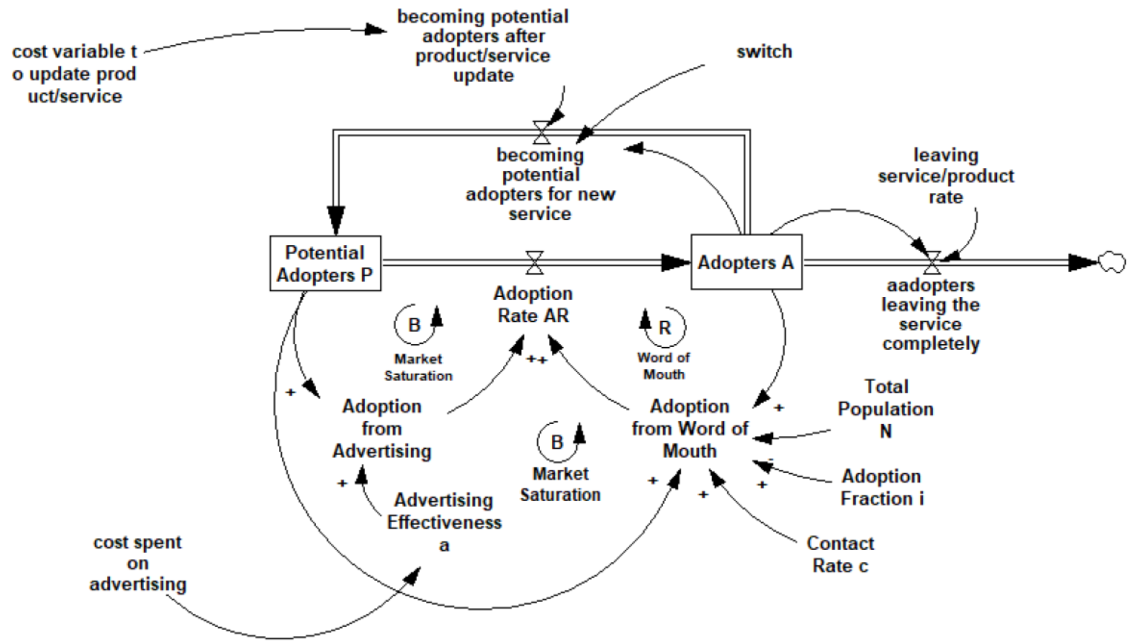

Figure 19 Updated structure of the Bass model

In the updated version, the adopters do not stay in the same state for the entirety of the simulation time: on the contrary, they have the option of abandoning the product service altogether (indicated by the flow "adopters leaving the service completely") or becoming again potential adopters but for the new version of the product/service. That means that the company spends money to update the product/service in time intervals. The higher the cost of the company in that direction, the more willing people will be to adopt the new modified version, however, once again this relationship is not linear but resembles the non-linear relationship of figure 17. With the new structure of the model, the results are depicted on figure 20.

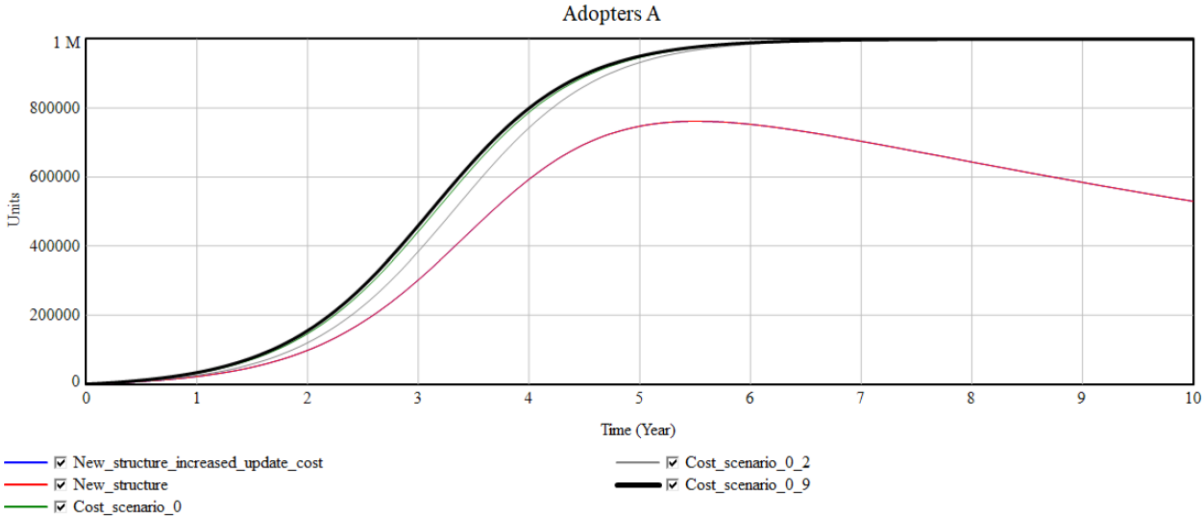

Figure 20 Results for the new model structure

Thus, as it can be observed, the adopters are lower in number, which is not unexpected since there are always people who abandon the product/service and there are people who become again potential adopters that wish to change to the updated product/service. Furthermore, the increase in the cost of updating the product/service does not seem to alter the behavior

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of the adopters significantly. Thus, similar to the cost for the advertising effectiveness, there is a limit to the spending of the companies that could actually yield important, increasing dividends.

Hence, even with this simple model, a decision maker could gain insights on how many people could actually adopt a product/service, and understand how effective advertising could be (or constantly updating the product/service). Such insights could help decision makes in better managing the resources of the company.

In conclusion, Systems Thinking and its operational methodology (System Dynamics) are a formal tool that can help decision-makers to represent a system hence, gaining insights into how potential policies could affect its behavior over time (Quadrat-Ullah & Karakul, 2007). Moreover, System Dynamics allows the integration of "soft variables", meaning variables that are not easily quantifiable, like aspects of human behavior. However, System Dynamics should not be used for point prediction. Rather it is more useful in helping to understand the structure of a system, its direction of change over time, the effect of feedback loops and time delays in potential policies.

3.3 Good practices of System Dynamics

Table 1 below represents when simulation and System Dynamics should be used and when other modeling approaches are more appropriate

Table 1 When it is appropriate to use System Dynamics

Recommended	Other methods might be more appropriate
The system must be evaluated several time under the same conditions	When we want predictions
The system must be evaluated in the presence of rare or risky events and conditions	For problems that can be solved with simpler methods, for example with analytical solutions of mathematical models
We want to make estimates, not easily measurable on real systems	For systems that do not have a systemic nature
	When the cost (and time) of a simulation that provides accurate results is prohibitive

3.4 Additional Resources

Table 2 below summarizes additional, free resources that can be used to gain a deeper understanding on System Dynamics.

Table 2 Resources on System Dynamics

Resource	**Description**
(Kim, 1992)	Document that explains in detail systemic archetypes
https://www.systemdynamics.org/	The official society of System Dynamics practitioners

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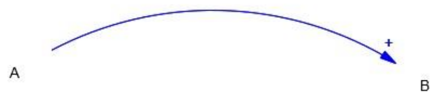
	with plenty of free resources
Vensim, Stella, Powersim, SYSDEA, Forio, Netlogo	Software that can be used for System Dynamics modelling
https://exchange.iseesystems.com/public/barnaf/bass-model-experience	A free simulator to experiment with the Bass model
https://forio.com/simulate/mit/fishbanks/simulation/login.html	A System Dynamics model of the fishing industry. It can be used also as a gaming exercise
https://exchange.iseesystems.com/public/isee/covid-19-simulator/index.html#page1	A simulator about COVID-19
https://forio.com/work/harvard-global-supply-chain-simulation/	A simulator about supply chain management

3.5 Multiple Choice Questions and Project Ideas

Following the theoretical part of the simulation, the students could be asked to answer a series of Multiple Choice Questions to determine whether they have internalized the knowledge or not. Some examples of Multiple Choice Questions are the following (The correct answer is marked in **bold**):

1) Two variables are connected as shown in the figure



If variable A decreases, what will happen to variable B?

- **a) It will also decrease**
- b) It will increase
- c) It will remain constant

2) Two variables are connected as shown in the figure

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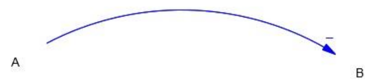
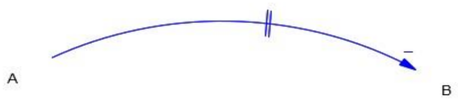


If variable A decreases, what will happen to variable B?

a) It will also decrease
b) It will increase
c) It will remain constant

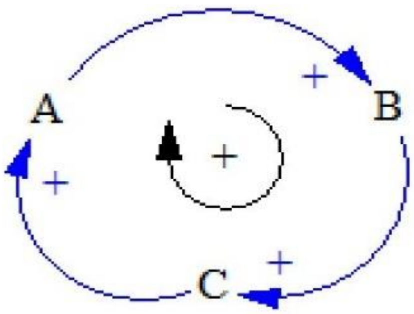
3) Two variables are connected as shown in the figure



If variable A increases, what will happen to variable B?

a) It will decrease
b) It will increase
c) It will remain constant
d) It will decrease after some time t

4) Three variables named A, B, and C form a feedback loop like the one shown in the figure below



How is such a feedback loop called?

a) Positive feedback loop
b) Negative feedback loop
c) None of the above

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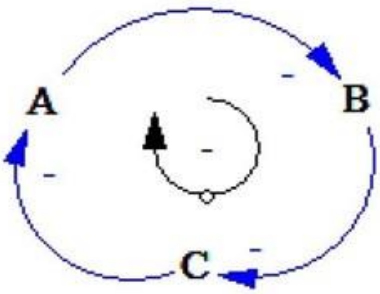
5) In the figure above, if starting from variable A, we increase A, what will be the ultimate result of the loop?

a) Variable B will decrease
b) Variable C will increase
c) Variable A will get a further increase
d) None of the above

6) Three variables named A, B, and C form a feedback loop like the one shown in the figure below



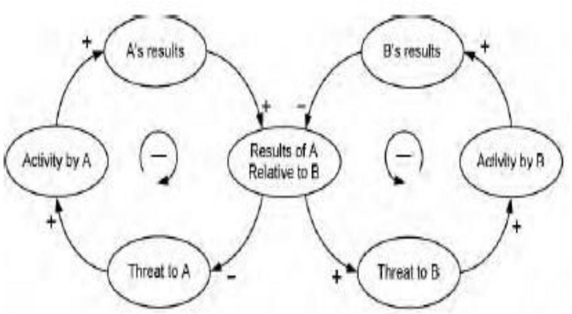
How is such a feedback loop called?

a) Positive feedback loop
b) Negative feedback loop
c) None of the above

7) In the figure above, if starting from variable A, we increase A, what will be the ultimate result of the loop?

a) Variable B will decrease
b) Variable C will increase
c) Variable A decrease, maybe even canceling the initial increase
d) None of the above

8) What is the name of the archetype that is represented by the CLD below?



a) Fixes that fail
b) Escalation
c) Tragedy of the commons

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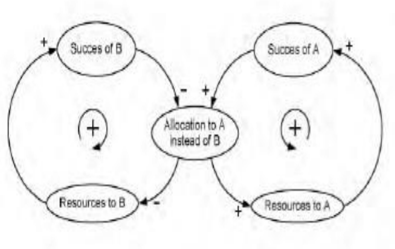
d) None of the above

9) What is the name of the archetype that is represented by the CLD below?



a) Success to the succesful
b) Escalation
c) Tragedy of the commons
d) None of the above

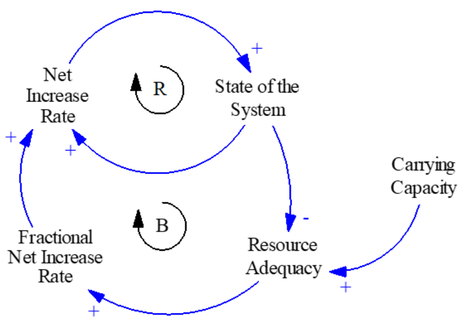
10) How would you describe the system archetype <u>success to the successful</u> to someone who has no knowledge of Systems Thinking?

a) Two parties compete for the same limited resources and even a small advantage results in a more resources being allocated to the most successful party
b) Two or more parties aim for relative advantage over the other
c) Growth is followed after reaching a limit by stagnation and possibly a collapse
d) None of the above

11) Assume that two universities receive governmental funding based on who has the largest number of researchers. These funding is used to hire even more researchers, which makes the university even better in order to receive funding for the next year. Which systemic archetype is described here?

a) Limits to growth
b) Tragedy of the commons
c) Escalation
d) None of the above

12) What do you believe will be the behavior of the system that is represented by the following graph?



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a) Positive feedback
b) Negative feedback
c) S-Shaped growth
d) Oscillations

13) A company has 10 employees/staff and wants to hire more people. For the first 2 years, the hire 2 new persons per year, the third year they hire 5 persons per year and the fourth year they hire no one. During that period no employee left the company. What is the number of employees at year 5?
a) 10 people
b) 12 people
c) 19 people
d) None of the above

14) A company has 10 employees/staff and wants to hire more people. Management has decided to set a goal of hiring 20 extra people in the next 3 years, in other words reaching 30 employees in 3 years. How many people will be hired each year will depend on the actual number of employees that work in the company. Based on that description, what will be the hiring rate behavior?
a) Decreasing
b) Increasing
c) Increasing but with a lower rate as years pass
d) None of the above

15) Global temperature increases due to radiative forcing caused by atmospheric greenhouse gas concentration that is initially driven by anthropogenic greenhouse gas emissions. Higher atmospheric temperatures increase the potential for forest fire making forest fires more frequent, in particular due to climate change induced drought (IPCC,2019). Forest fires release CO_2, increasing GHG concentrations and, hence, global temperature, which further increase the potential of forest fire. What type of feedback loop is the one described?
a) Negative or Balancing Feedback Loop
b) Positive or Reinforcing Feedback Loop
c) Feedback Loop that generates s-shaped behavior
d) None of the above

16) Assume that a city gets its water from a water tank/reservoir. The higher the population of the city the higher the demand for water. As the demand increases, so does the water usage by the citizens which reduces the water level in the tank/reservoir. Assuming that the city suffers from lack of rain and that the citizens do not have any other means of drinking water, the mayor decides that as the water level in the reservoir falls the price of the water must increase which decreases the overall demand. What type of feedback loop is the one described?
a) Negative or Balancing Feedback Loop

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b) Positive or Reinforcing Feedback Loop
c) Feedback Loop that generates s-shaped behavior
d) None of the above

17) A country has a certain Number of researchers and innovators. These people do research and produce a certain Number of scientific papers. These papers after a delay are translated to Devices and services, which give to businesses ideas to create new opportunities to sell these devices and services. Consequently, the Economic activity of the country increases, which means that the country's welfare will increase. An increased welfare means that the funding for research and innovation will increase which will give the opportunity to new researchers and innovators to work. What type of feedback loop is the one described?

a) Negative or Balancing Feedback Loop
b) Positive or Reinforcing Feedback Loop
c) Feedback Loop that generates s-shaped behavior
d) None of the above

18) Suppose that a company wants to reduce the amount of paper that is using for its operations. To do so, they increase the number of electronic devices and services that they use. Thus, the use of an increased number of electronic devices and services reduces the amount of paper. At the same time, the increase in the number of electronic devices and services increases in the short term the cost of the company. Furthermore, to use these electronic devices and services the company must train their employees with appropriate training programs which further increases the cost. Finally, the use of that many electronic devices increases the use of electricity which further increases the cost of the company. Which of the statements below is correct?

a) The main characteristic of the above description is that it contains a positive/reinforcing loop that leads to exponential increase of cost
b) The main characteristic of the above description is that it contains a negative/balancing loop that leads the system to an equilibrium
c) The main characteristic of the above system is that it contains no feedback loops, it is linear and as a result it cannot be considered as a Systems Thinking description
d) None of the above

19) The unit of time in a model concerning the large-scale introduction of electrical vehicles (EVs) is expressed in *month*. The production capacity of a company that produces EVs is modeled as a stock variable with units expressed in *EV=month*. The enormous growth of the expected demand for new EVs leads to an increase of the production capacity of EVs. What unit needs to be used for this increase of the production capacity?

a) $\frac{EV}{month}$
b) $\frac{EV*month}{1}$
c) $(\frac{EV}{month})^2$
d) $\boldsymbol{\frac{EV}{month^2}}$

20) The behavior of a stock variable is expressed by a differential equation?

a) **True**
b) False

21) In Systems Thinking it is assumed that exogenous variables and data determine the behavior of the system under study.

a) True
b) **False**

22) If a feedback loop contains 1 (one) negative link between two of its variables then the feedback loop is considered positive/reinforcing.

a) True
b) **False**

23) In Systems Thinking we are more concerned with the exact prediction of numbers or the precise reproduction of a real world system, rather than understanding how the internal structure of the system can affect its behavior over time.

a) True
b) **False**

24) Complex issues are often characterized by more than one archetype.

a) **True**
b) False

25) During the Cold War, the world's superpowers – USA and the Soviet Union – were engaged in an arms race especially concerning nuclear weapons. The larger the number of nuclear weapons manufactured by USA, the larger the threat that the Soviet Union felt, which made their leaders to order the development of new and more Soviet nuclear weapons to match the USA power. However, the development of Soviet nuclear weapons made the perceived threat to USA greater which forced them to develop even more nuclear weapons. What kind of systemic structure is the one described?

a) Balancing feedback loop
b) Two feedback loops that result in S-shaped growth
c) **Reinforcing loop that leads to escalation**
d) The description does not contain systemic structures

In addition, the students could be asked to do small projects with System Dynamics. The following table provides some topics, along with resources that can be used to start on the small project.

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Table 3 Project Ideas for System Dynamics Models

Project Idea	General Idea	Keywords	Example of papers
Make a CLD of the system of Rare Earth minerals and explain its dynamics	Rare Earth minerals are used in small quantities in a lot of modern devices and applications. Consider a generic mineral and create a model of its system	Extraction of mineral, demand of mineral, average life, processing of mineral etc.	1) Kifle, D., Sverdrup, H., Koca, D., & Wibetoe, G. (2013). A simple assessment of the global long term supply of the rare earth elements by using a system dynamics model. *Environment and Natural Resources Research*, *3*(1), 77. 2) Keilhacker, M. L., & Minner, S. (2017). Supply chain risk management for critical commodities: A system dynamics model for the case of the rare earth elements. *Resources, Conservation and Recycling*, *125*, 349-362.
Fish and ships	Make a model of the fishing system. Consider a generic type of fish and the system of fishermen (think of fishing for whales in the 19th century)	Reproduction of fish, ship creation rate, profits for fishermen, demand for fish etc.	https://mitsloan.mit.edu/teaching-resources-library/fishbanks-a-renewable-resource-management-simulation
Electrical vehicles and lithium	How the introduction of new and more electrical vehicles will affect the lithium resources	Extraction of mineral, demand of mineral, average life, processing of mineral etc.	Alamerew, Y. A., & Brissaud, D. (2020). Modelling reverse supply chain through system dynamics for realizing the transition towards the circular economy: A case study on electric vehicle batteries.*Journal of Cleaner Production*,*254*, 120025.
Freight Decarbonization	Decarbonization strategies have a specific time to take effect, and it is essential to consider their	Fuel consumption, standard of living, travel costs, fleet efficiency	Ghisolfi, V., Tavasszy, L. A., Correia, G. H. D. A., Chaves, G. D. L. D., & Ribeiro, G. M. (2022). Freight Transport Decarbonization: A Systematic Literature Review of System Dynamics

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	time dependence. The system dynamics approach is well suited to represent feedback, lagged responses, and the time dependence of decarbonization strategies.		Models. *Sustainability*, *14*(6), 3625.

4. Simulation Models

In the context of the SDGLabs project, several simulation models were developed using the methodology of System Dynamics. The models are meant to help students understand how various systems work, how they can develop a social enterprise withing these systems and finally, test various policies and investigate the consequences of their actions. This section will illustrate how the development of the models occurred within the context of the project.

4.1 Business Model Canvases

The first action that was to analyse the case studies that were developed in Intellectual Output 2 and create several Business Model Canvases that would assist in deriving the variables and causal relationships for the development of the simulation models. The canvases that were developed were the following:

Habitat for Humanity

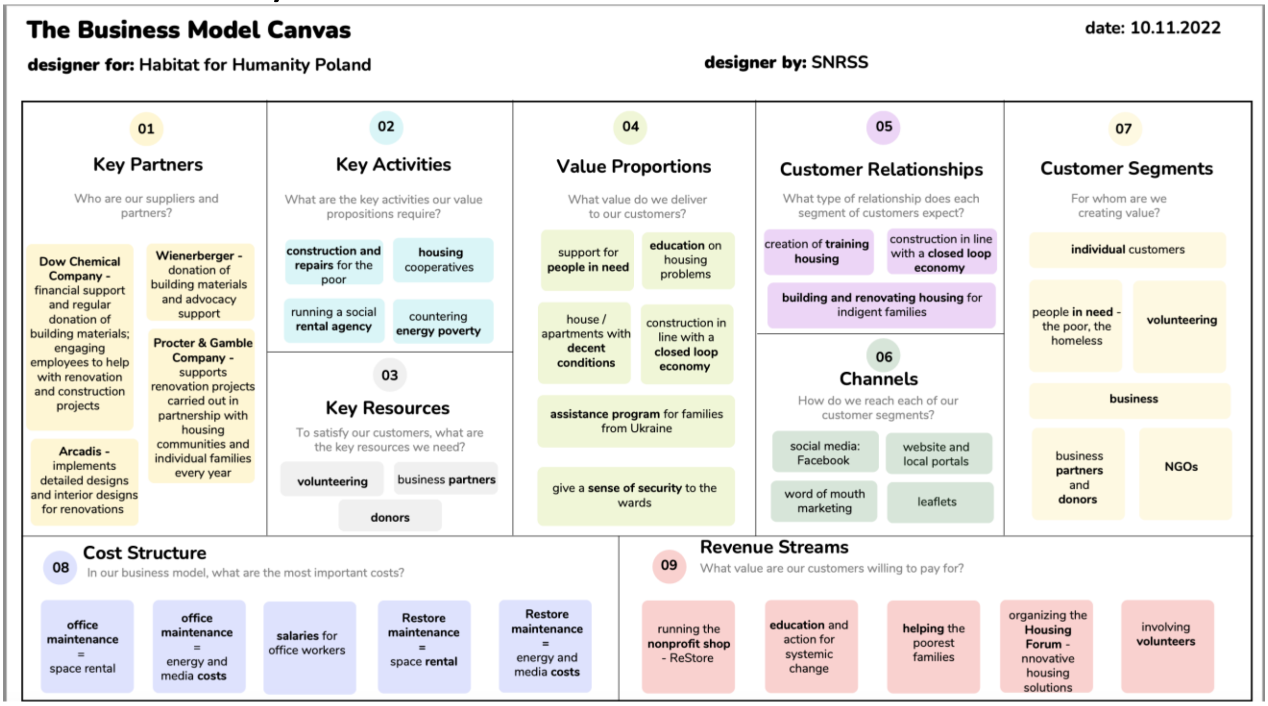

Figure 21 Habitat for Humanity Business Model Canvas

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Fundacja Inspekt

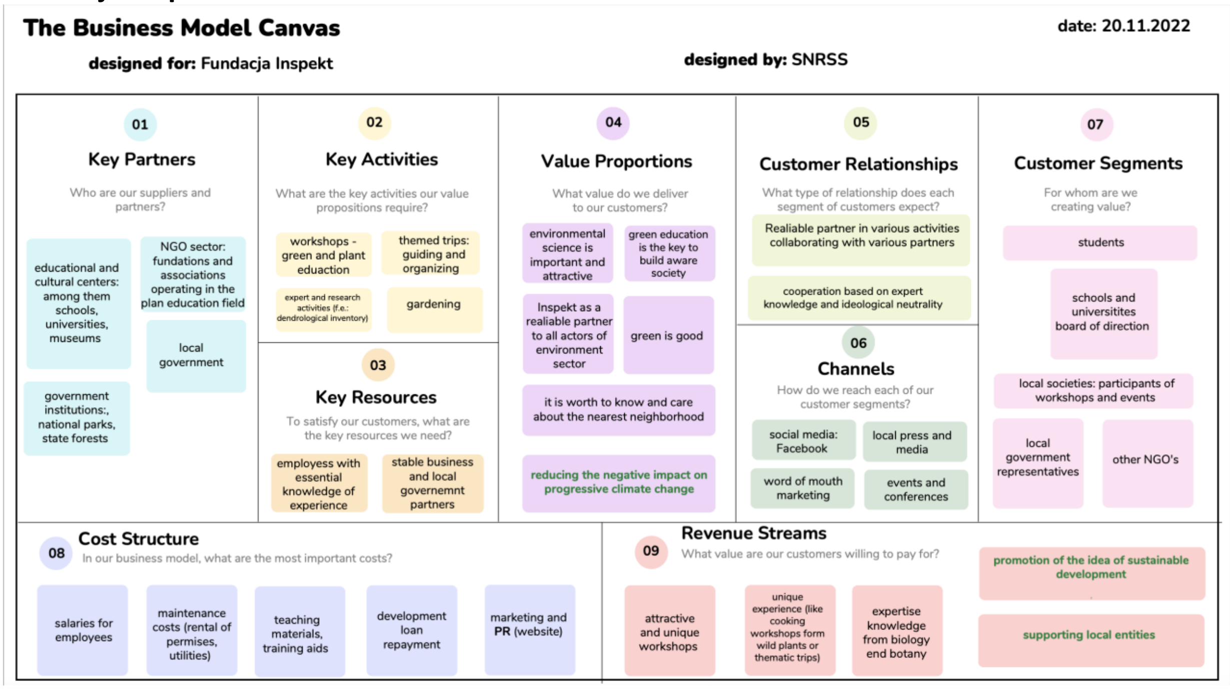

Figure 22 Fundacja Inspekt Business Model Canvas

Spółdzielnia Socjalna Komunalka

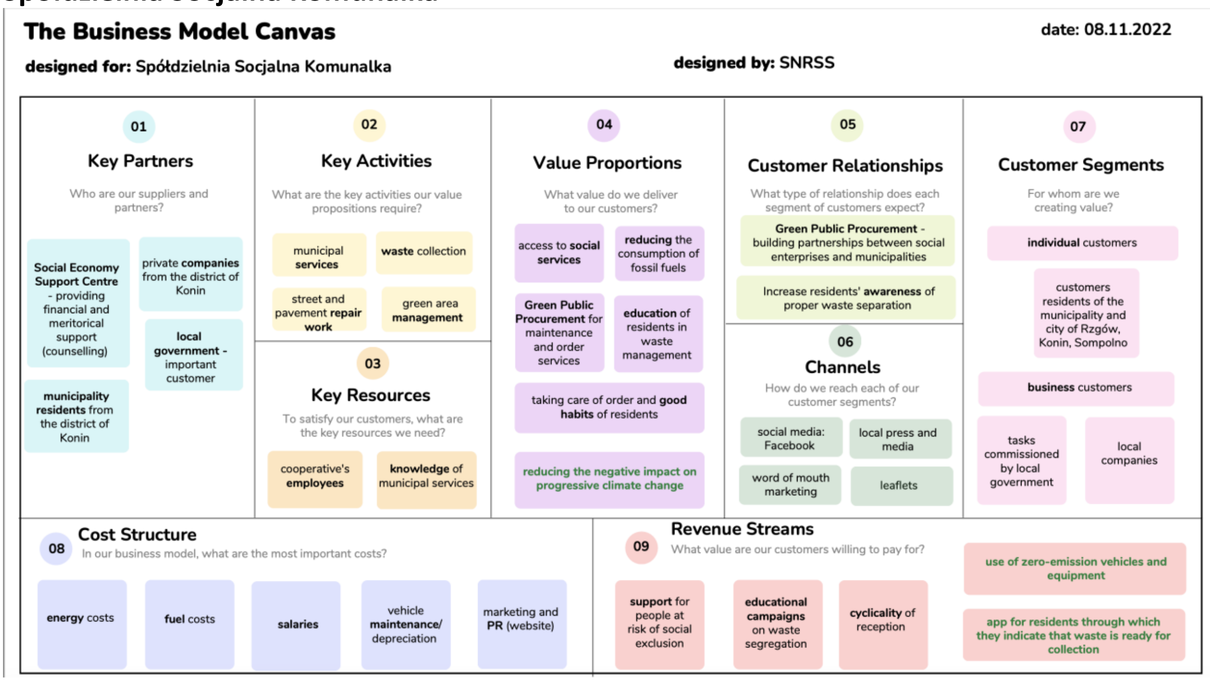

Figure 23 Spółdzielnia Socjalna Komunalka Business Model Canvas

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NRG Solar Foundation

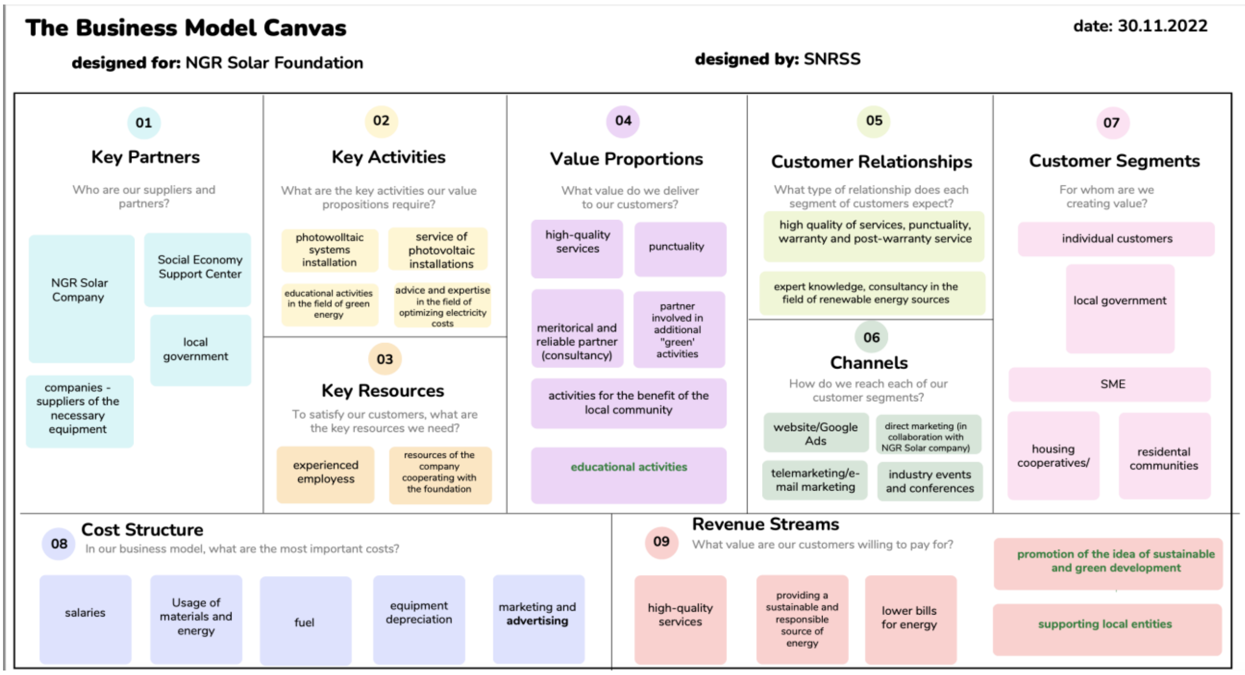

Figure 24 NRG Solar Foundation Business Model Canvas

Spółdzielnia Socjalna Powrócisz Tu / (eng. Come Back here)

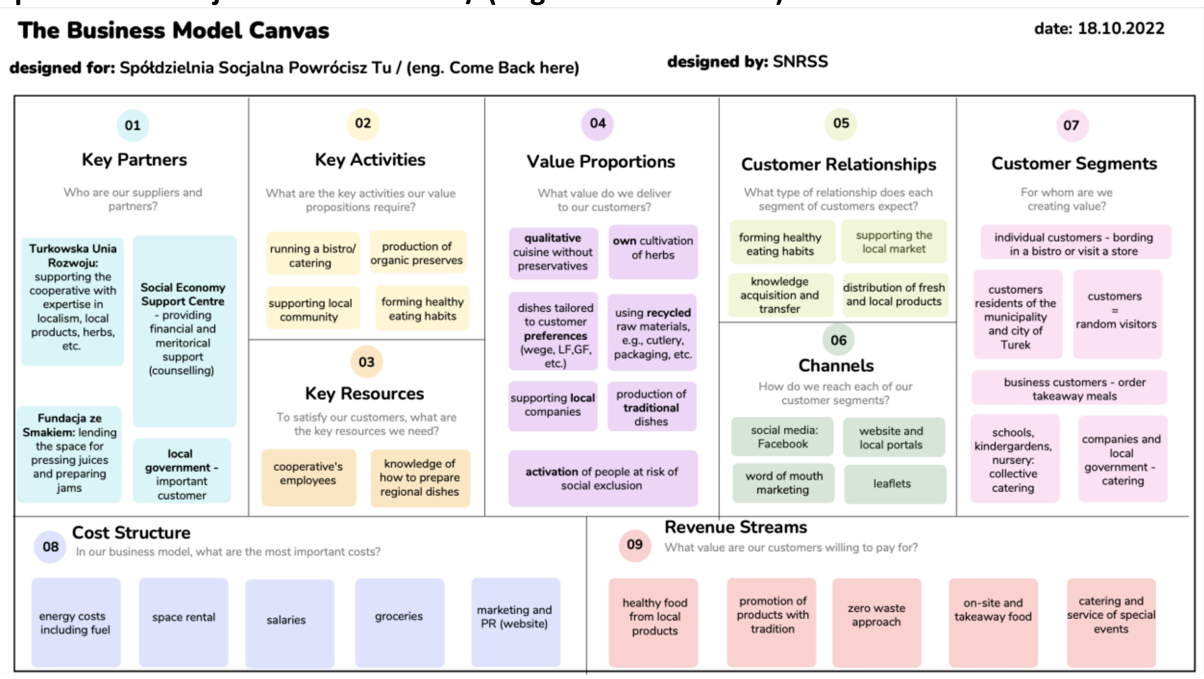

Figure 25 Spółdzielnia Socjalna Komunalka Business Model Canvas

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Social Bistro „Roof"

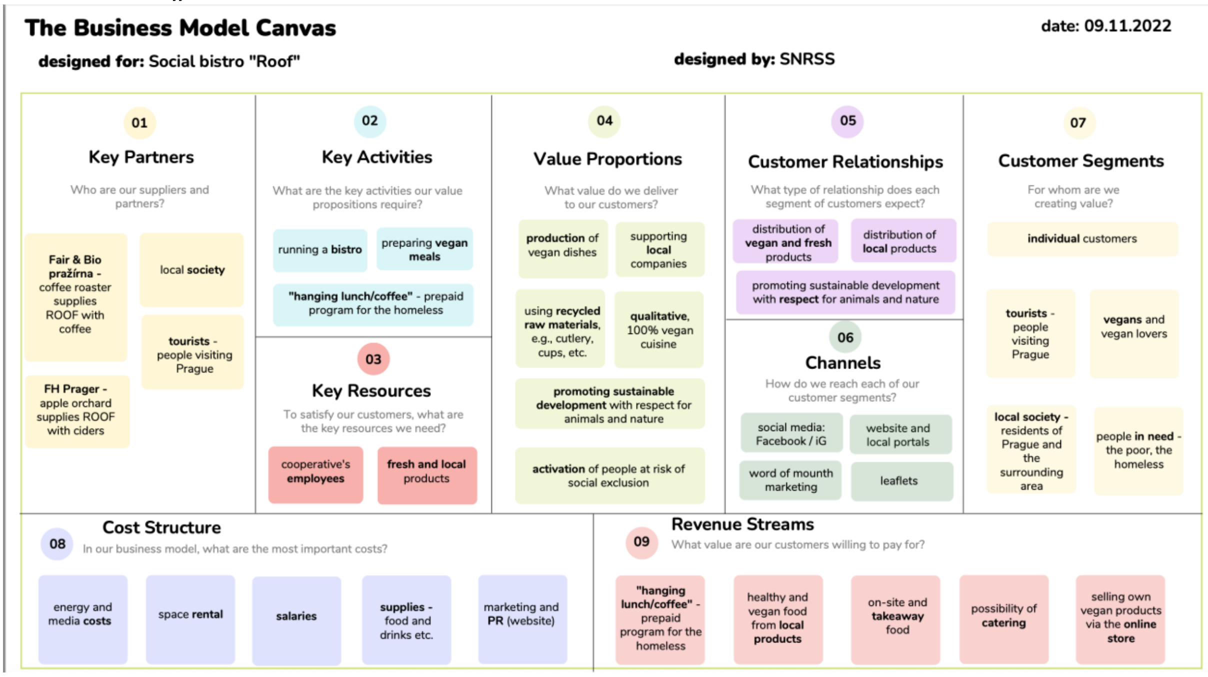

Figure 26 Social Bistro "Roof"

4.2 Data Requirements

In addition to the model canvasses, the partners were asked to gather data regarding several key variables that would help the model development process in two ways: (1) the values could be used in several variables in the models (2) determine a baseline for causal relationships and behaviors that were used as reference in the models.
The data along with their sources are presented in the table below.

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Table 4 Data for Greece

Food waste per country	**Pct of population in poverty per country**	**Pct of Population in danger of social exclusion per country**	**Penetration of renewables in country**	**Number of social housing blocks etc. in the country**	**Number of buildings that were built before 2000 per country/or number of buildings that were modernized (with new insulations, new heatings systems etc.)/ renovated**		**GHG emissions by buildings in the country**	**Number of cooperatives in region/country**	**Number of installed panels in the country**	**Photovoltaic penetration/usage in country**	**Unemployment rate**	
2021	latest entry 2021	2021	latest entry 2020	A stategic plan has been launched	Before 2000	After 2000	2019 (it concerns the emissions for the entire construction sector for 2019. x1000 tonnes)	It concerns agricultural and forest cooperatives	2019 (MWp)	2022 (percentage of pv in the total production of electricity)	2021 (persons)	Greece
191kg/person or 2.048.000 tones/country	29,50%	28,9% in danger of social exclusion or poverty (therefore it might overlap with the previous factor)	21,70%	0	3629130	476507	22.698	1399	2828	14.2%	1100099	
					Reference (https://www.statistics.gr/census-buildings-2011)		(https://www.statistics.gr/el/home?p_p_id=com_liferay_portal_search_web_portlet_SearchPortlet_INSTANCE_3&p_p_lifecycle=0&p_p_state=maximized&p_p_mode=view&_com_liferay_portal_search_web_portlet_SearchPortlet_INSTANCE_3_mvcPath=%2Fview_content.jsp&_com_liferay_portal_search_web_portlet_SearchPortlet_INSTANCE_3_redirect=https%3A%2F%2Fwww.statistics.gr%3A443%2Fel%2Fhome%3Fp_p_id%3Dcom_liferay_portal_search_web_portlet_SearchPortlet_INSTANCE_3%26p_p_lifecycle%3D0%26p_p_state%3Dmaximized%26p_p_mode%3Dview%26_com_liferay_portal_search_web_portlet_SearchPortlet_INSTANCE_3_redirect%3Dhttps%253A%252F%252Fwww.statistics.gr%253A443%252Fel%252Fhome%253Fp_p_id%253Dcom_lifera	reference (http://www.minagric.gr/index.php/el/for-farmer-2/sillogikes-agrotikes-organoseis)	Reference (https://helapco.gr/wp-content/uploads/pv-stats_greece_2019_2Apr2020.pdf)	Reference (https://www.ot.gr/2022/11/17/green/fotovoltaika-pente-rekor-stin-ellada/)	reference (https://www.dypa.gov.gr/storage/statistika-stoikheia/sighkentrotika-ana-etos/sygkentrotikos-pinakas-eggegrammenhs-anergias-gia-to-etos-2021.pdf)	

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Table 5 Data for Poland

Food waste per country	Pct of population in poverty per country	Pct of Population in danger of social exclusion per country	Penetration of renewables in country	Number of social housing blocks etc. in the country	Number of buildings that were built before 2000 per country/or number of buildings that were modernized (with new insulations, new heatings systems etc.)/ renovated	GHG emissions by buildings in the country	Number of cooperatives in region/country	Number of installed panels in the country	Photovoltaic penetration/usage in country	Unemployment rate	
Poland - 5 mln tons/per year / source: Program Racjonalizacji i Ograniczania Żywności (PROM) /Food Rationalization and Waste Program/ 26.12.2021	5,2% - the extent of extreme poverty in Poland in 2020//Statistic Poland	17% (At-risk of poverty of social exlusion rate) source: Data for European Union: EU-27 (from 2020). b Data based on EU-SILC 2019. c Provisional. In: Poverty in Poland 2019-2020/ Statistic Poland	16,3% source: Renewable energy in Poland 2020/Statistic Poland	66 267 - number of dwellings with social rental contracts at the end 2021/ source: Statistic Poland	NA	373 675,391 kt/ whole country in 2020	Poland - 1547 social cooperatives; Greater Poland (region) - 198 //2019 source: Ministry of Family, Labour and Social Policy	around 1,2 mln/ August 2022	2% source: Statistic Poland 2020	Poland - 2,7% in 2022 // souce: Statistic Poland	Poland

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Table 6 Data for Czech Republic

Food waste per country	Pct of population in poverty per country	Pct of Population in danger of social exclusion per country	Penetration of renewables in country	Number of social housing blocks etc. in the country	Number of buildings that were built before 2000 per country/or number of buildings that were modernized (with new insulations, new heatings systems etc.)/ renovated		GHG emissions by buildings in the country	Number of cooperatives in region/country	Number of installed panels in the country	Photovoltaic penetration/usage in country	Unemployment rate	
33,4 kg - 37 kg per person per year https://www.foodnet.cz/cs/aktuality/3789-vyzkum-plytvani-jidlem-je-pro-lidi-v-cr-dulezite-tema-pomaha-pozitivni-motivace	8,1 %, year 2021,https://www.novinky.cz/clanek/ekonomika-prijmova-chudoba-v-cesku-ohrozuje-900-tisic-lidi-40384718	the same as population in poverty	17,3% in 2020, https://www.mpo.cz/cz/energetika/statistika/obnovitelne-zdroje-energie/vyvoj-podilu-obnovitelne-energie--264684	4149 in the end of 2020 (https://www.mmr.cz/getmedia/3b785f5d-3fef-446a-af5f-29413791982e/Koncepce-bydleni-2021_1.pdf.aspx?ext=.pdf)	496940 flats in family and apartment houses were built until 2001 in CR (https://www.czso.cz/csu/czso/13-1131-05-casova_rada-4_2_bydleni)	GHG emissions for households in 2018 in the CR 10,2 %, in total all GHG E 129,39 mil. tons (https://faktaoklimatu.cz/infografiky/emise-cr-detail)	N/A	3116 - only members of associations ,not all, 31.12:2021	41634 solar power station-with 2200MW till end of 2021 in total, https://oenergetice.cz/energetika-v-cr/v-cr-bylo-loni-instalovano-62-mw-solarnich-elektraren-mezirocne-o-petinu-vice	N/A	september 2022: 2,2 % https://www.czso.cz/csu/czso/cri/miry-zamestnanosti-nezamestnanosti-a-ekonomicke-aktivity-zari-2022	Czech Republic

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4.3 Software requirements and Logic of the simulation models

The purpose of the SDGLabs models is to make them available for free for all students and interested users. In addition, the project team decided that the software requirements should be as low as possible so that the models can be accessed and simulated without the barriers that might be imposed with the installation of third-party software. For that reason, the System Dynamics Software Stella Architect was used[2]. In addition, the software provides the option to develop intuitive and easy-to-use Interfaces that can be uploaded in the company's servers and be accessed for free for everyone with the link. Finally, all the models and the user interfaces that were developed have a Creative Commons licence that makes them free for all.

Models 1-5 are focused on repeating core concepts of System Dynamics (like Causal Loop Diagrams) and developing small quantitative models that will help the students to familiarize themselves with how the models work, how they can be simulated, how to experiment with different policy levers etc.

Models 6-11 are relatively more complex models that focus on specific social enterprises that were analyzed with the Business Canvasses. These models introduces economic terms like profitability, price mechanisms, market forces etc. and illustrate to the students how they can affect the sustainability of a social enterprise.

Models 12-17 focus on the housing sector. This models' cycle begins with a Causal Loop Diagram and each consecutive model builds and expands the previous one (adding more and more elements, thus adding more complexity) until the last model of the cycle which introduces a simulated city where spatial zones are also present and there is interactions among population, businesses, road networks etc.

Models 18-21 focus on the energy sector. Similar to the previous cycles, each consecutive model builds upon the previous one. The models cover different areas of the energy sector: from renewable panels to homes, to insulation and energy consumption reaching all the way to country level with energy transitions and the effects of geopolitical events (like the war in Ukraine) on the processes of energy transition.

The following paragraphs contain information on these models and instructions on how they can be used.

4.4 Simulation Models

4.4.1 Models 1 and 2

Models 1-2	**Title:** Bass Model of Diffusion
Link	https://exchange.iseesystems.com/public/georgios-tsaples/bass-model-of-diffusion
Objective	
The objective of the model is for students to understand what is the potential market of a new business and how potential clients can become actual clients. The exercise contains two models: one qualitative and one quantitative. **Qualitative model.** The qualitative model serves a double purpose: first to familiarize students with the concept of Causal Loop Diagrams and second to explain the function of the Bass model of diffusion.	

[2] https://www.iseesystems.com/store/products/stella-architect.aspx

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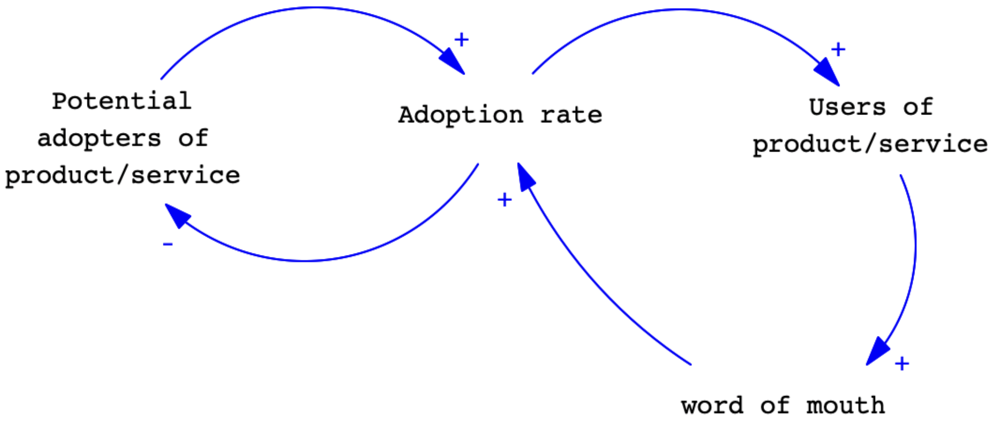

Thus, the qualitative model entails scenario questions, where students are asked to identify the nature of the feedback loops, the type of behavior they could generate and apply this knowledge to an arithmetic scenario.

Quantitative model

The quantitative model translates and updates the typical Bass model of diffusion with the inclusion of new variables that represent cost of advertisement and cost for updating the product/service. The students are given the option to experiment with the quantitative model and gain insights regarding the behavior of the model.

References

Bass, F. M. (1969). A new product growth for model consumer durables. Management science, 15(5), 215-227.

Bassi, A. M., & Lorenz, T. M. (1993). Management flight simulators: Development of a multiplayer, asymmetric, network, ILE. Science, 39(12), 1439-1458.

García, J. M. (2020). Theory and practical exercises of system dynamics: modeling and simulation with Vensim PLE. Preface John Sterman. Juan Martin Garcia.

Lai, M., & Poltera, Y. (2009). Lecture with computer exercises: Modelling and simulating social systems with matlab (p. 27). Technical Report.

Lee, H. J., & Oh, H. (2020). A study on the deduction and diffusion of promising artificial intelligence technology for sustainable industrial development. Sustainability, 12(14)

Pruyt, E. (2013). Small system dynamics models for big issues: Triple jump towards real-world complexity.

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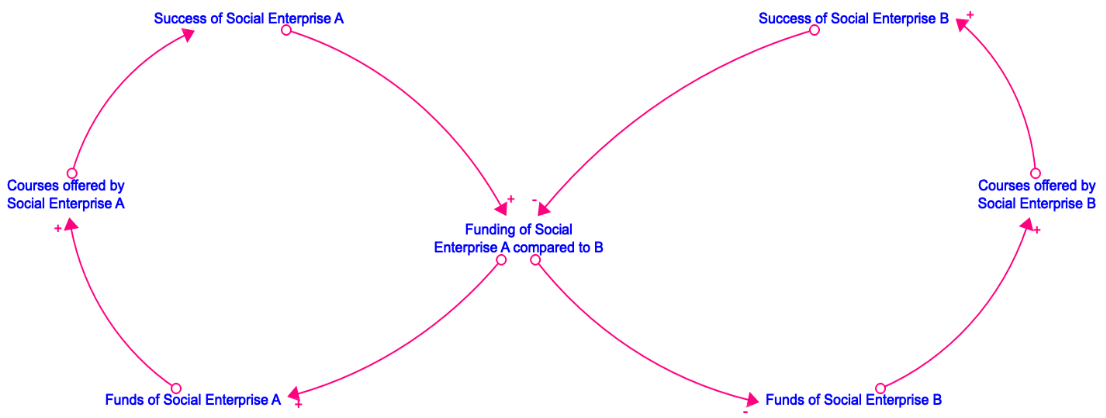
4.4.2 Model 3

Model 3	**Title:** Success to the Successful
Link	https://exchange.iseesystems.com/public/georgios-tsaples/sdglabs-model-3

Objective

The objective of the model is to explain to students how two entities that compete for the same resource (either resource or market share) could become sustainable or fall out of business. There are numerous examples in technological history: ipod vs. zune for example.

The model is qualitative in nature (Causal Loop Diagram) and the students are asked a series of questions regarding the nature and behavior of the feedback loops that are formed.



The particular model is very important because this minimum structure can describe a lot of real-life systems. For that reason, these diagrams are called Systemic Archetypes and the particular one is called: Success to the Successful

References

Kim, D. H., & Anderson, V. (1998). Systems archetype basics. Waltham, Mass, Pegasus Communications Inc.

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4.4.3 Models 4 and 5

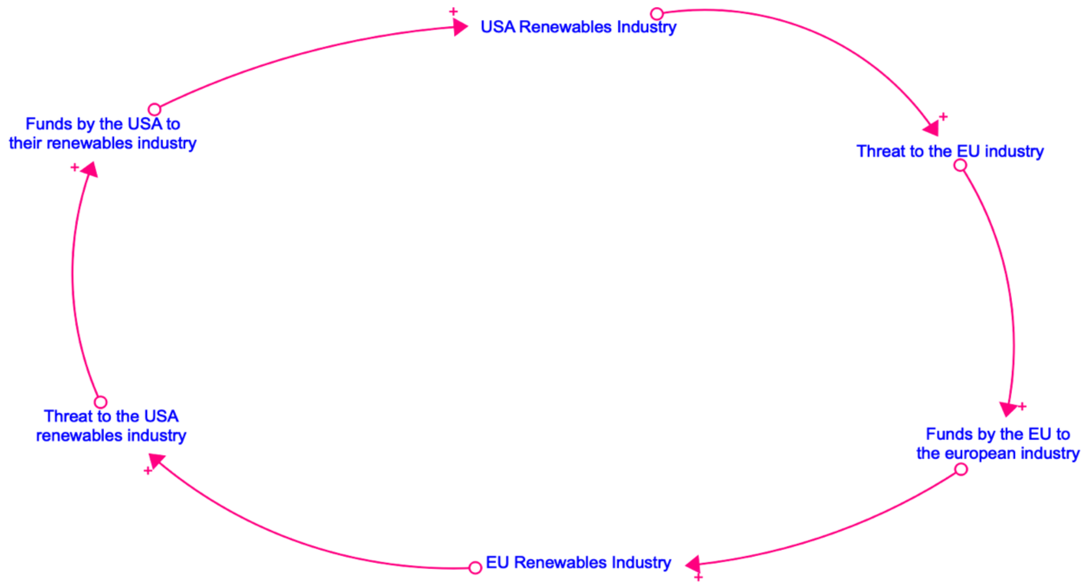
Model 4, 5	**Title:** Escalation
Link	https://exchange.iseesystems.com/public/georgios-tsaples/sdg-labs-models-4-5

Objective

The purpose of the two models is to describe how a systemic escalation can occur. Escalation is a type of behavior where two similar entities attempt to gain an advantage one over the other, very often in detriment to the environment. A characteristic case of escalation was the nuclear proliferation during the Cold War. The exercise contains two models: one qualitative and one quantitative.

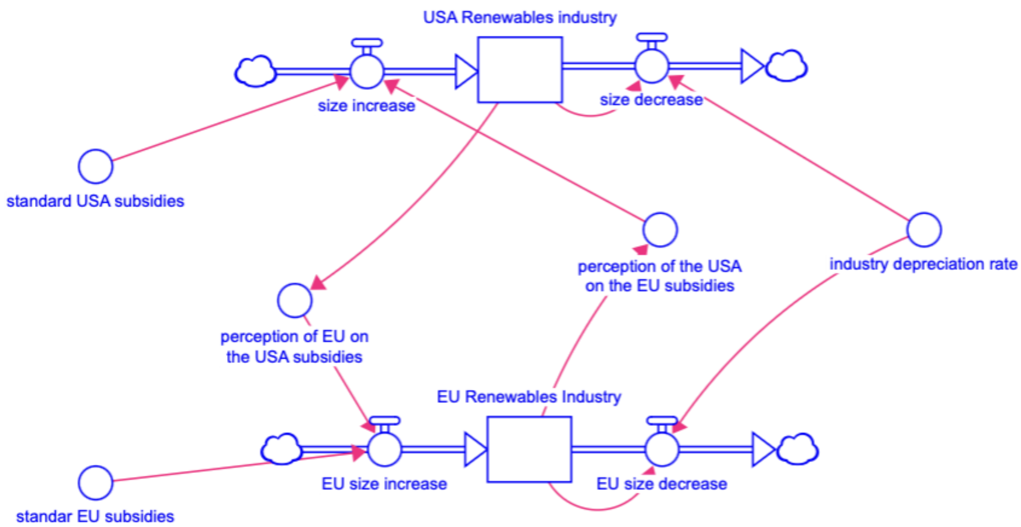
Qualitative Model

The qualitative model describes the systemic behavior of escalation through the recent real-world example of promoting subsidies for the renewables industry in the USA and EU. The model is a Causal Loop Diagram and the students are asked a series of questions to test their knowledge regarding CLDs and what behavior could emerge from such a system.



Quantitative model

The quantitative model translates the CLD into differential equations, which allows the students to observe the behavior of the system over time. In addition, they are allowed to experiment with the intensities of the subsidies for each country (USA- EU) and investigate which country (block of countries) would gain the biggest market share in the renewables industry under different conditions.



In addition, the students are asked a question about how realistic is the particular quantitative model. Answers include: the EU is treated as a homogeneous entity, while it consists of different countries with different industries and characteristics. Moreover, the model does not take into account the ability of a network to absorb the energy that is produced by renewable sources. Finally, the model does not address the issue of land availability, since renewable installations are land-intensive. The model's purpose is for students to understand the dynamics of competition and escalation.

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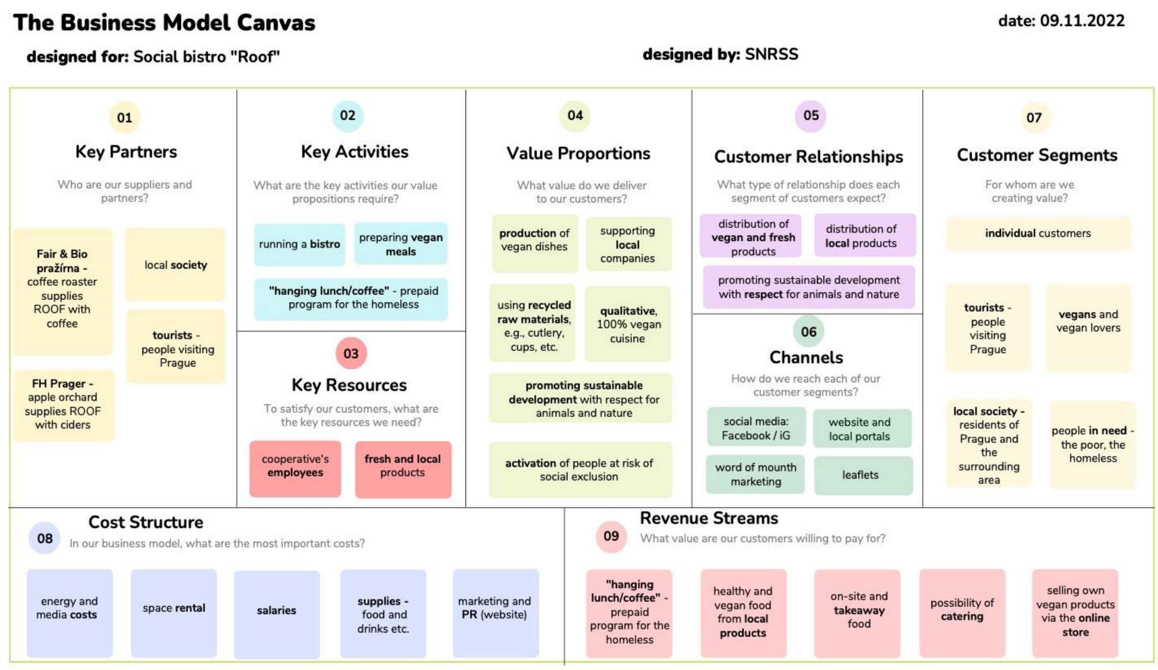
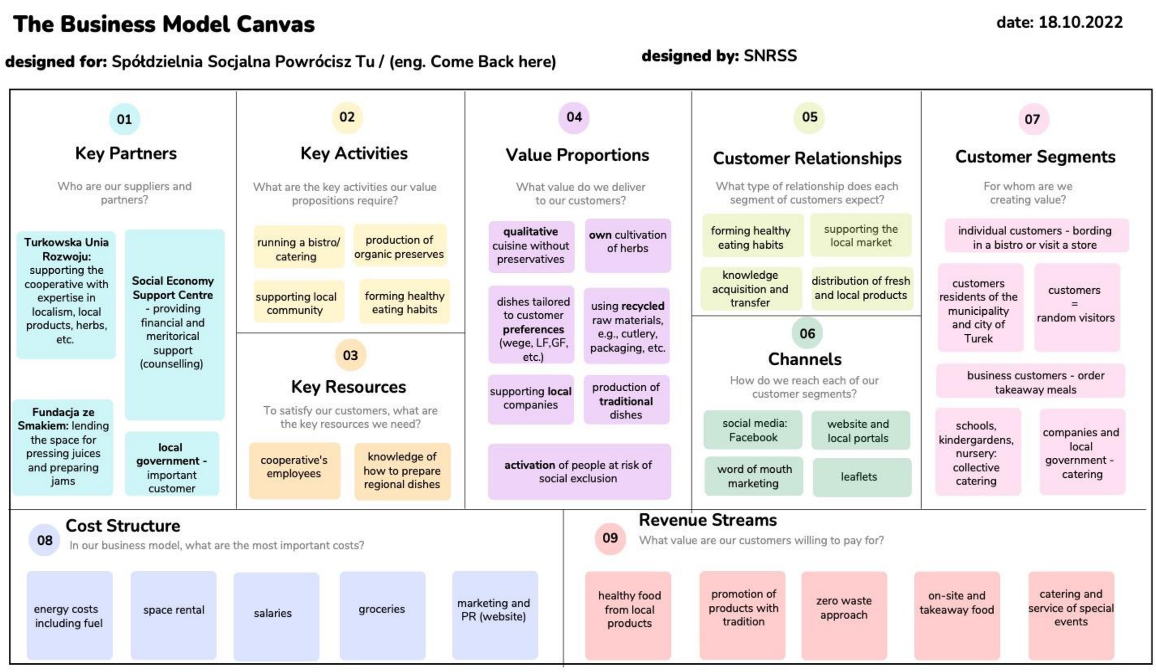
4.4.4 Model 6

Model 6	**Title:** Market Forces 1
Link	https://exchange.iseesystems.com/public/georgios-tsaples/sdg-labs-model-6/index.html#page1

Objective

The objective of the model is to illustrate how real-life economy can escape typical equilibrium situations as described in traditional economic theories. To explain this situation, the model uses two of businesses model canvasses (and enterprises) that were developed (Social Bistrot- Come Back Here).





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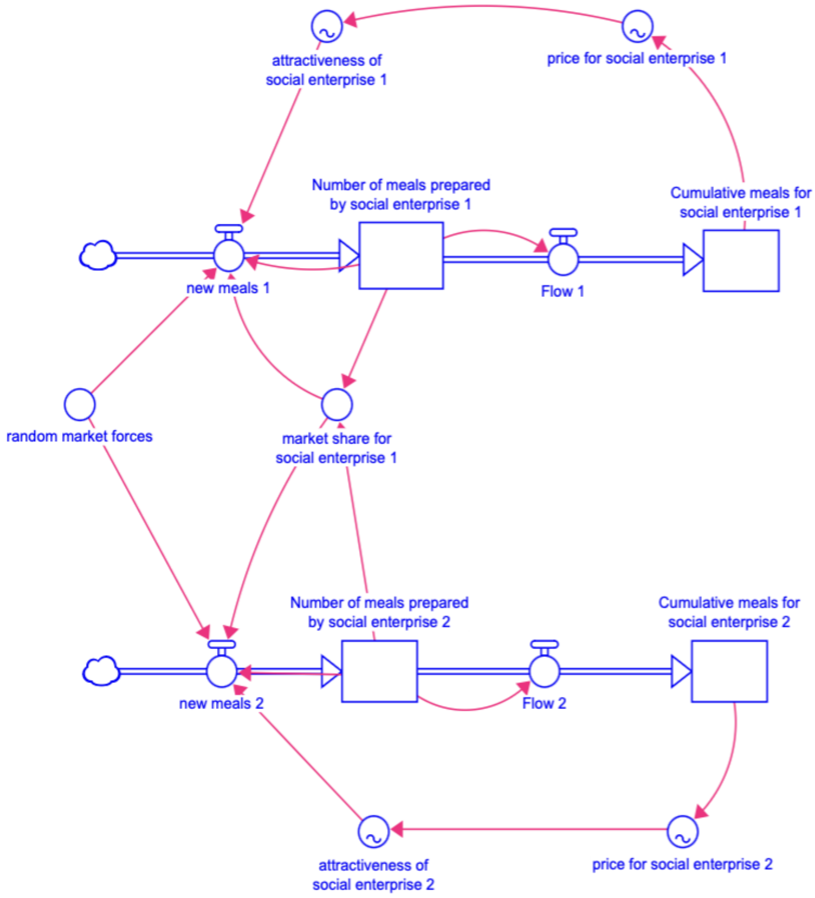
The quantitative model that is developed, represents two social enterprises with the following characteristics:

- They run a bistro (to generate revenues)

- They promote healthy eating habits

- They try to offer back to the community, by feeding the homeless for example.

Consequently, they are (at least partially) in competition, which acts as a continuation of the escalation models (4 and 5).



Both enterprises have the same structure and both have to deal with random market forces, which is the central variable of the model: its value will drive how many meals will be prepared by each enterprise, following the decision rule:

if the market share is larger than those market forces, then the number of meals increases compared to the previous time step of the simulation.

If the attractiveness of each bistro is not larger than the random variable (random market forces), then the number of new meals that is produced is constant and equal to the previous time step of the simulation

The students are not given the option to experiment with a specific variable/policy lever. However, they should simulate the model many times, since the random market forces variable is random and in each simulation will get a different value, thus the whole model behavior will change. The students should understand the following:

- Market Mechanisms maybe more influential than any decision that the entrepreneur could apply

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- The mechanism of decision could result in different overall behavior. For example it could lead to equilibrium (negative feedback).
- The nature of the loop could determine the success or failure of an enterprise

References

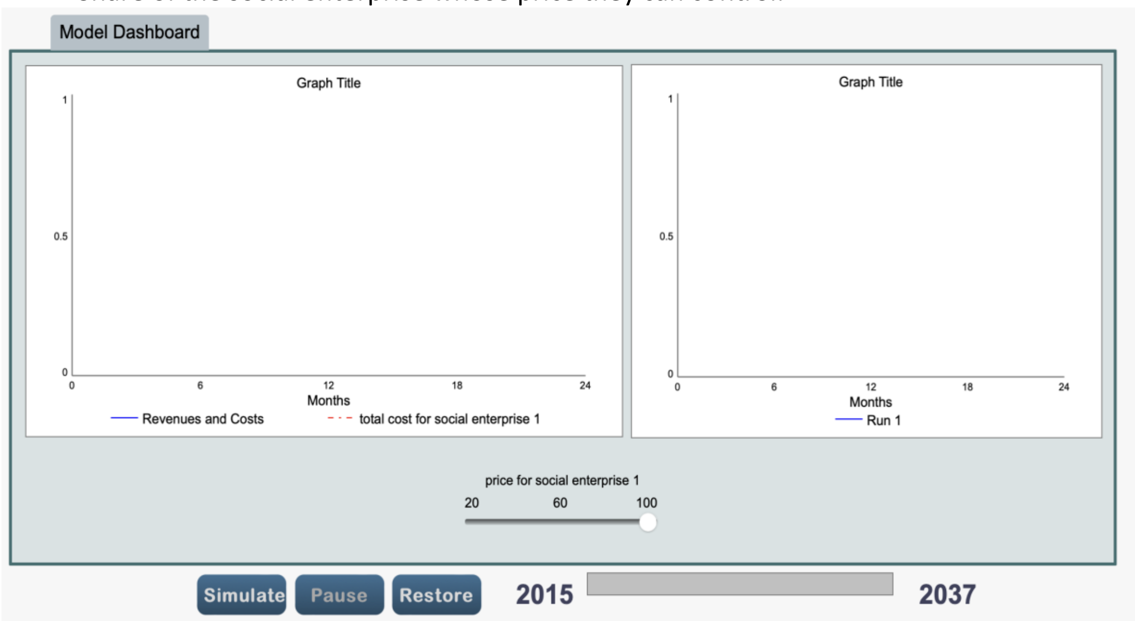
Ruth, M., & Hannon, B. M. (1997). Modeling dynamic economic systems (Vol. 1). Springer Science & Business Media.
Arthur, W. B. (1990). Positive feedbacks in the economy. Scientific american, 262(2), 92-99.
Arthur, W. B. (1994). Positive feedbacks in the economy. The McKinsey Quarterly, (1), 81-96.

4.4.5 Model 7

Model 7	**Title:** Market Forces 2
Link	https://exchange.iseesystems.com/public/georgios-tsaples/sdg-labs-model-7

Objective

Model 7 updates model 6 in the following manner: the price of each meal that is prepared by the represented social bistro is not determined automatically by the model. Instead the student can set their own price for only one of the social enterprises; the other enterprise keeps the same, automated mechanism. Moreover, the complexity of the decision that the students need to take increases as they will have to keep track of Revenues, Costs and the Market Share of the social enterprise whose price they can control.



To start the simulation, the student must press the Simulate button. At any point they can pause the simulation and experiment with the policy. Once they are satisfied with the level of the variable they can press the Simulate button again and the run will continue. Once the simulation is ended, the value of the variable/policy will revert to its original value. After the end of the simulation, the student has the option to press the Restore button (all the previous runs are deleted) or not (the previous runs remain and there can be a comparison of the results).

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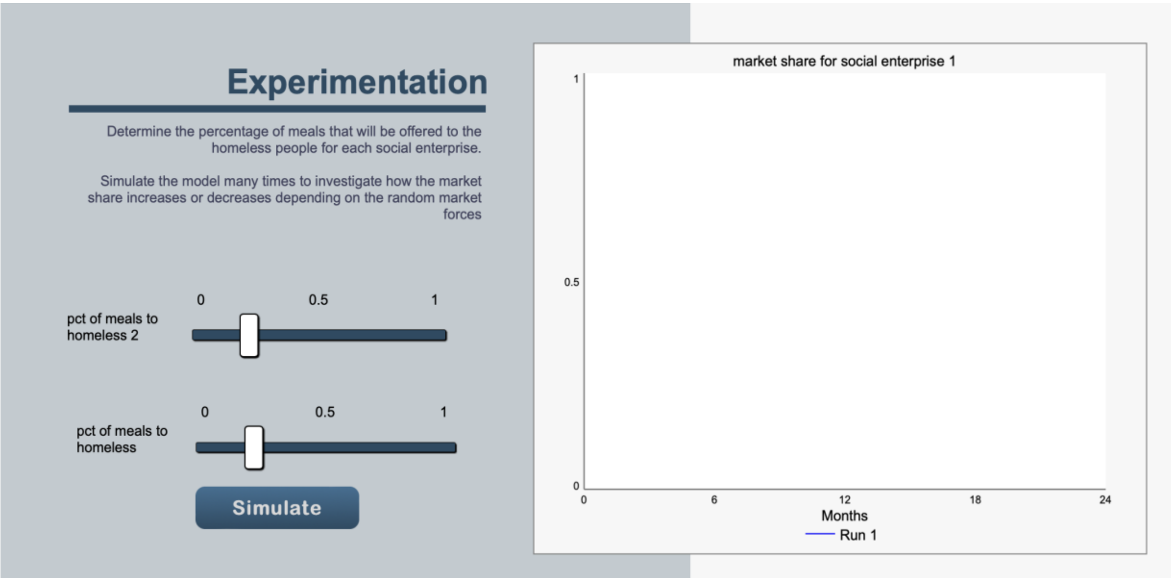
4.4.6 Model 8

Model 8	**Title:** Profitability and Social Impact 1
Link	https://exchange.iseesystems.com/public/georgios-tsaples/sdg-labs-model-8

Objective

Model 8 is a continuation and update of model 7. In this updated version of the model, each social enterprise's attractiveness does not depend only on the price of their products (the lower the better) but also on how many of their prepared meals are going for free to the community (for example to offer sustenance to homeless people). Thus, the objective of the model is to allow students to experiment with various policies and investigate how they can establish profitable businesses, with a positive social impact, while continuing to be subject to random market forces.



The students should internalize that:

- When more variables affect attractivess, the system becomes more complex

- Price and social impact are not incompatible, meaning that an enterprise could keep a relatively high price but offer to the community and still be attractive

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4.4.7 Model 9

Model 9	**Title:** Profitability and Social Impact 2
Link	https://exchange.iseesystems.com/public/georgios-tsaples/sdg-labs-model-9

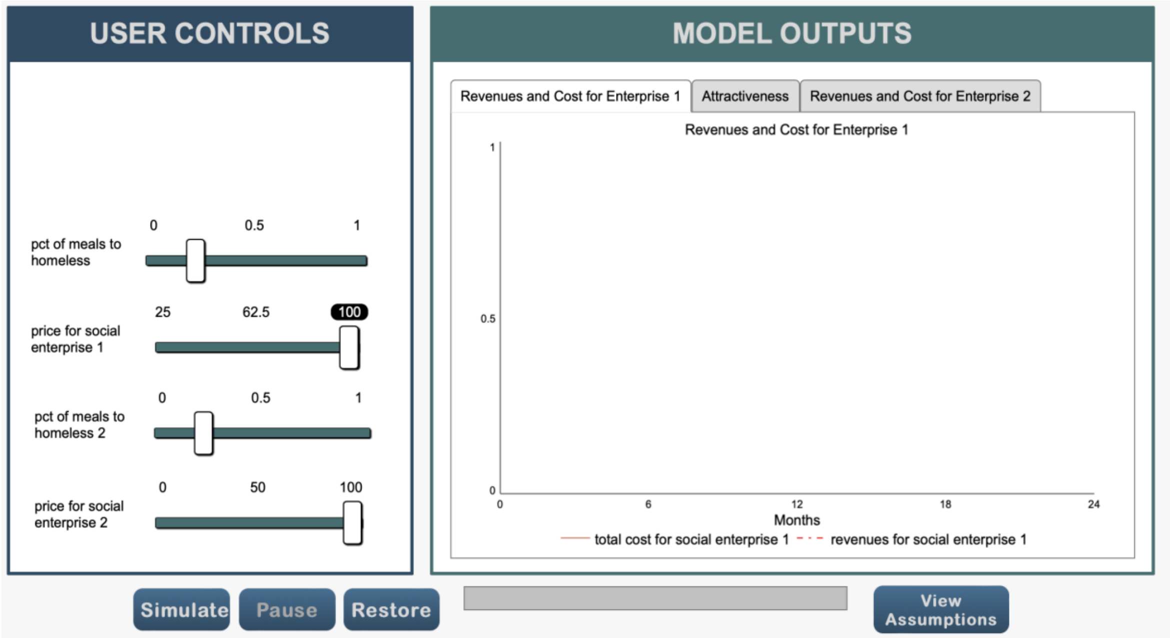
Objective

Model 9 is an updated version of Model 8. Firstly, each social enterprise, prepares the new meals that are separated (according to the value of "pct meals to homeless") to meals that are given to the community for free and the "Paid meals for social enterprise" that are sold through the social enterprise. Similar to the previous models, the cost per meal is a function of the cumulative number of meals.

Moreover, the attractiveness of each social enterprise is determined by a combination of price (the lower the better) and the percentage of meals that are offered to the homeless (the higher the better). In addition, because the market's behavior is unknown how much importance (weight) is given to each factor, is determined randomly at every step.

Thus, for each enterprise, the revenues are generated from a smaller set of meals, while the costs are, of course, determined by the total number of meals.

The students can experiment with the price per meal and the percentage of the meals that are returned to the community for both social enterprises and are asked to simulate and test different scenarios to investigate the complexity that social entrepreneurs face in their effort to sustain a business and make a meaningful social impact.



To start the simulation, the student must press the Simulate button. At any point they can pause the simulation and experiment with the policy. Once they are satisfied with the level of the variable they can press the Simulate button again and the run will continue. Once the simulation is ended, the value of the variable/policy will revert to its original value. After the end of the simulation, the student has the option to press the Restore button (all the previous runs are deleted) or not (the previous runs remain and there can be a comparison of the results).

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4.4.8 Model 10

Model 10	**Title:** Recycling Material
Link	https://exchange.iseesystems.com/public/georgios-tsaples/sdg-labs-model-10

Objective

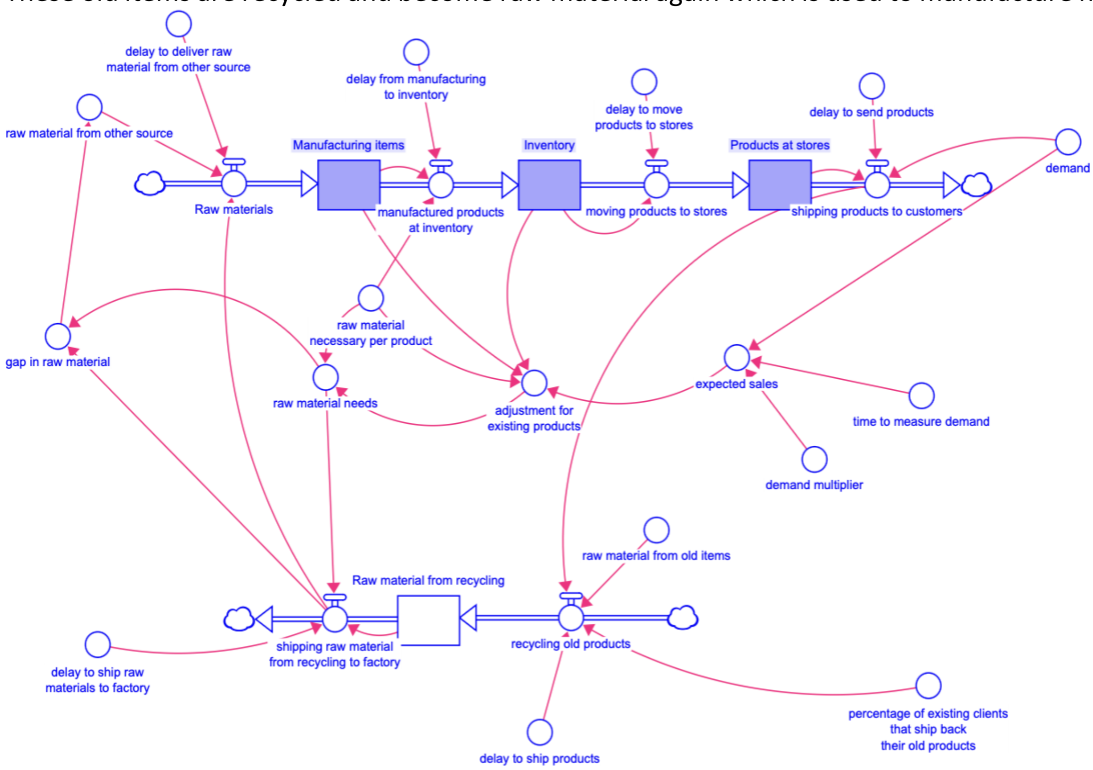
The objective of Model 10 is to illustrate how companies/enterprises can use recycling as a means to reduce their dependencies (and costs) from finite resources. The model that is developed, represents a company that manufactures an item (sunglasses, mobile phones, cars etc.). After manufacturing them, the company sends the products to a central warehouse (Inventory) where they are stored until they are requested by the stores who sell them to customers.

To differentiate from other similar companies, this hypothetical enterprise has two ways to secure raw material to manufacture the items.

Firstly, they order the material from other companies (traditional way).

Second, they ask from customers who have already purchased an older version of the item and wish to replace it with a new one, to send the old item back to the company.

These old items are recycled and become raw material again which is used to manufacture new items.



Important variables that need attention are the following:

- Demand multiplier: It is a measure of how many more items the stores will order from the central warehouse (inventory) in order to satisfy future demand. It can be thought of as such: Imagine you are the store owner and you have seen that in the previous period you had sold 10 items. In order to satisfy future clients, you do not want to have only 10 more items in store; you want a minimum quantity (safety stock) that would cover any increase in demand.

- Time to measure demand: How far back you look as a store owner to anticipate future demand depends on this variable.

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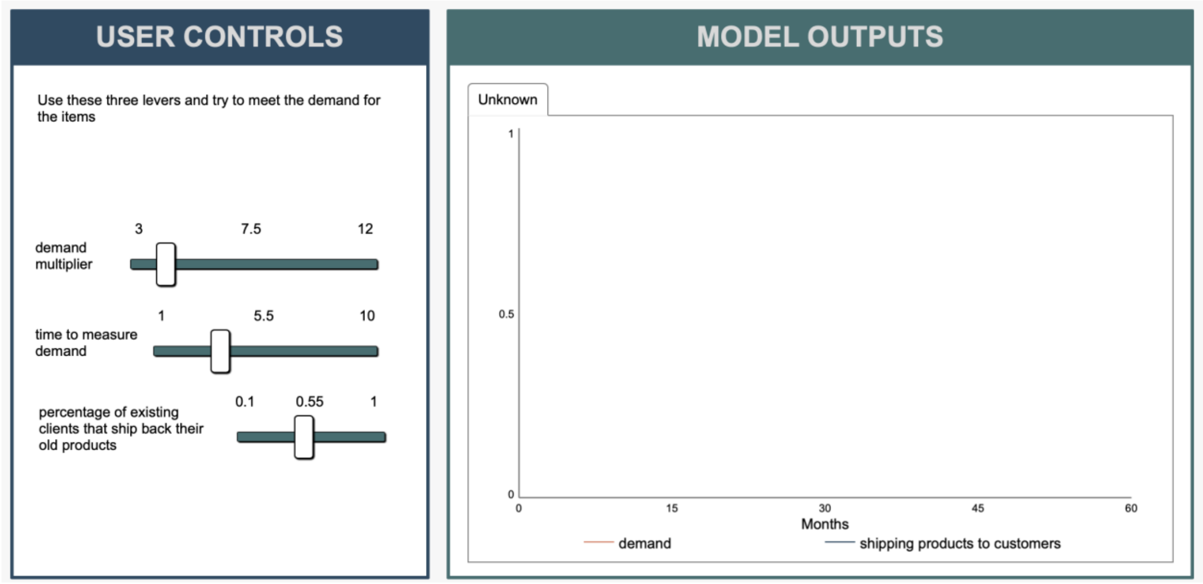
- percentage of existing clients that ship back their old products: It represents the percentage that send back their old products to be recucled.

The students are asked to experiment with three policy levers and attempt to meet the (pre-defined) demand



Even with a simple model such the one presented, it can be seen that in a supply chain it is not very easy to meed demand, let alone when the enterprise operates under the principles of circular economy.

In addition, there are important elements missing that would make the model more complex, but more realistic as well. For example, cost is not included (cost of recycling vs. cost of ordering material), incentives that would increase the percentage of people that ship back their items (like reduced price for new items) etc.

As mentioned before, this simple case study illustrates the difficulty in operating in a supply chain, but at the same time it can show how much raw material/resources can be saved if such a business model (circular economy) is applied successfully.

To start the simulation, the student must press the Simulate button. At any point they can pause the simulation and experiment with the policy. Once they are satisfied with the level of the variable they can press the Simulate button again and the run will continue. Once the simulation is ended, the value of the variable/policy will revert to its original value. After the end of the simulation, the student has the option to press the Restore button (all the previous runs are deleted) or not (the previous runs remain and there can be a comparison of the results).

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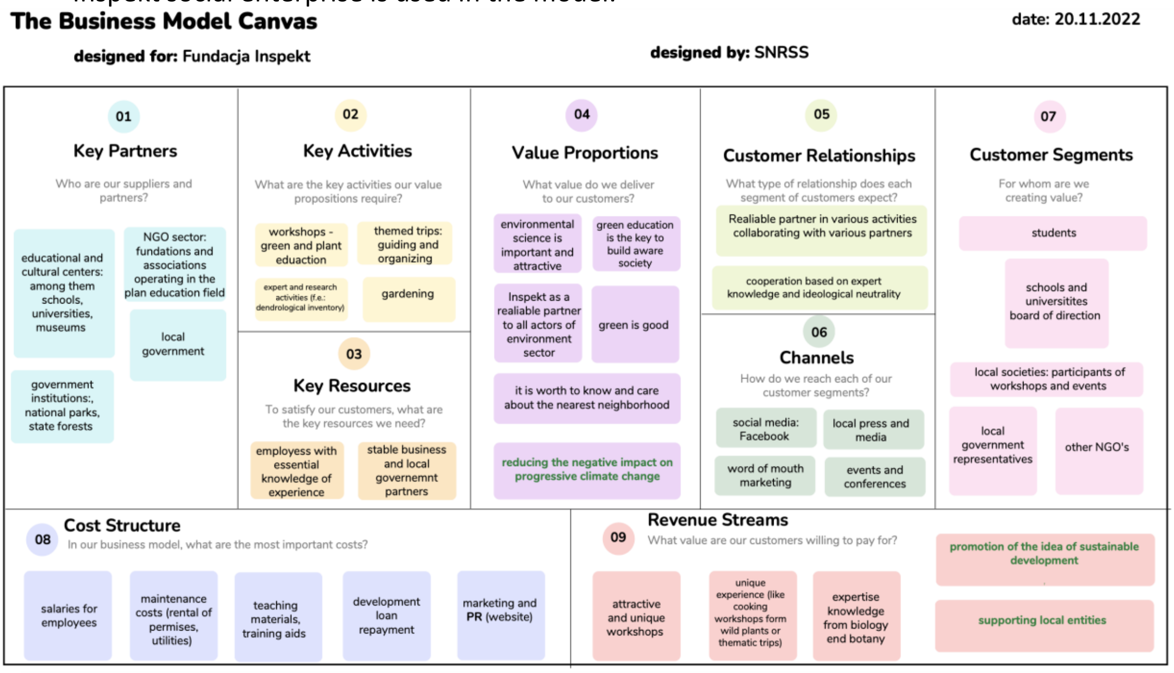
4.4.9 Model 11

Model 11	**Title:** Recycling Material and Learning
Link	https://exchange.iseesystems.com/public/georgios-tsaples/sdg-labs-model-11

Objective

Model 11 is an update of model 10. Its purpose is to introduce a policy structure that represents efforts to teach and inform people about the merits of recycling. As case study, the Fundacja Inspekt social enterprise is used in the model.



With this structure, the attitude of people towards recycling is represented. This attitude depends on the perception of how much material was saved through recycling and of course with the workshops that are organized through the cooperation of the enterprises.

These workshops are represented by the variable "workshops from companies to promote recycling". It takes values from 0 (no workshops organized) to 1 (a very high number of workshops organized).

The higher the value of the stock "Clients' behavior towards recycling" (it takes values from 0 to 1), the higher the percentage of clients that will return their old items for recycling.

Consequently, with the new model, the student can experiment with three policies/decisions and attempt to meet the predefined demand.

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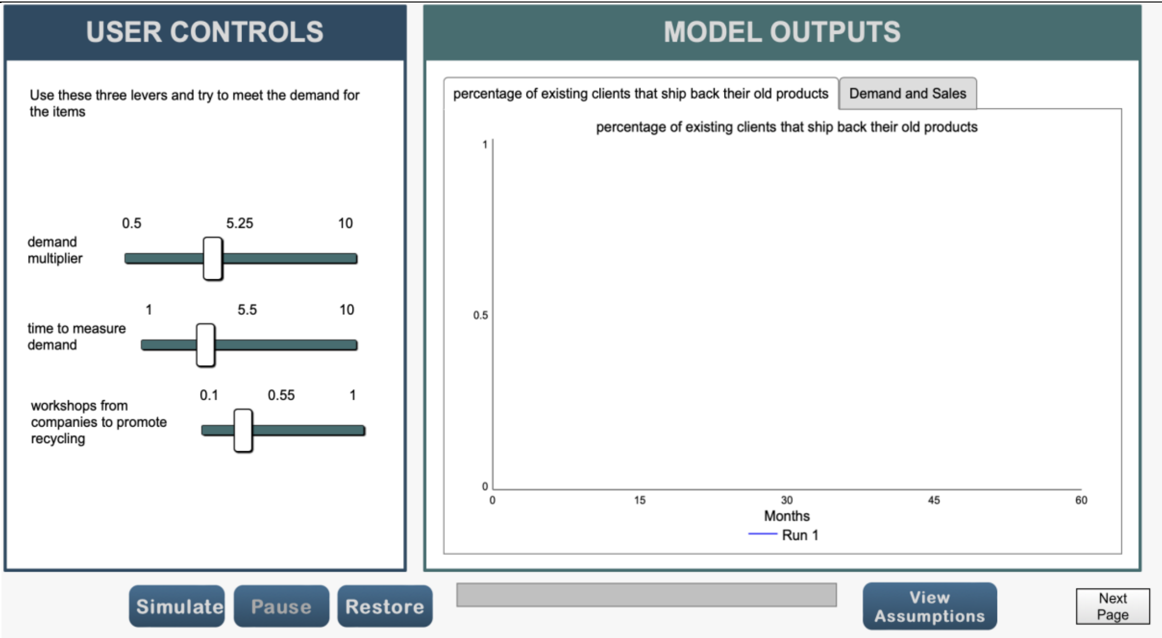

Key insights of the model are the following:

An increased number of workshops will increase the percentage of people that will send their products for recycling, but only for a short period. The model assumes that people forget easily, thus they will revert to old habits (not recycling) soon.

Moreover, the increased percentage of clients that send items for recycling will decrease the orders for raw materials from other resources, but without coordination this saving in material (a) will not be perceived immediately by the customers (b) it might not satisfy immediately the needs for raw material to manufacture new products.

These differences on when people perceive the impact of their actions to how much the attitude towards recycling could increase to when the increased percentage of clients that return their items for recycling could impact the orders for raw materials results in the oscillations in the behavior that are observed

To start the simulation, the student must press the Simulate button. At any point they can pause the simulation and experiment with the policy. Once they are satisfied with the level of the variable they can press the Simulate button again and the run will continue. Once the simulation is ended, the value of the variable/policy will revert to its original value. After the end of the simulation, the student has the option to press the Restore button (all the previous runs are deleted) or not (the previous runs remain and there can be a comparison of the results).

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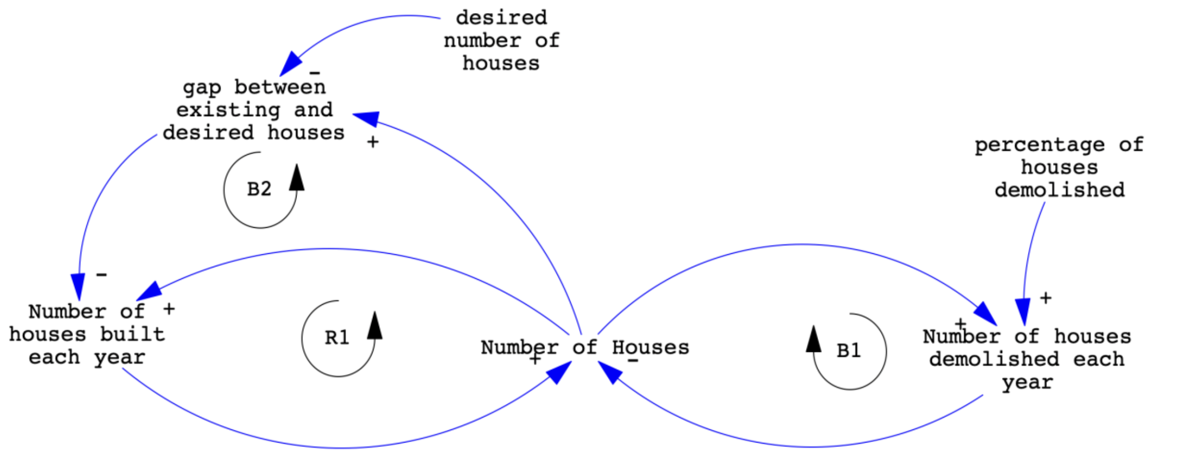
4.4.10 Model 12

Model 12	**Title:** Housing Dynamics 1
Link	https://exchange.iseesystems.com/public/georgios-tsaples/sdg-labs-model-12

Objective

The objective of the model is to simulate the housing market and attempt to find solutions to various problems that would be beneficial without producing unintended consequences. The model contains the description of a simplified housing system and students are asked to design a Causal Loop Diagram and answer typical questions such identifying the number of feedback loops etc. The final CLD that the students should produced is the following:



References

Eskinasi, M. (2014). *Towards housing system dynamics: Projects on embedding system dynamics in housing policy research* (Doctoral dissertation, Delft: Eburon Academic Publishers).

4.4.11 Model 13

Model 13	**Title:** Housing Dynamics 2
Link	https://exchange.iseesystems.com/public/georgios-tsaples/sdg-labs-model-13

Objective

The objective of Model 13 is to develop and present a quantitative version of the Causal Loop Diagram of Model 12. The new, quantitative model entails a simple "ageing" structure for houses.

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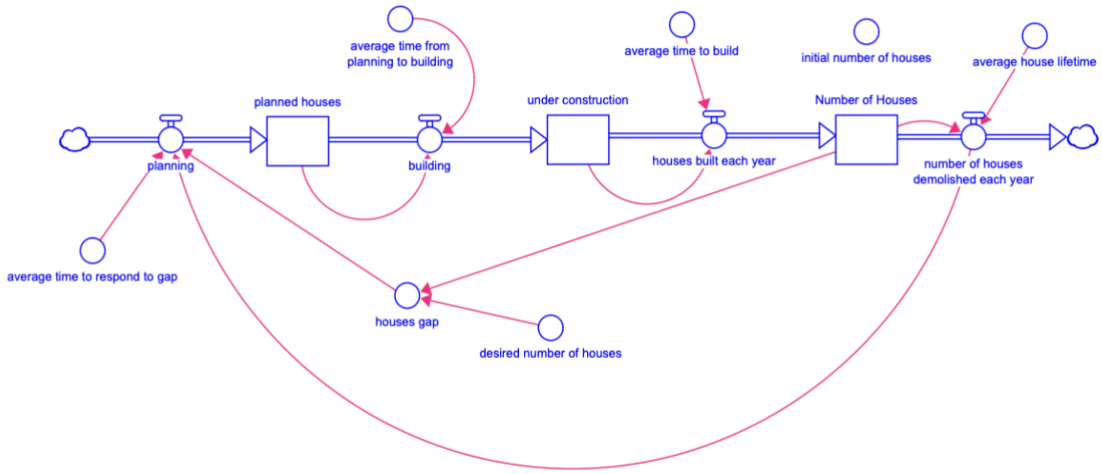

Data from the data collection process of the intellectual output were used. Important variables to consider:

- initial number of houses: The number of houses that are currently existing in the town/area/city under study. For the particular model, the case of Greece was chosen where there are approximately 4,1 million houses.

- desired number of houses: How many houses more a policy maker (or the market) are desired in the area under study

- average time to respond to gap: a delay that signal how fast the whole process of building houses will go. It is the moment from when a gap is observed until the first action to plan a new house is taken.

The student has the opportunity to experiment with different policies/variables and observe the dynamics of the housing market. Furthermore, the values of the initial houses (in the model) can change to any of the number that was presented in the data table of the current deliverable.

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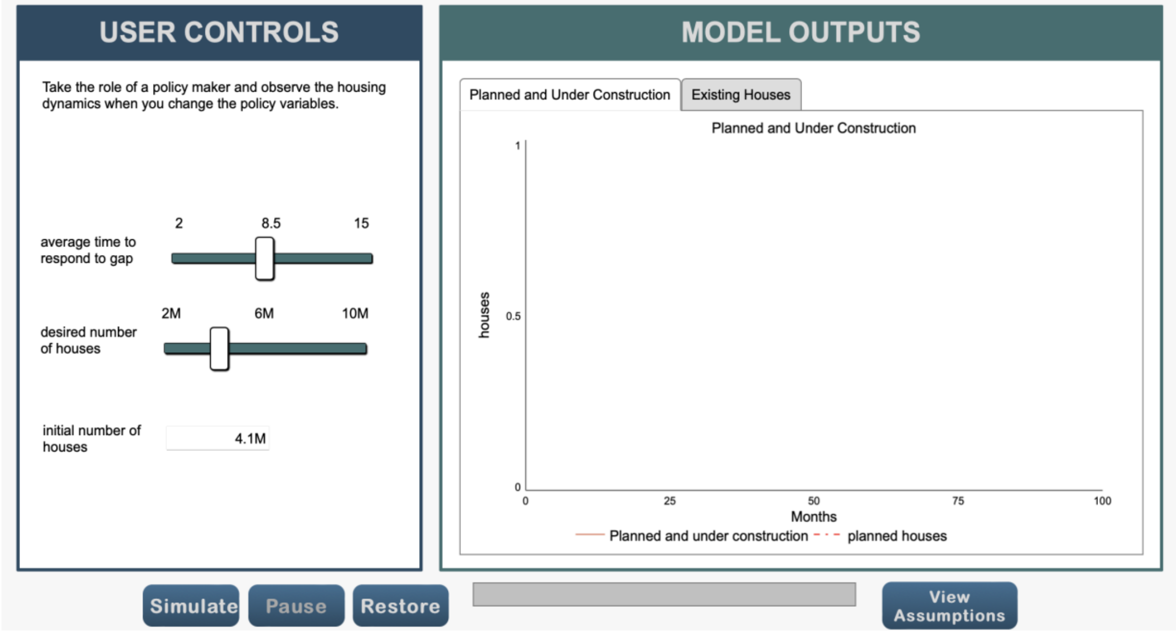

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References

Pruyt, E., 2013. Small System Dynamics Models for Big Issues: Triple Jump towards Real-World Complexity. Delft: TU Delft Library. 324p

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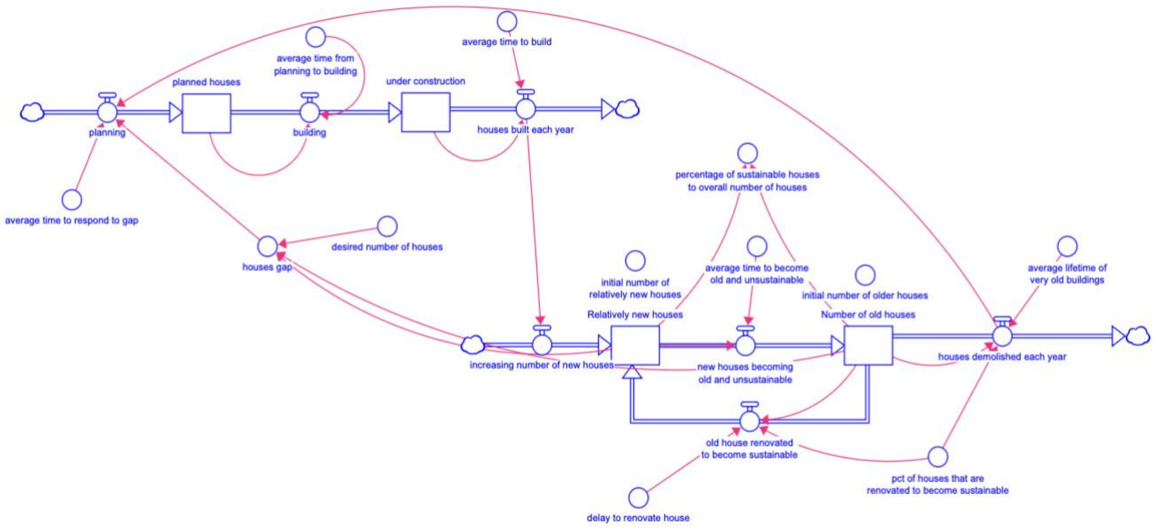
4.4.12 Model 14

Model 14	**Title:** Housing Dynamics 3
Link	https://exchange.iseesystems.com/public/georgios-tsaples/sdg-labs-model-14

Objective

The objective of Model 14 is to expand model 13 and account for newer and older buildings. Thus, the model attempts to represent an ongoing effort of social enterprise and policy makers to modernize older buildings and make them more sustainable and carbon neutral.



In the updated model, there are relatively new houses that as time progresses become old houses (assumed unsustainable).

Once in that stock, there is the option to renovate, which moves the house to the stock of Relatively new houses, or not which keeps the house in the stock of Old houses and remains there until it is demolished.

The rest of the model remains the same.

Important variables:

- percentage of sustainable houses to overall number of houses: An indicator that illustrates the sustainability of the sector

- delay to renovate house: how much time it takes to renovate a house and move it from the stock of the old houses to the stock of the new ones

- pct of houses that are renovated to become unsustainable: the percentage of old houses that each year become more sustainable.

The students are asked to experiment with even more policy variables and attempt to minimize the creation of "boom and bust" cycles that seem to be developed in real-life cases.

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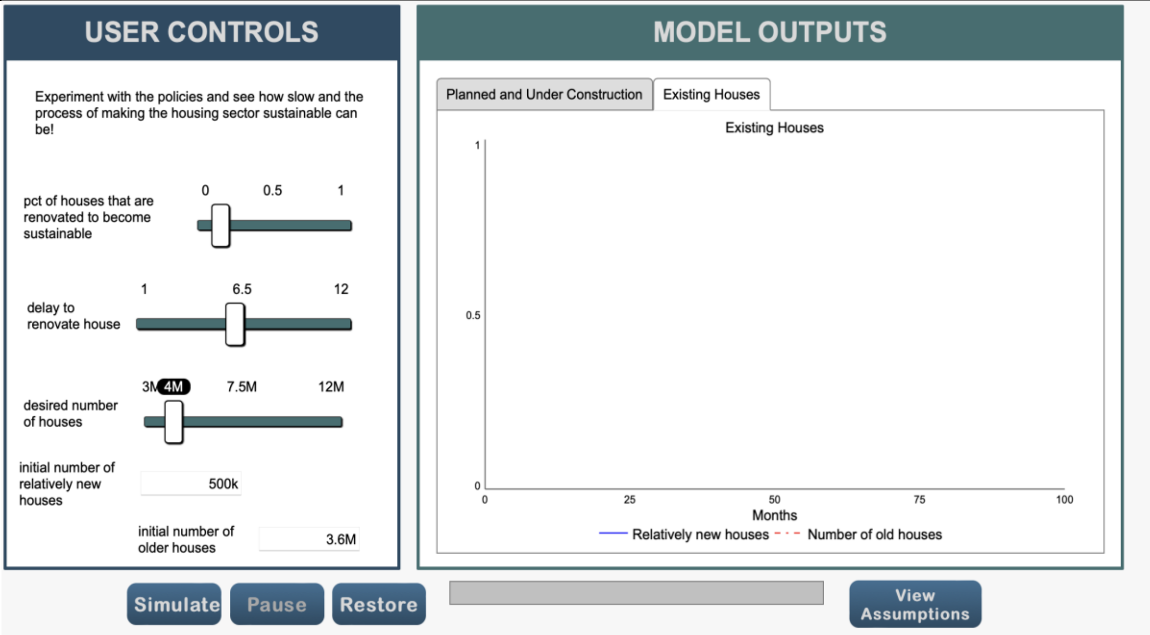

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References

https://www.statistics.gr/census-buildings-2011

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4.4.13 Model 15

Model 15	**Title:** Housing Dynamics 4
Link	https://exchange.iseesystems.com/public/georgios-tsaples/sdglabs-model-15

Objective

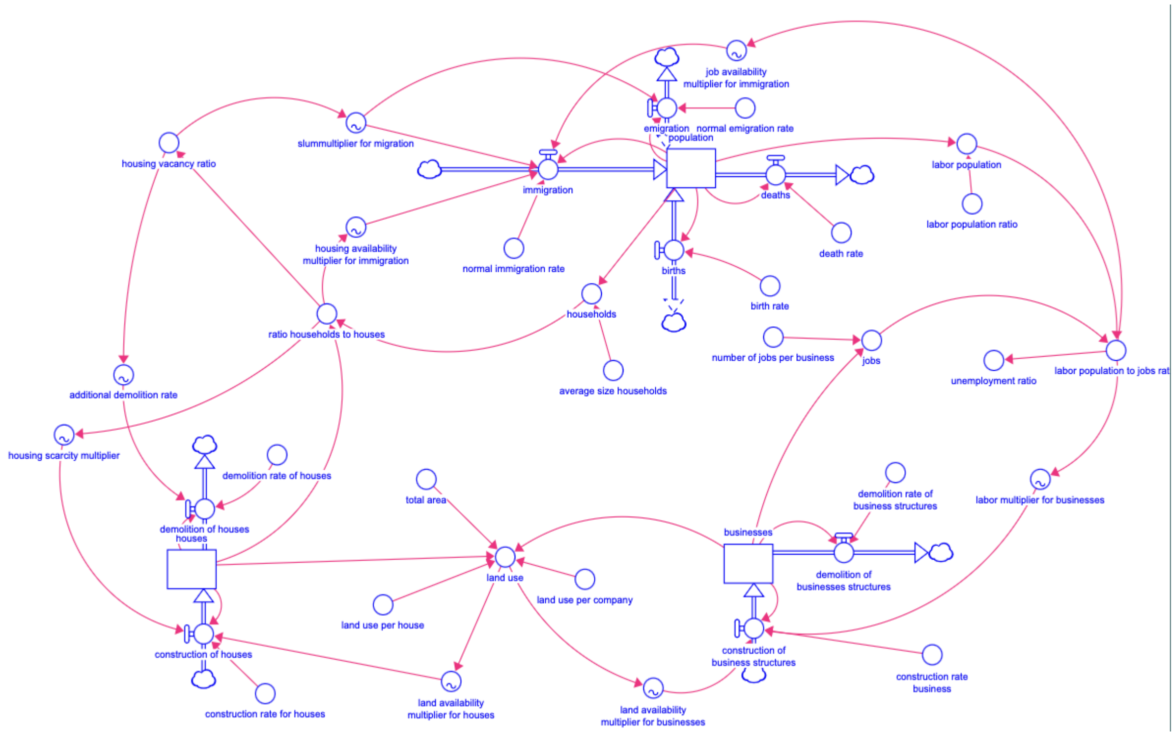
Model 15 continues the trend of updating the previous model. In this setting, not only the buildings/homes sector, but an entire urban environment is modelled. One of the most important models that have been developed and illustrates the dynamics of a city is Urban Dynamics by Forrester (Forrester, 1970). In this model, there is a business structure, a housing structure and a population structure.

Each structure depends on the other ones through feedback loops and all are competing for the same, underlying resources: New businesses cannot be developed unless older ones are demolished in order to free land. But for land to be free it must not be occupied by houses (existing ones or ones under development).

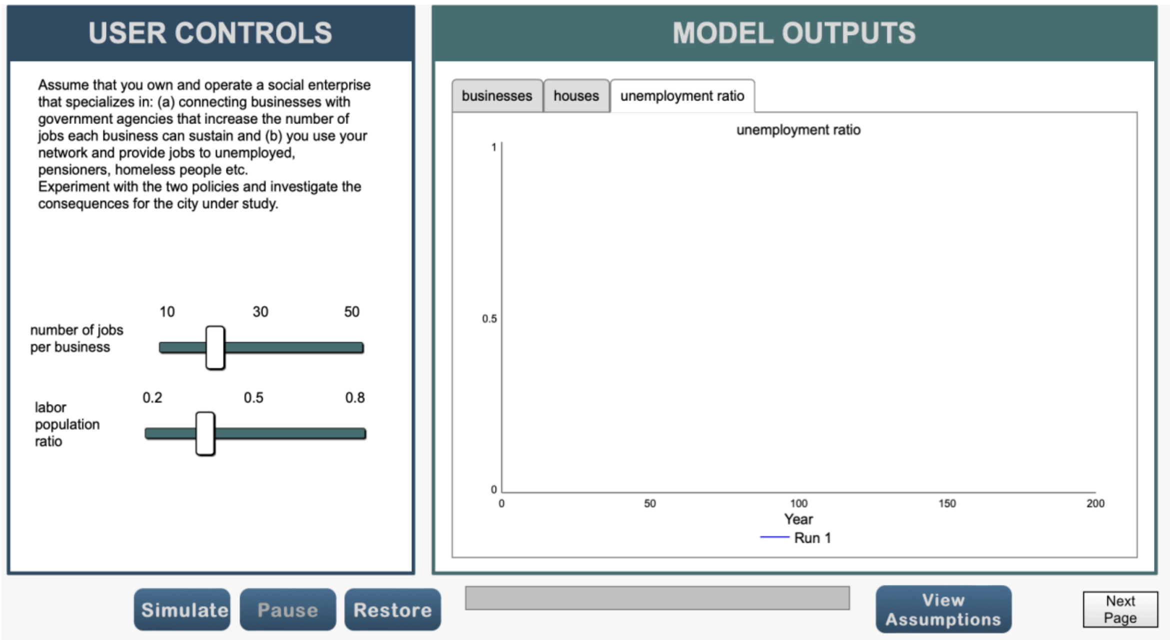
New businesses create new opportunities for jobs which increases the attractiveness of the area and new people might come in. But in order for the new people to have jobs, they must compete with the existing population for the jobs etc.

Even with this small and relatively simple description of the system, an immensely complex model emerges that could be of assistance to policy makers and entrepreneurs.

Model 15 is an adaptation of the work presented in Ghaffarzadegan et al. (2011) and it shows the dynamics of an area/city in which there is a population, a housin sector and a business sector.



The model asks the student to assume that they own a social enterprise that specializes in: (a) connecting businesses with government agencies that increase the number of jobs each business can sustain and (b) you use your network and provide jobs to unemployed, pensioners, homeless people etc



Key insights of the model include:
As the number of houses and business increases, two effects emerge:
(a) The attractiveness of the area increases
(b) Land becomes scarce

The unavailability of land has major consequences as the whole system is driven to stagnation.

Increasing the number of jobs that a business can sustain (for example through a government program) has a relatively fast positive effect, as the unemployment rate decreases. However, businesses cannot hire more people through the normal, organic way which leads the system again to a sort of equilibrium/stagnation that was observed in the previous case.

Increasing the labor to population ration (for example by making available for work pensioners or homeless people) increases instantly the unemployment rate (since there are more people availabel for work, but the number of jobs remain constant). Until more jobs are created and the system reaches to its equilibrium point.

To start the simulation, the student must press the Simulate button. At any point they can pause the simulation and experiment with the policy. Once they are satisfied with the level of the variable they can press the Simulate button again and the run will continue. Once the simulation is ended, the value of the variable/policy will revert to its original value. After the end of the simulation, the student has the option to press the Restore button (all the previous runs are deleted) or not (the previous runs remain and there can be a comparison of the results).

References

Forrester, J. W. (1970). Urban dynamics. IMR; Industrial Management Review, 11(3), 67.
Ghaffarzadegan, N., Lyneis, J., & Richardson, G. P. (2011). How small system dynamics models can help the public policy process. System Dynamics Review, 27(1), 22-44.

4.4.14 Model 16

Model 16	**Title:** Urban Dynamics and Social Impact
Link	https://exchange.iseesystems.com/public/georgios-tsaples/sdg-labs-model-16
Objective	
Model 16 closes the housing section of the models with an even more complex expansion of the previous models. The models that were described so far assume that the area/town/city under study is a homogeneous entity. However, in reality this is not the case: cities consists of blocks and neighborhoods, they have not only houses and businesses but also roads, they suffer from traffic, they offer services, the have population that moves around the city daily, population that leaves the city permanently, population that comes to the city permanently etc. We assume a city with 5 zones/neighborhoods placed as in the figure to the right. We assume that Zone 1 is the city center while all the other zones are peripheral to it. Each zone has: (a) a population (b) new, mature and declining businesses (representing retail stores, supermarkets etc.) (c) Services industry (meaning businesses that offer services: accounting, engineering, etc.) (d) a road network (e) a housing sector with new and old houses	

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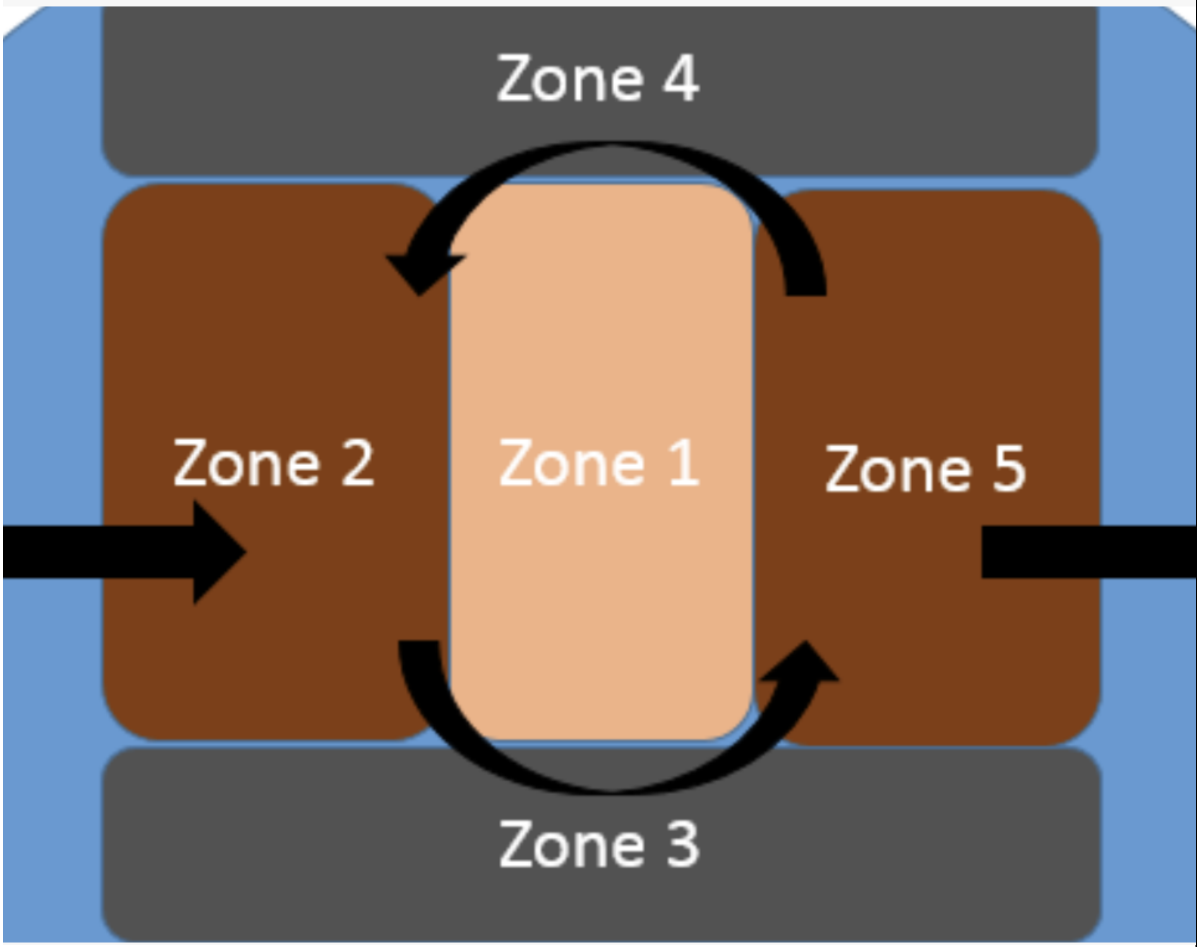

In addition, the population is not static: they move in different zones depending on the zone's attractiveness.

The zone's attractiveness depends on:

(a) the traffic (higher traffic smaller zone attractiveness

(b) jobs (higher number of jobs larger zone attractiveness)

(c) housing availability

(d) Services (higher number of services larger zone attractiveness)

In addition, there is an overall City Attractiveness that is mainly dependent on the total number of jobs (in all zones) and is a factor for the immigration/emigration dynamics).

The students are asked first to simulate the model with the given values and observe the various dynamics that are formed.
Following the base case simulation, the students are led to a dashboard with a plethora of policies and options to choose from.

Firstly, the various options/policies are described.

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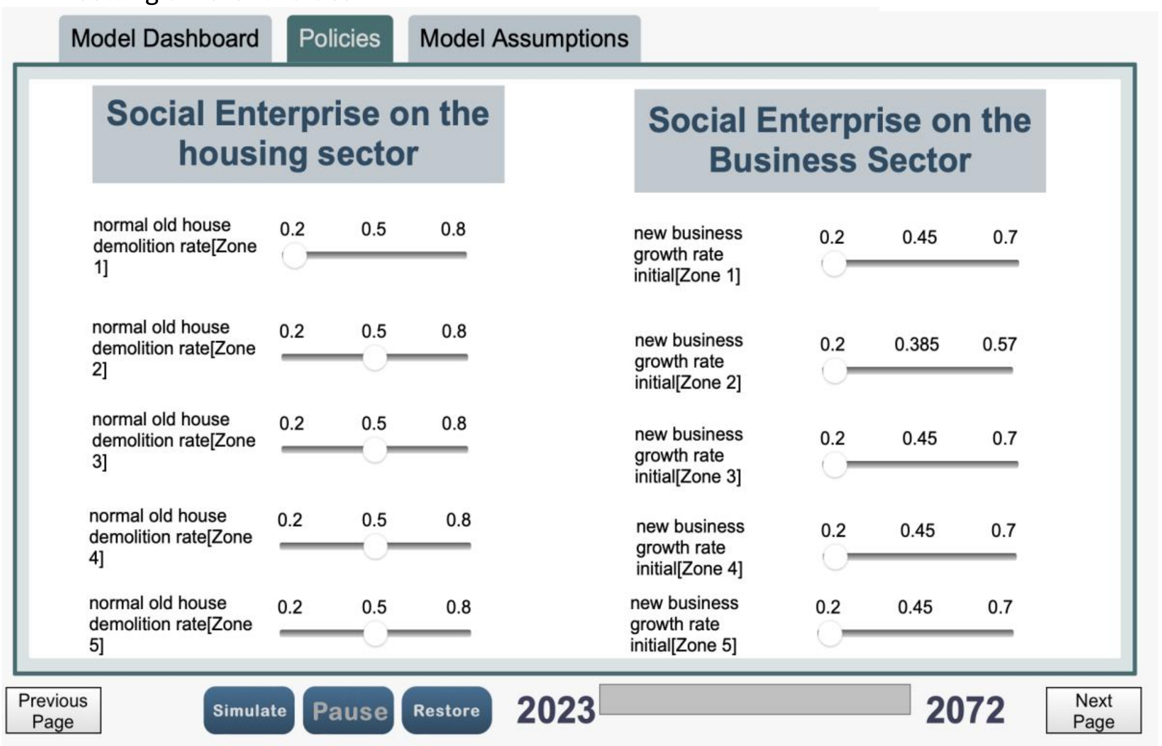
In the Policies Tab of the interface, the students can see and experiment with those policies by setting different values.



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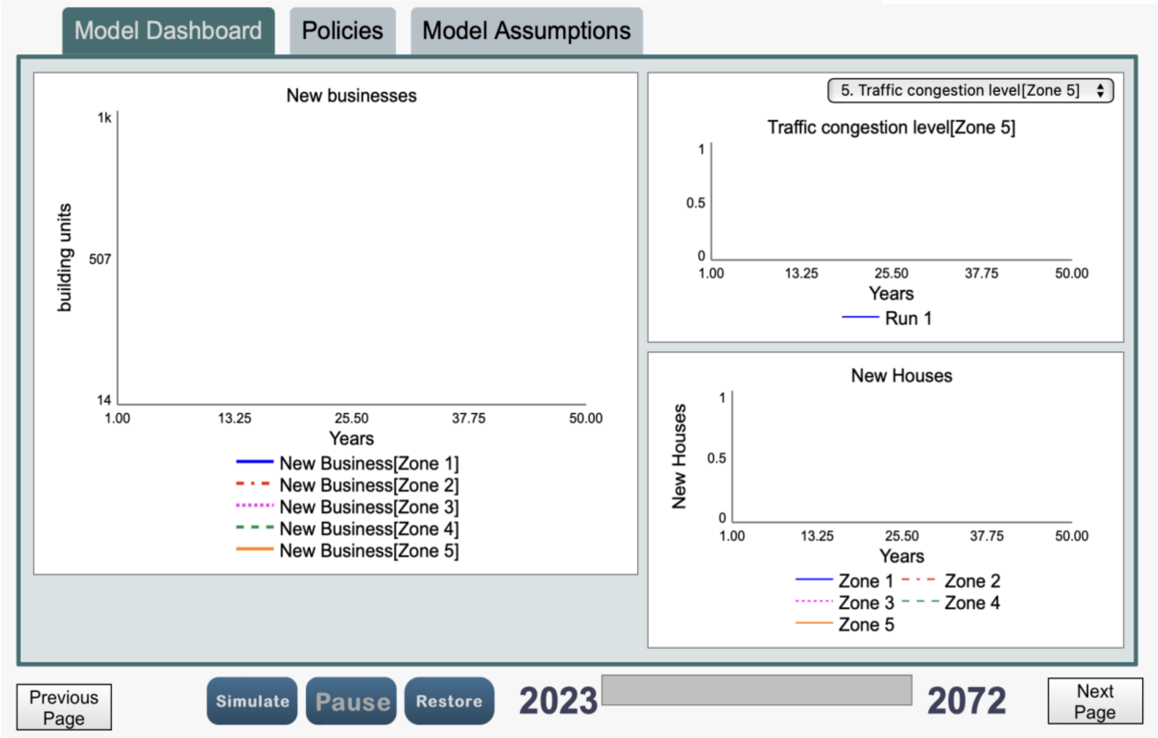
Finally, the students can see the results of their experimentations (values of different policies) in the Model Dashboard tab, where the behavior of various KPIs/variables is displayed.



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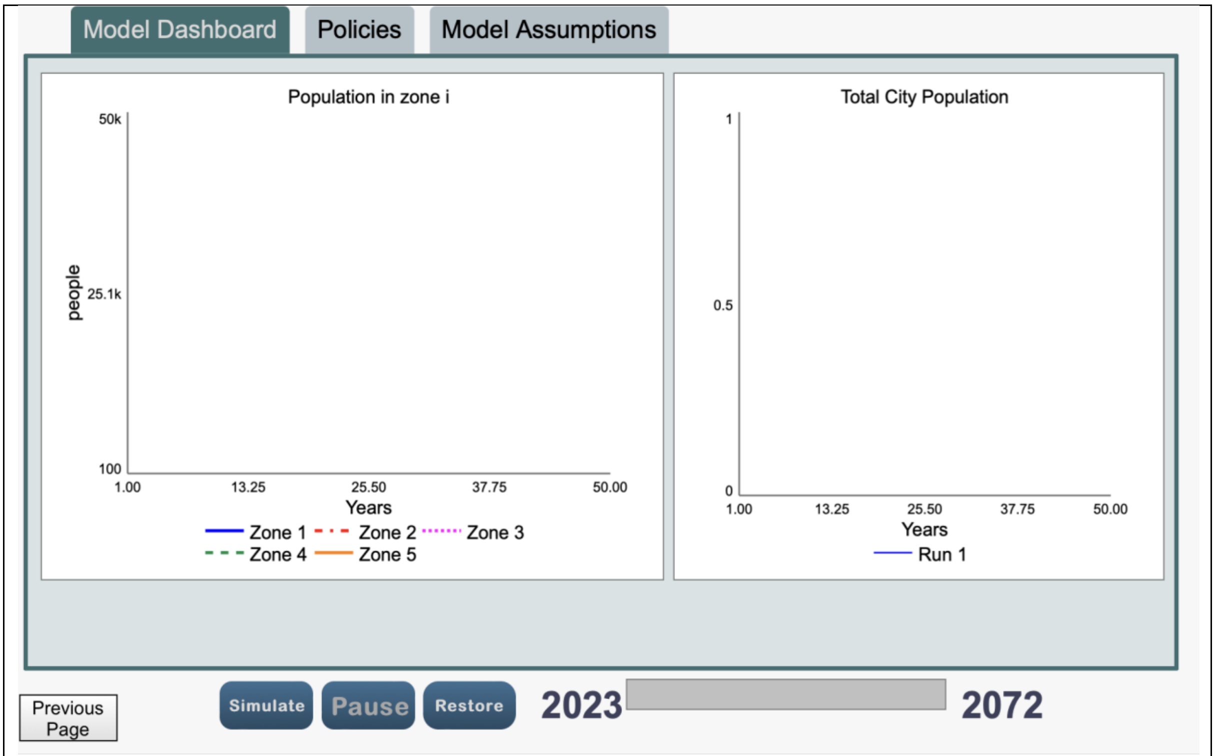

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4.4.15 Model 17

Model 17	**Title:** Households and Energy 1
Link	https://exchange.iseesystems.com/public/georgios-tsaples/sdg-labs-model-17

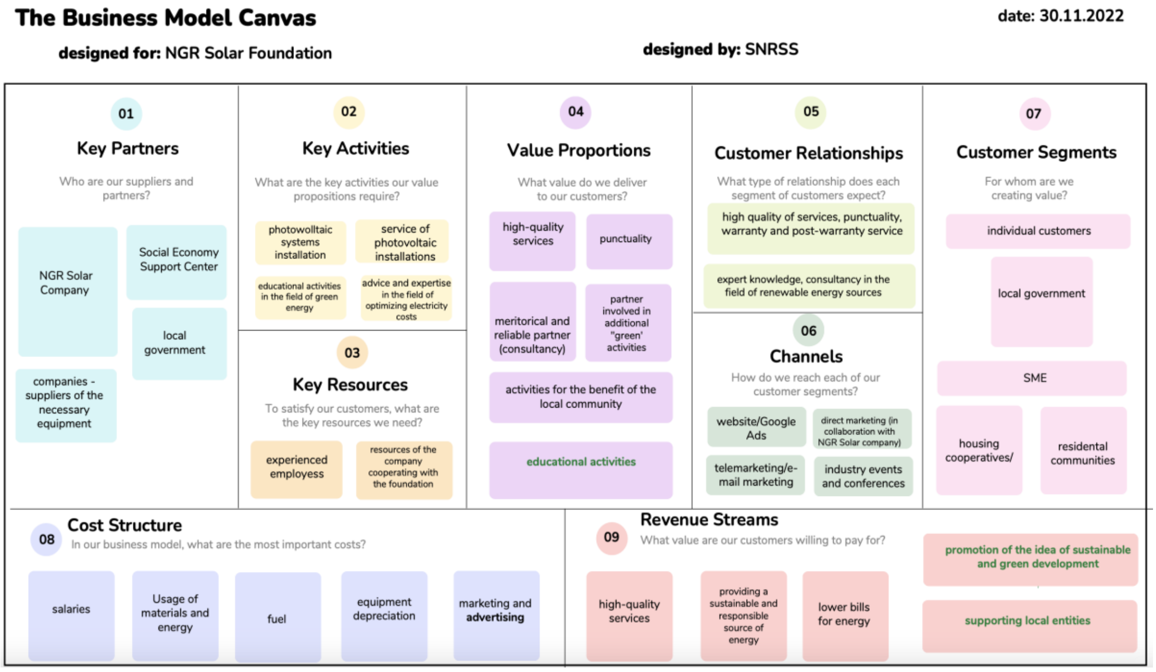
Objective

Model 17 begins a new cycle of modes that are focused on the energy sector. Model 17 asks the student to make the assumption that they have founded a social enterprise that is focused on installing and maintaining photovoltaic panels on households.

Moreover, it is assumed that the social enterprise will develop a marketing campaign to assist in convincing more home owners to install photovoltaic panels

The purpose of the System Dynamics model is to assist in analyzing the impact and gaining insights on the intensity of the marketing campaign that the social enterprise should follow.

The model relies on the following Business Canvas:



The model consists of a structure that measures the installed solar panels in an area (in m2). These solar panels are responsible for the solar energy that is generated in the area. The other sources are Hydro, Wind and other types of energy (for example, coal or nuclear. All the other types of energy are assume exogenous to the model).

In addition, there are certain households in the area under study. These households either have installed panels or not. For those that do not, there is a mechanism to adopt (and install) panels through an adoption rate, which depends on the cost for installation per m2.

This cost is not constant: as the installed panels increase, it is assumed that the cost per m2 is reduced: as more and more households install photovoltaic panels, the installation cost decreases (for the next ones that wish to install).

Finally, the households consume a certain amount of energy and to investigate the surplus of energy in the area, the energy from all the sources in inserted into the Surplus stock which is depleted by the energy consumption of the households.

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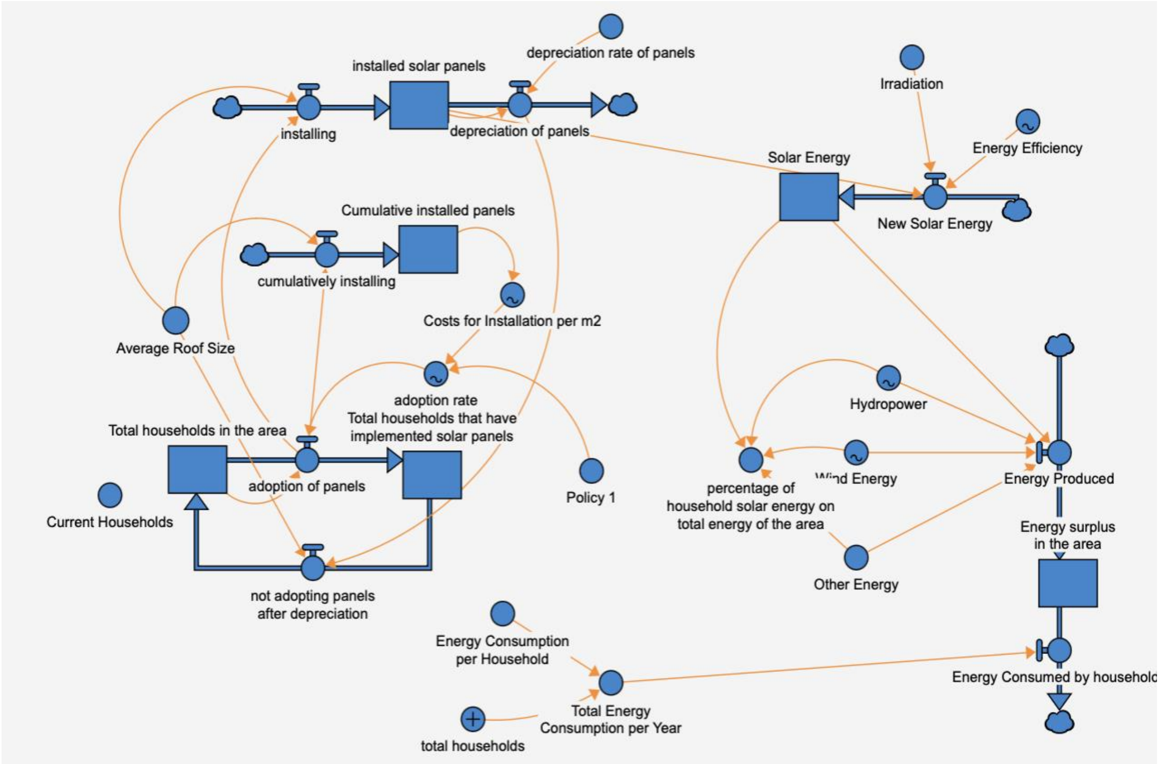
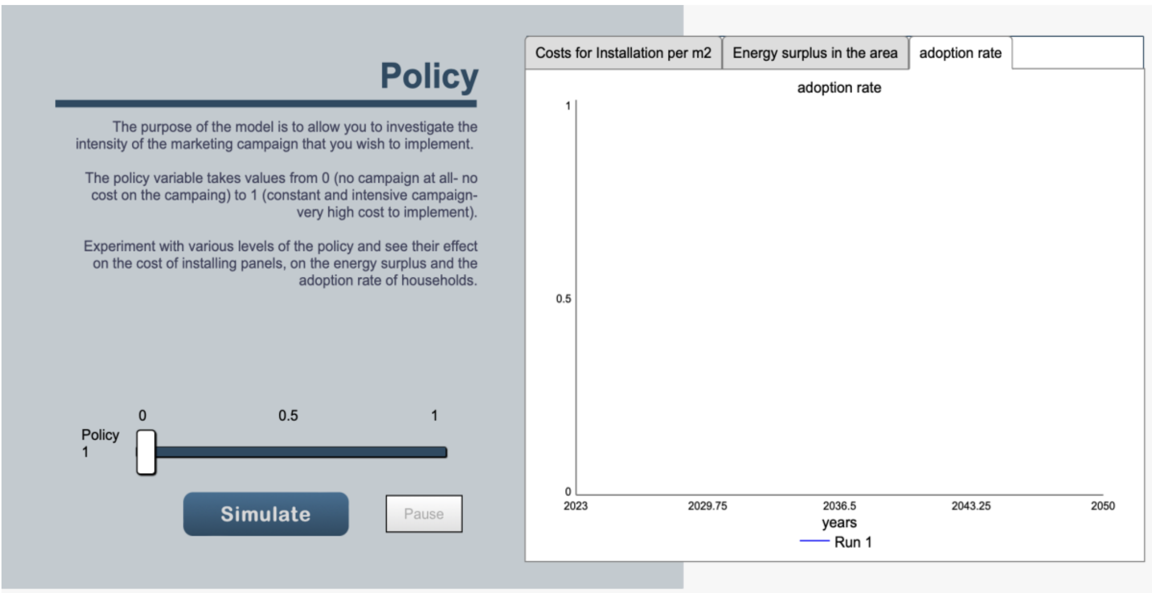
This stock can be seen as a KPI: the more solar energy is produced (compared to the other sources), the higher the surplus of energy.



The purpose of the model is to allow the students to investigate the intensity of the marketing campaign that they wish to implement. The policy variable takes values from 0 (no campaign at all- no cost on the campaing) to 1 (constant and intensive campaign- very high cost to implement).



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The following insights can be derived from the model: (a) The market is limited: You cannot have infinite growth as an enterprise. There is a limited number of households in the area that can adopt panels, which is reduced everytime a rooftop is filled (b) There is a delay between installing solar panels and seeing their effects in the overall community with regards to energy savings (c) The transition to a more sustainable energy mix (with a lot of renewable) cannot be based on individual policies (like installing panels). It needs to be accompanied by a systematic reduction of the polluting energy sources (d) Marketing campaigns can be impactful but they need to be sustained in time, intensive and even then, their effects might be manifested with a delay.

4.4.16 Model 18

Model 18	**Title:** Households and Energy 2
Link	https://exchange.iseesystems.com/public/georgios-tsaples/sdg-labs-model-18
Objective	
Model 18 is an expansion and update of model 17: In the previous model, the focus was on increasing the production of energy for households from renewable sources (solar). However, any attempt towards sustainability will have to include reduction in the consumption of energy. For households and houses this can be achieved through proper insulation. Insulation, in principle, can assist in reducing the energy consumption in buildings, thus leading to savings and a more environmental-friendly way of life. Consequently, in this model, the focus will be not only in increasing the adoption of solar panels in households, but also reducing their energy consumption. The updated version of the model contains a structure, with which houses either have insulation or not. The transition from a non insulated house to an insulated one, depends on the price of insulation. Similar to previous models, the price declines as more and more insulation installations occur. In addition, the energy consumption of insulated houses declines; this decline is not constant: as more and more houses get insulated, the urban environment becomes more sustainable, thus the overall energy consumption decreases. Finally, similar to the previous case, the students are asked to assume that they are the owner of a social enterprise that wishes to expand its operations from installing solar panels to installing also insulation. Thus, they organize workshops and marketing campaigns to convince people about the advantages of insulation (Policy 2).	

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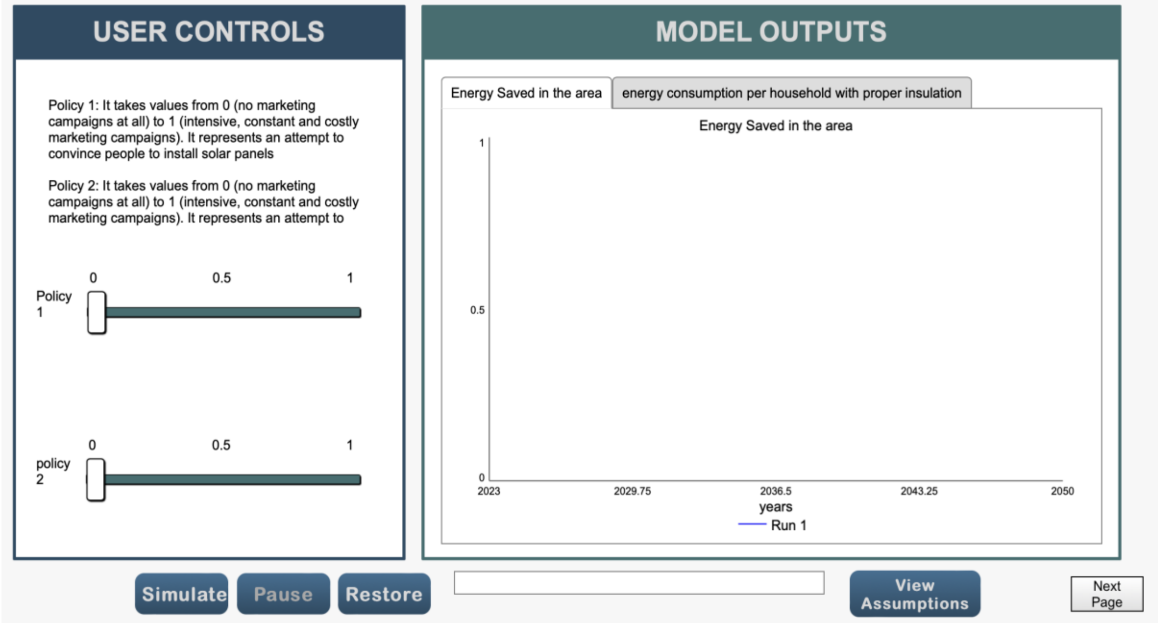

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Key insights that are revealed in the model are the following:
The model does not take into account the intermittent nature of renewable energy. For example, with solar panels to be used as the sole producer of energy for householdes, batteries are necessary.

The model does not take into account (explicitly) the other sources of energy: the decision whether people would install solar panels would also depend on the price (and availability) of those sources.

Insulation (and hence reduction in energy consumption) can be a powerful tool for a sustainable future.

Only the introduction renewables might not be the answer to sustainability.

Renewable energy and reduction in energy consumption are the keys for sustainable development.

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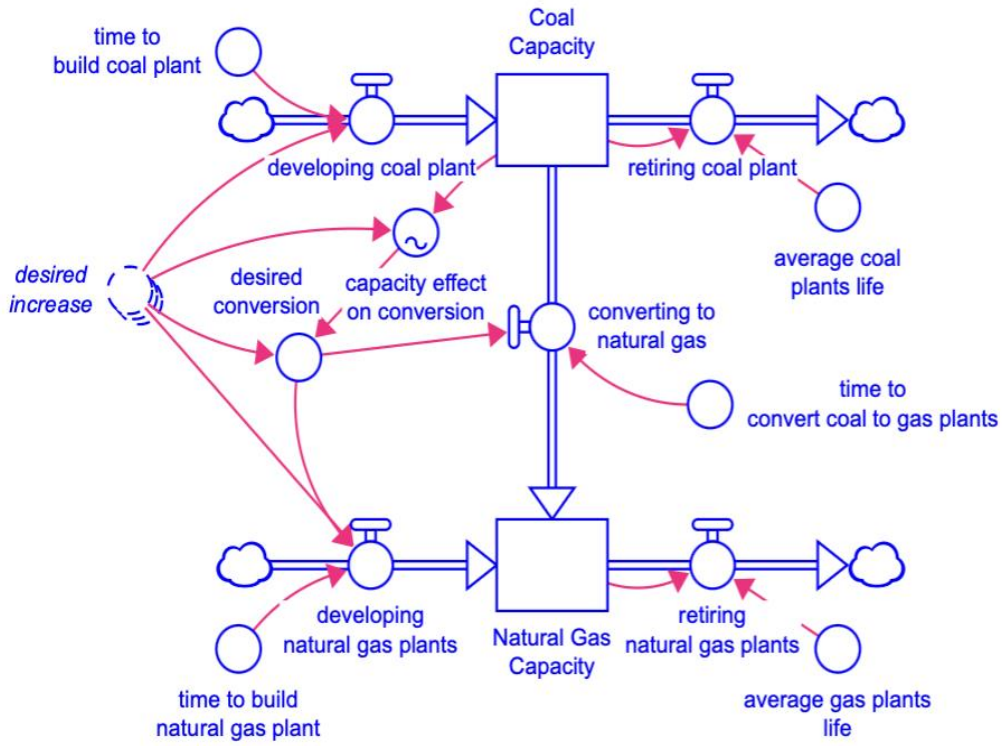
4.4.17 Model 19

Model 19	**Title:** Energy Transitions 1
Link	https://exchange.iseesystems.com/public/georgios-tsaples/sdg-labs-model-19

Objective

The purpose of the model is to illustrate in a simple manner how countries have dealt with the transition from coal plants to natural gas plants for the production of electricity.



The students are asked to experiment with the Needed capacity for the area under study, along with determining the relative price for the development of coal plants and natural gas plants.

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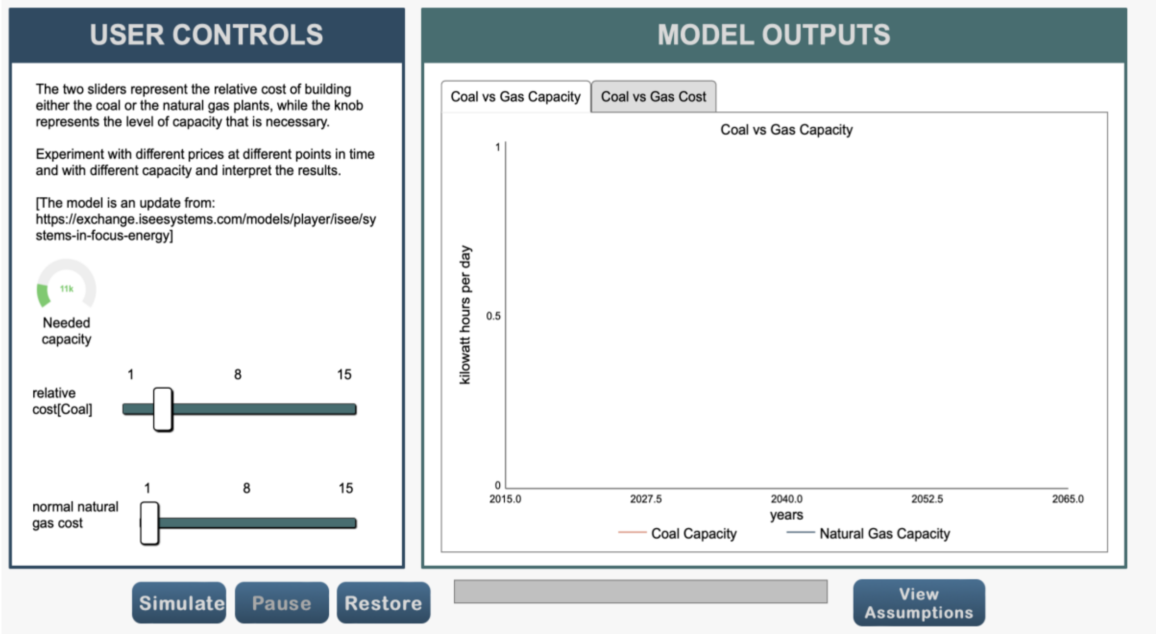

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References

https://exchange.iseesystems.com/models/player/isee/systems-in-focus-energy

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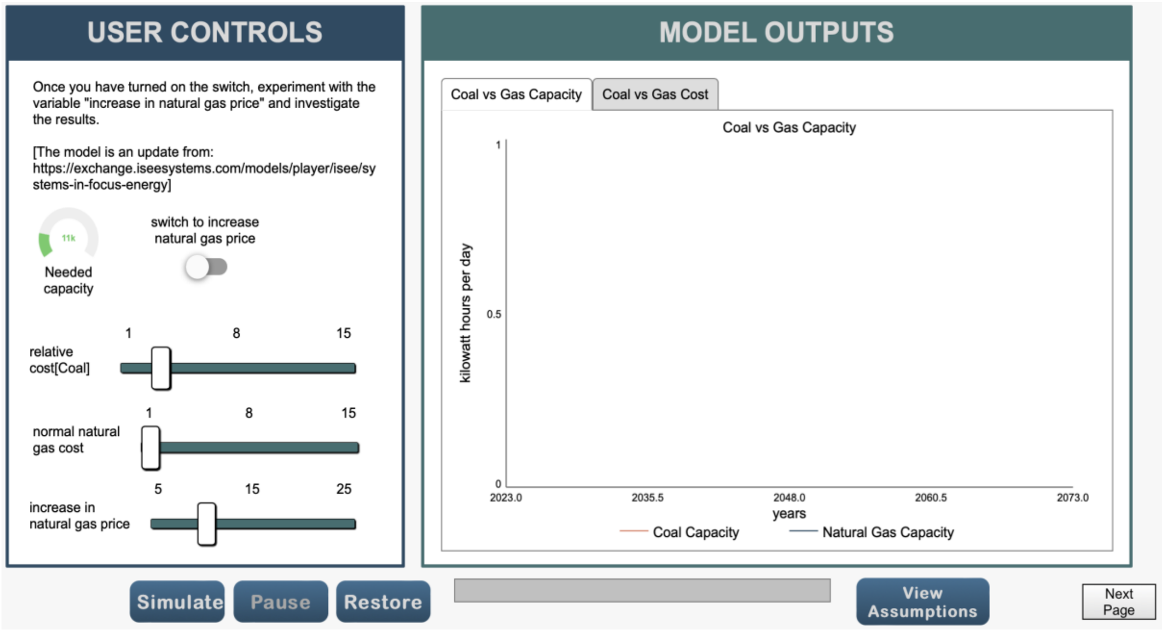
4.4.18 Models 20 and 21

Models 20 and 21	**Title:** Energy Transitions 2
Link	https://exchange.iseesystems.com/public/georgios-tsaples/sdg-labs-models-20--21

Objective

The last model entails a double update of Model 19. In the first update (Model 20), the students are asked to ponder about how transition from coal plants to natural gas can be hindered or accelerated from geopolitical events like the war in Ukraine.

The students can simulate such a critical event by turning on the relative switch at any point in the simulation time.



Moreover, once they have decided the existence of the critical event they will have to determine the increase in the natural gas price by moving the relative slider.

However, models 19 and 20 do not consider the existence of other sources for the production of electricity like hydro-power and renewable energy. Model 21 is the final update of the model where all resources for power generation are considered and in addition, a cost structure for all of them has been included.

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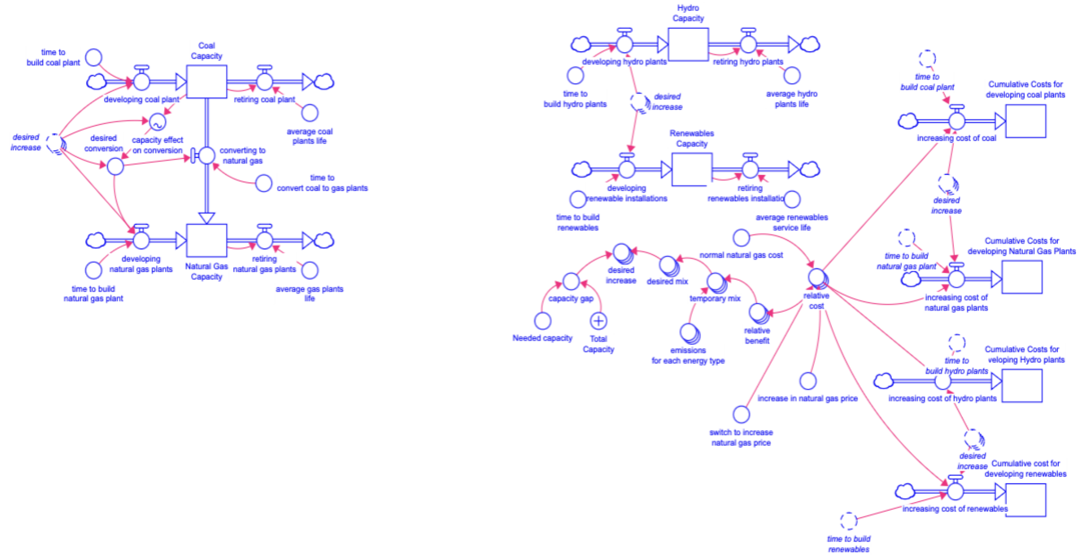
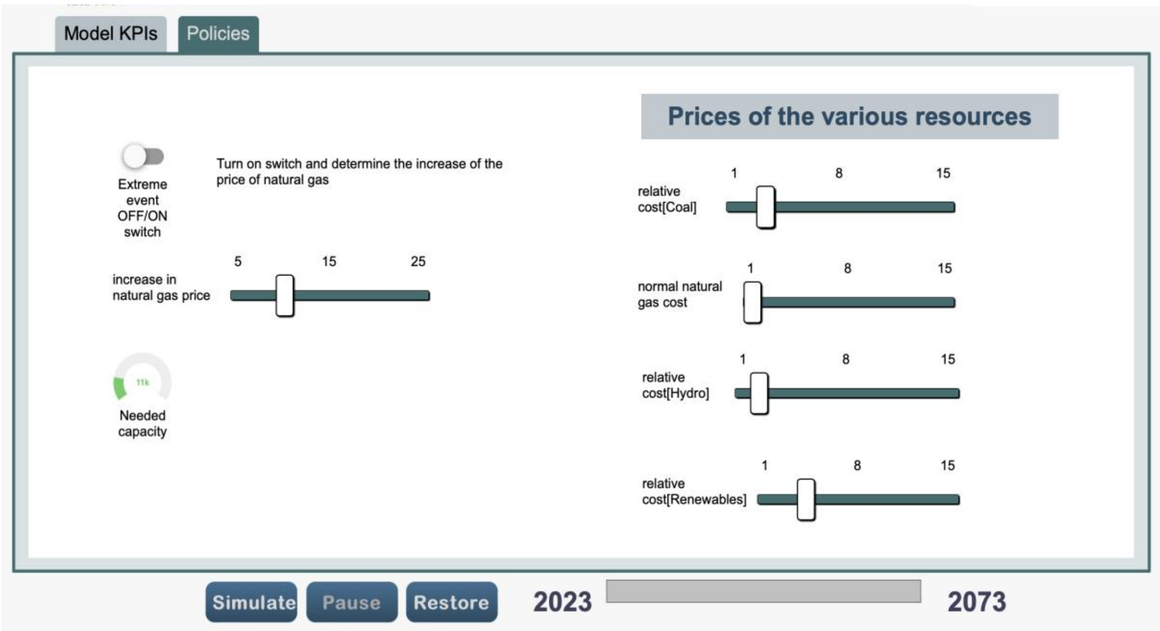


The new updated model includes the capacity from hydro plants and renewables along with their respective installation costs.

The students are asked to experiment with the prices of all the resources, the needed capacity and the extreme event of a sudden increase of the price of natural gas and try to accomplice the following objectives:

(1) keep the installation costs of all plants as low as possible

(2) try to increase the capacity of renewables as high as possible



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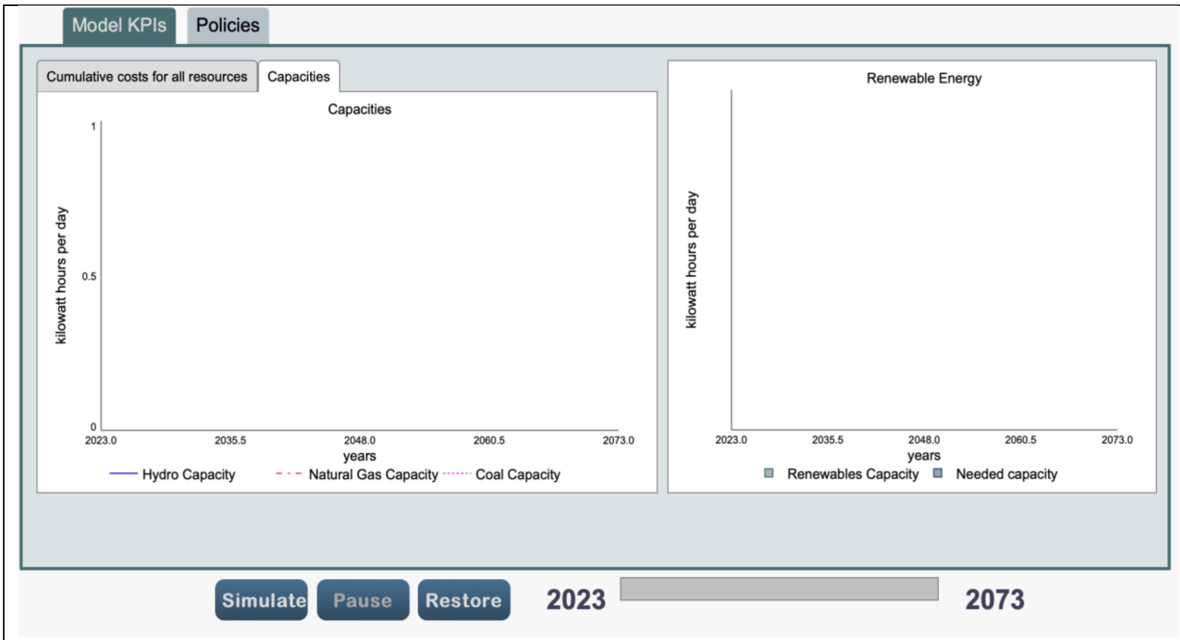

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