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1. Introduction

Helping students of higher education to achieve competences in addressing urbansustainability andadapting their decisions in that perspective is not easy because urban systems are very complex and each element of the urban system has its own role in urban dynamics. System Dynamics (SD) has provided for more than 60 years the methodological principles and the technical tools needed to address the issues of dynamic complexity in social systems and has been subsequently selected as the main methodology for this study. SD, according to a wide scientific literature and several educational experiences,helps to improve the understanding of urban dynamics, raising awareness about the related complexities and the need of system thinking approach to urban sustainability.
The competences developed by students who use SD will allow them to deal with complex decisions and decision-making processes in their future careers in private and public organizations and provide insights into the complexity and the effort required to achieve the Sustainable Development Goals promoted by UN.

To introduce students to system thinking, we have developed a small, illustrative simulation model that is described in this document. Such a model is intended to allow for simplified experimentation in a consequence-free environment. In detail, the simulation model can be used to identify scenario exemplars on how we can achieve sustainable urban transportation and a balanced societal metabolism, while taking into account formal decision-making processes. Thus, greater insights will be provided to the policy makers of the future regarding the complexities of decisions in complex environments and about uncertain issues where many stakeholders are simultaneously involved.
Building on the information and knowledge about the concepts of “sustainable mobility” and “societal metabolism”presented and explained in details by the previous Project outcomes, the research team in charge of the SDmodel defined the core relations that are at the basis of a complex urban environment, subsequently developed the simulation model, defined potential policy levers and investigated the system's behaviour.

In a later stage of the project, the simulation model will be translated into an Interactive Learning Environment (ILE) by the team of the SYDIC and will be offered as an online tool.Being available online, the ILE will allow students (along with existing policy makers and non-experts) to interact easily with the underlying SD model and experiment freely with their own decisions, thus gaining insights into which policies work best, which generate unwanted consequences and under which conditions urban systems present counterintuitive behaviour.

The innovative aspect of the ILE is that they bring the students in contact with simplified Decision Support Systems that provide them with the opportunity to see the consequences of their actions/policies without the dangers (cost, time restrictions etc.) of real life.

Building on these considerations, this work is structured as follows: Section 2 provides a brief introduction about System Dynamics, specifically presenting its key principles and describing its fundamental tools; Section 3 provides the State of the Art considering previous research in the field of System Dynamics and in reference to (Urban) Sustainability. In detail, this section summarizes the main characteristics of several SD model describing the main issue/ of sustainability being addressed, the key topics being discussed, and a list of the key variables (stocks) included in such models. External links to the original sources are also provided, where available.Section 4 presents the SD model specifically developed for this study, and hereafter named SUSTAIN Model. More in detail, Section 4.1. presents the Causal Loop Diagrams of the model, while Section 4.2. described the stock and flow diagram of the SUSTAIN Model. Last, Sections 4.3. and 4.4. offer some insights on how to use scenario analysis to test the Sustain Model, and about the key learning points that might be identified interacting with the Sustain Model.

2. What is System Dynamics

System Dynamics, proposed by Forrester (1997), is a computer-aided approach to policy analysis and design. It applies to dynamic problems arising in complex social, managerial, economic, or ecological systems—literally any dynamic systems characterized by interdependence, mutual interaction, information feedback, and circular causality (Sterman, 2000). It uses modelling and computer simulation to improve the understanding of complex systems, often associated with complex problems. The main advantage in using this type of methodology is that it provides with a vision that considers many themes inside a system as interconnected with each other, contrary to those past approaches where systems are analyzed individually and on a sectoral basis. In fact, the SD approach faces the theme of interconnection with the creation of diagrams and models, in which information, that might be deduced from such methodology, are schematized.
The system dynamics approach involves:

- Defining problems dynamically, in terms of graphs over time.
- Striving for an endogenous, behavioural view of the significant dynamics of a system, a focus inward on the characteristics of a system that themselves generate or exacerbate the perceived problem.
- Thinking of all concepts in the real system as continuous quantities interconnected in loops of information feedback and circular causality.
- Identifying independent stocks or accumulations (levels) in the system and their inflows and outflows (rates).
- Formulating a behavioural model capable of reproducing, by itself, the dynamic problem of concern. The model is usually a computer simulation model expressed in nonlinear equations, but is occasionally left unquantified as a diagram capturing the stock-and-flow/causal feedback structure of the system.
- Deriving understandings and applicable policy insights from the resulting model.
- Implementing changes resulting from model-based understandings and insights.

A system perspective implies the existence of interconnected elements to fulfill a function or a purpose over time. Those elements can be of physical or information composition. While observing food systems, for example, we find interrelations among different elements carrying out the food production, supply, processing, distribution and consumption activities. Thus, food production requires elements such as land, seeds, water, capital, workers and their labor. Some elements constitute stocks which accumulate or decrease over time (e.g., land for agriculture, water or capital), due to information or material flows. Information flows mainly drive decisions, in this case, an investment rate is made after gathering certain information on the system performance or conditions. Material flows constitute physical elements altering the state of stocks. Those accumulation processes determine the change of critical resources or drivers for food production or distribution and are fundamental to assess their sustainability (Armendáriz, V., Armenia, S., &Atzori, A., 2016).

Modelling the system under study in this way allows policy-makers to make decisions based on scientific analysis of future scenarios and provide them with a supporting tool that could be used in synergy while planning and defining policies to get economic and socio-environmental benefits (Armenia et al., 2018).

System Dynamics Tools

System Dynamics approach employs various tools for extrapolating information about complex systems and discovering hide and counter-intuitive behavior. In this sense, the CLD approach, as said typical of the Systems Thinking approach, is heavily qualitative but is the starting point for the production of a quantitative model. Notwithstanding its qualitative value, the analysis of CLDs can introduce several important results. The main advantage in using this type of analysis is that it provides with a vision that considers many themes inside a system as interconnected with each other, contrary to those past approaches where systems are analyzed individually and on a sectoral basis.
The outcome of a CLD is a combination of causal links between variables. Links can be of two types:

- Positive (S): when the independent variable (arrow tail) changes, then the dependent variable (arrow head) changes in the same direction.
- Negative (O): when the independent variable (arrow tail) changes, then the dependent variable (arrow head) changes in the opposite direction.
-

There are two types of feedback loops: reinforcing feedback loop and balancing feedback loop (indicated by + and – inside the loop). Also, it is possible to indicate a time delay between the two variables (Figure 1).

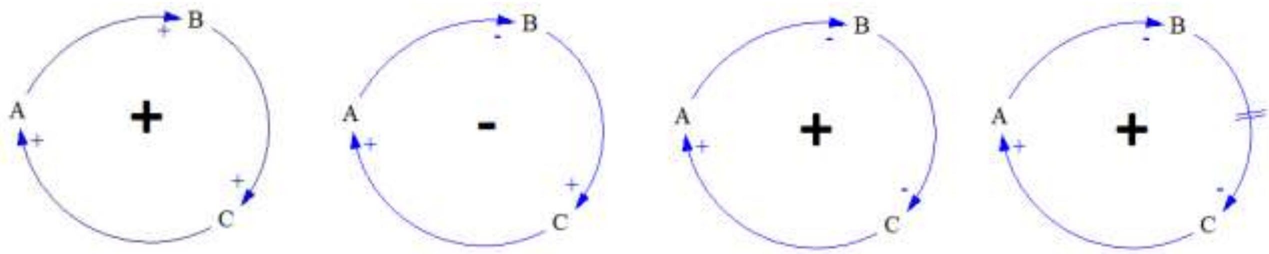

Figure 1. Starting from the left: Positive loop, negative loop, positive loop due to even number of negative links and delayed loop

Positive, negative, and delayed loops can give birth to a variety of systemic structures, named system archetypes, which can assist in taking a closer look at the problem displayed by a certain system and diagnosing the optimal solution (Mirchi et al., 2012)

Systemic archetypes are modular structures that highlight a particular behavioral pattern. They can be used, individually or together with others, to infer a set of behaviors that can be found in the evolving observable variables of a system. The Fifth Discipline by Senge (1990) states that "If reinforcing and balancing feedback and delays are like the nouns and verbs of systems thinking, then the systems archetypes are analogous to basic sentences or simple stories that get retold again and again." Therefore, founding these types of patterns inside a system, it is possible to give a deeper explanation about its dynamics and performance. Thanks to this, the following actions for fixing systemic problems will be more accurate and thorough.

Another step of System Dynamics methodology is represented by the translation of the Causal Loop Diagram in a Stock and Flow model, which is another important tool of SD. The S&F model is a simulation model that represents the system under study from a quantitative point of view, allowing user for policy experimentation in free-consequence environment. Furthermore, using computer simulation models is much cheaper in terms of cost and time, rather than experimenting with the actual system, to know if the targeted objectives could be achieved when a certain policy is implemented (Timms et al., 2011).

S&F symbolism consists of:

- the **stock** (represents things in the model that can accumulate, the stock will rise and drop depending on its flows and will remain constant while in equilibrium),
- the **flow** (is the rate of change of a stock. Inflows add to a stock, outflows take away from the stock. Equilibrium occurs when inflows to all stocks are equal to the outflows),
- and the **information link** (blue arrow in the model represent the direct influence of the current value on another).

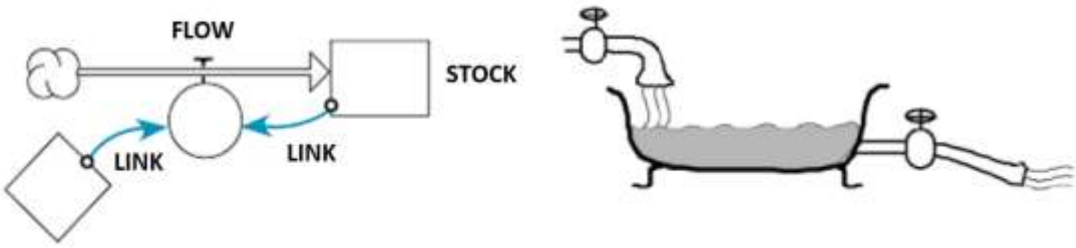

Figure 2. S&F conceptualization

In the end, SD modeling is an iterative process to get better system understanding and to design and evaluate policies. As shown in Figure 3, the modeling process demands the identification and definition of a problem or a goal. The overall system conceptualization results in a qualitative or quantitative model formalization, which often improves our initial system understanding. The simulation model allows for testing the model validity with empirical data, experimenting with policy alternatives and eliciting insights which increase the likelihood of performing a good policy analysis.

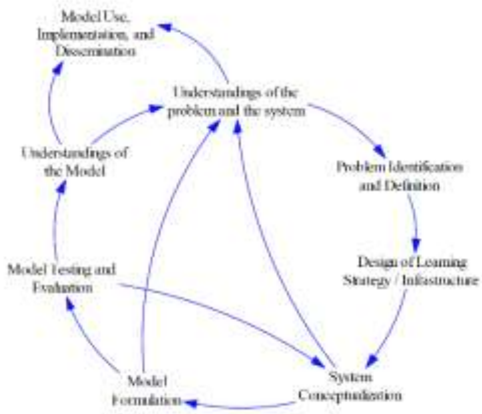

Figure 3. Model creation process

3. State of The Art about (Urban) Sustainability Models

As D. Meadows stated, “operational games based on System Dynamics models have been used in System Dynamics teaching since the first days of the field”[1].Nowadays, SD games are used to analyse complex issues in a variety of domains and sectors, thus boosting learning and decision-making.

A comprehensive review of the state of art would be nearly impossible; on the contrary, it is possible to search and dig the wide body of literature as well as the available online sources in order to get a glimpse of the extent to which SD-based games are used in education (managerial education as well as school education).

[1]Meadows, D. (1989). Gaming to implement system dynamics models. In *Computer-based management of complex systems*(pp. 635-640). Springer, Berlin, Heidelberg.

Subsequently, this literature review has as its primary sources the following ones: Google Scholar, the official website of the System Dynamics Society (SDS), the SD bibliography published on the website of the SDS, and the list of cases retrieved from the website of the SDS.

Notably, the SDS website already provides a repository of case studies dealing with a variety of system and complex issues. See the list at https://www.systemdynamics.org/list-of-all-cases (see Appendix A).

Other repositories provide a variety of case studies and SD-games. Examples can be found surfing the website of the MIT Management Sloan School and the websites of the main software houses/SD experts.

The former one (https://mitsloan.mit.edu/LearningEdge/simulations/Pages/System-Dynamics.aspx) provides a number of SD-based games (full description in Appendix B) mainly dealing with climate and environmental-related issues.

The latter refers to a number of software houses producing and promoting their own SD software, or to webpages managed by SD experts who developed SD software. These websites provide hundreds of SD simulations and models in a variety of sectors, ready to use.
In reference to the aim of this research, we mention the following ones:

- Strategy Dynamics, at https://strategydynamics.com/microworlds.aspx
- ISEE Systems, at https://exchange.iseesystems.com/
- Forio, at https://forio.com/solutions/business-strategy-simulation-games/

Notably, in reference to the aims of this research project, our review of the literature as well as of the online sources was limited to a set of complex issues (and therefore variables) considered relevant for the development of the board game. Specifically, the review focused on the key domains of urban sustainability and related keywords orsub-systems, as follows:

- **Environment**
    - Green areas
    - Purifiers
    - Waste management policies (processes efficiency improvement)
    - Waste management infrastructures and assets (landfills, incinerators)
- **Energy**
    - Consumption effect toward market
    - Market energy prices
    - Nearly Zero Energy Building
- **Transport**
    - Public transport
    - Urban zoning

    - Goods/food supply chain
- **Urban planning**
    - Road planning
    - Space allocation (housing, parks, industrial, services)
- **Services**
    - Healthcare
    - Education & Culture
    - Entertainment & Sport
    - Administration

The review subsequently allowed identifying a number of SD-based games/simulations, whose key features are summarized below.

3.1. Environment

Table 1. List of simulation model on Environment

Main Sector	Name	Main Issue and Key Concept	Key stocks
Renewable resources	Fishbanks: A Renewable Resource Management Simulation By: Dennis Meadows, John Sterman and Andrew King	Fishbanks is a multiplayer web-based simulation in which participants play the role of fishers and seek to maximize their net worth as they compete against other players and deal with variations in fish stocks and their catch. Participants buy, sell, and build ships; decide where to fish; and negotiate with one another. Policy options available to instructors include auctions of new boats, permits, and quotas. To provide the opportunity for students to learn about the challenges of managing resources sustainably in a common pool resource setting, with realistic resource dynamics. https://mitsloan.mit.edu/LearningEdge/simulations/fishbanks/Pages/fish-banks.aspx	• Fish • Ships • Money
Waste management	Sustainable Zero Waste Tyre Life Cycle (by Aldrich)	Describes the supply chain of tyres from creation to disposal, recycle and renew. Modelling zero waste supply chains, understanding processes, reorganizing phases, dealing with several dynamic issues. https://exchange.iseesystems.com/?query=waste&name=on&description=on&keywords=on&sims=on&models=on&diagrams=on&limit=100&from	• Tyres • Landfill • Tyres Recycled

		Author=	
Waste Management	(2018) Policies for Small Island States to manage tourism-driven growth while controlling waste generation the case of the Maldives	The tension between tourism-driven economic growth and environmental degradation from a limits-to-growth perspective. Findings are counterintuitive; policies focused on better waste management alone are self-defeating, because they increase tourism, growth and waste generation, undermining attractiveness and growth later. Policies that limit tourism demand improve economic and environmental health. https://onlinelibrary.wiley.com/doi/full/10.1002/sdr.1607	• Tourists • waste • resorts • tourist awareness of pollution
Waste management	(1998) Planning for sustainable solid waste management in urban India	This article presents a system dynamics model which captures the dynamic nature of interactions among the various components of the USWM system in a typical metropolitan city in India (Causal loop of socio-demographic and socio-economic structure, household structure, consumption and mobility behaviour of population) https://bit.ly/2ALJugv	(only CLD) • External costs • Total transport volume • GHG emissions
Urban metabolism (water)	(2016) A system dynamics urban water management model for Macau, China	A system dynamics urban water management model was proposed to simulate the dynamic interactions between urban water demands and society, economy, climate, and water conservation. https://doi.org/10.1016/j.jes.2016.06.034	• Water demand • GDP • Population

3.2. Energy

Table 2. List of simulation model on Energy field

Main Sector	Name	Main Issue and Key Concept	Key stocks
Energy (water)	(2018) Modelling the dynamic interactions between London's water and energy systems from an	Cities are concentrations of demand to water and energy systems that rely on resources under increasing pressure from scarcity and climate change mitigation targets. In this work, a novel system dynamics model is developed with an	(Several sub-models) • Demand Service Per Capita • Demand Consumption Per Capita

	end-use perspective	explicit representation of the water-energy interactions at the residential end use and their influence on the demand for resources. The modelling tool provides a base for this that can be adapted to the context of any industrialised country. https://bit.ly/2TFe6qX	• Efficiency Addition • Population • Water Distribution Water Supply • Water Supply Capacity Per Electricity
Energy-pollution	(2018) Dynamic assessment of urban economy-environment-energy system using system dynamics model: A case study in Beijing	The study combines System Dynamics model and Geographic Information System to analyse the energy-environment-economy (3E) system both temporally and spatially, which explicitly explore the interaction of economics, energy, and environment and effects of the key influencing factors https://bit.ly/2CZIhUh	• SO2 emission • COD emission • Nonrenewable stock • Solid waste emission • Capital input • Technology in production
Urban metabolism (carbon)	(2018) A Proposal to Integrate System Dynamics and Carbon Metabolism for Urban Planning	This study introduced a system dynamics model to study the stocks, flows, activities, and drivers within an urban system, and developed a double-layer model to implement metabolic modeling at two spatial scales. The system dynamics model is built from the perspective of demand-driven to simulate the input of different resources and materials in the urban metabolism. https://bit.ly/2RGbTOk	• population • income • industrial commodities • agricultural stock • total wealth product

3.3. Transport

Table 3. List of simulation model on Transport field

Main Sector	Name	Main Issue and Key Concept	Key stocks
Transport	(2014) A review of system dynamics models applied in transportation	A review over 50 journal papers which have applied system dynamics to a transportation problem, which demonstrates the application of CLD or Stock flow models which provide something different to the more traditional transport modelling approach either in terms of insight or coverage of the problem	(several models) • Congestion • vehicles • CO2emission

		https://www.tandfonline.com/doi/abs/10.1080/21680566.2014.916236	
Transport - air pollution	(2002) Using system dynamics to improve public participation in environmental decisions	Computer simulation models and systems thinking could be powerful tools for democracy, This article describes a case study using group model building to support a stakeholder advisory group examining transportation and related air quality problems. One of the most valuable effects of the approach was the information feedback it added to the advisory process. https://onlinelibrary.wiley.com/doi/abs/10.1002/sdr.237?casa_token=ypuyfA4EAcgAAAAA:Ofh6p2V3yRHrU4vuvC7-QA16uSW6U49_SXlscOFnit1M_MEqguKRQatXmP50foG10llodpr-MY3U	(17 stocks, e.g.) • Population • lane miles • buses • CO • bicycle routes
Urban transport	(2015) Evaluation of sustainable policy in urban transportation using system dynamics and world cities data: A case study in Isfahan	Urban transportation causal loops were conceptualized and the dynamic relations among urban transportation variables were created to develop the pertinent urban dynamics model. Trip generation, modal share, transportation supply and equilibrium between supply and demand were the key modules of the developed model. https://doi.org/10.1016/j.cities.2014.11.003	(only CLD, main variables) • Transportation pollution • Transportation energy consumption • Transportation land consumption • Transportation cost for government • Direct trip cost for user • Indirect transportation cost for user
Transport	(2013) A System Dynamics Approach for Evaluating Policies on Prioritizing Public Transportation	The paper provides a modeling framework based on the system dynamics approach by which policy makers can understand the dynamic and complex nature of the policies on prioritizing public transportation within a transportation socioeconomic system. By using this framework, researchers and practitioners can make modifications on the	• GDP • Population • NOx • Number of private vehicles

		system structure to evaluate the impacts of policies on prioritizing public transportation such as: license control policy, policy of low fares, traffic control policy. https://www.scientific.net/AMM.391.628	
Transport	(2010) A systems dynamics approach to explore traffic congestion and air pollution link in the city of Accra, Ghana.	The paper aims to provide a system dynamics perspective of the problems. Most of the drivers and cause-effect relationships of traffic congestion and its attendant air pollution are investigated and analyzed using causal loop diagrams. Through causal loop diagrams, alternatives were proposed to limit the effectiveness of negative loops. The goal is to stimulate public transport use while decreasing car use in the near future. Three main measures that policy makers could consider are development of a public transport system, road network expanding and enhancing, and travel demand management alternatives https://www.mdpi.com/2071-1050/2/1/252	CLD only
Transport	(2013) System dynamics model of Shanghai passenger transportation structure evolution.	Based on the data from a comprehensive transportation survey of Shanghai in 2004 and 2009, this paper analyzed the evolution of urban passenger transportation structure using the system dynamics approach. Using statistical methods to calibrate the parameters and validate the model. This model is practical in actual quantitative analysis of the evolution of Shanghai passenger transportation structure. The next step is to apply this model to simulate the dynamic development trend of Shanghai urban passenger transportation structure for long-term dynamic strategic quantitative analysis https://www.sciencedirect.com/science/article/pii/S1877042813022532	• Population • Car • Coach • Motorcycle • Taxi • Bus • Rail • Truck
Transport	(2011) Factors analysis of urban transport system in Beijing: Based on system dynamics	This paper first establishes a system dynamics model of Beijing urban transport system. Then, based on data simulation, it tries to find out the main factors of urban traffic and its impact on urban transport. According to the simulation results, we propose	• Total number of family • Parking spaces • Car price • Population

		the following traffic control measures:(l) Compared with the vehicle purchase tax, The policy effect of fuel surcharges is more obvious, it can be taken as the focus regulatory methods;(2) In a certain stage, GRPC is obvious positive correlate with RPPD, therefore, Beijing should accelerate the development of subway system;(3) Increase in the number of public buses, with optimized circuit design and improved bus service, private car growth rate can be adjusted. https://ieeexplore.ieee.org/document/5986549	• Disposable income per capita • Number of private cars • bus • taxi Fuel cost • Rail passengers
Transport	(2019) The Brazilian urban mobility policy: The impact in São Paulo transport system using system dynamics	This paper aims to analyze the influence of Brazilian policies in the urban transport system focusing on environmental, economic and traffic variables. For this, it conducted a case study in the Metropolitan Region of São Paulo (MRSP). The results point to the importance of the policy implementation to reduce the negative externalities of urban transport system. A strong policy implementation reduces the emission of pollutants, especially if the learning in its implementation is fast. The desirable impact of Mobility Management strategies implementation in the traffic congestion was achieved when this implementation is rapid and effective. In the proposed model, the BUMP encourages only the replacement of private transport by the public transport. The model did not check the policy effect for replacing the motorized modes by nonmotorized ones. https://www.sciencedirect.com/science/article/pii/S0967070X17302354	• Vehicle population • population • GDP • Number of public bus • Road network • Stock of CO2
Transport	(2003). System dynamic applied to study the urban traffic congestion of Hanoi	The paper aims to provide system dynamic approach applied to study the existing urban transportation situation of Hanoi. In the paper, all causes and effects of traffic congestion was investigated and analyzed by the effected method. Long-term policies and measures are proposed and evaluated based on it. In order to avoid the positive loop (3),	CLD only

		government policy and planning would be considered as a main factor to affect transport situation of Hanoi. Development of public transportation system is the first priority, with busses. On the supply side: capacity of transportation system in general and road network in specific is needed to expand. On the demand side: travel demand management is needed for reducing the potential increasing number of motorcycles and cars. Many alternatives to control the number of private vehicles were proposed, for example, import tax, motorcycle and car registration fee, vehicle owner fee, different prices of petrol for public and private vehicle. https://www.semanticscholar.org/paper/SYSTEM-DYNAMIC-APPLIED-TO-STUDY-THE-URBAN-TRAFFIC-Anh/c2ff5eb9b5d8a17ed498c68fb2cc952f3800bf00	
Transport	(2008) System dynamics model of urban transportation system and its application	This paper presents a system dynamics approach based on the cause-and-effect analysis and feedback loop structures. The proposed SD model comprises 7 submodels: population, economic development, number of vehicles, environmental influence, travel demand, transport supply, and traffic congestion. The suggestions to the policy on vehicles include three aspects: (i) restrict the ownership and use of vehicles in an acceptable way; (ii) restrict private vehicles and simultaneously improve the service level of public transport; (iii) implement the restriction policy and simultaneously put emphasis on the research and development of emission-reducing technologies. https://www.sciencedirect.com/science/article/abs/pii/S1570667208600276	• GDP • Population • Stocks of NO2 • Total-lane kilometers

3.4. Urban planning

Table 4. List of simulation model on Urban Planning

Main Sector	Name	Main Issue and Key Concept	Key stocks
Urban planning	(2011) How small system dynamics models can help the public policy process	The major strength of the URBAN1 model is its ability to illustrate in a concise manner how the feedback structure of an urban system can endogenously generate stagnation and then decay. (…) Growth does not slow fast enough, though, to prevent overshoot in the population, stock of housing, and stock of business structures. (…) Eventually, an equilibrium is reached in which "the standard of living declines far enough to stop further inflow" (…) https://www.sciencedirect.com/science/article/pii/S0895717711003803	• Business structures • Population • Housing
Urban planning	(2018) A system dynamics model for simulating urban sustainability performance: A China case study	The sustainability performance of Beijing from 2005 to 2030 is simulated based on three scenarios https://doi.org/10.1016/j.jclepro.2018.07.154	• Total population • Urbanization rate • GDP
Urban agriculture	(2018) Participatory systems approaches for urban and peri-urban agriculture planning: The role of system dynamics and spatial group model building	System dynamics and participatory planning can be used in urban agriculture policy. https://doi.org/10.1016/j.agsy.2016.09.022	• Marketed products • consumer awareness • income • population • Participant UA

3.5. Services

Table 5. List of simulation model on Services

Main Sector	Name	Main Issue and Key Concept	Key stocks
Education	The University Game By: Barlas and Diker	The model focuses on the academic aspects of university management systems. It specifically deals with resource allocation and provides a broad set of performance indicators to monitor the results of these allocations. Understanding complexity in an academic setting. Learning to balance a set of policies. https://www.researchgate.net/publication/221000175_An_interactive_dynamic_simulation_model_of_a_university_management_system	• Graduate Faculty Members • Under-graduate Faculty Members • Vacant Positions • No. of Students
Services	People Express Simulator By: Sterman	Managing a company, in order to promote growth and a quality service. Key decisions: Aircraft purchases, Fares charged, marketing as a fraction of revenue, hiring and target service scope. The purpose of the simulator is to give the player insight into the issues raised by the case; to illustrate the difficulties of co-ordinating operations and strategy in a growth market; and to understand the dynamic interconnections among a firm, its market, and its competitors. https://strategydynamics.com/microworlds/people-express.aspx	• Aircrafts • Customers • Cash
Services	EBank Simulator By: Kim Warren	eBank presents the difficult challenge of matching staffing levels with rapidly varying workloads, when there are unavoidable delays in getting the staff required. Customer acquisition and retention is dictated by interest rates being set. Balancing of key resources is vital for successful business performance, and difficult when things are changing fast. https://strategydynamics.com/microworlds/ebank.aspx	• Savers • Trainees • Experienced staff
Services	Beefeater Restaurants	Users act as the executive management team of a business starting with 10 restaurants and work to grow	• Customers • Restaurants

	By: Kim Warren	the business and its profitability over 10 years. Decisions control customer experience, profitability, and business growth. Business performance over time (growth in sales and profits) depends on building the organization's resources, which requires investor support. https://strategydynamics.com/microworlds/beefeater.aspx	• Cash
Healthcare	Design of Simulators to Enhance Learning: Examples from a Health Care Microworld By: Hirsch G.B. and Immediato J.M.	The model stimulates to understand competitive market dynamics in a highly complex system. Also, it aims at teaching how to manage resources, balance short and long term effects, and allocate resources. Management simulators can be effective tools to improve strategic thinking in an organization and help its management and other staff respond to change. https://www.garybhirsch.com/health-care_files/a-health-care-microworld-paper-1.pdf	• Population • Health Status • Cash

4. SUSTAIN Model

4.1. The Causal Loop Diagram

The SUSTAIN CLD is composed by different variables, that represent areas of interest in a general modern urban system. The model, in fact, considers general aspects as GDP and population, as well as environment, transport, urban planning, waste and water management.
As the CLD (and subsequent Stock and Flow diagram) will be the basis for the future development of the game, which is the main outcome of the project, the core of the model is represented by the most important parameter for deciding who will win the game, i.e. the Attractiveness of the city. This variable is the synthesis of multiple variables that belong to many aspects of the urban system, defining the "wellbeing" of the population who lives in it.

The most important effect due to variations in the Attractiveness of the city is a variation of the number of people who lives in the city; this generates many impacts on different urban levels, triggering as many feedback loops. In fact, the majority of feedback loops we identified passes through the "Population" variable. It is kind of natural that this happens as, in the end, urban systems exist because of its inhabitants, indeed.

Analyzing the CLD, the most important feedback loops were identified and then divided into three main groups.

The first group is composed ofloops belonging to the “core” of the model, that is the relation between population, GDP and Industries and Services.

The first two reinforcing feedback loop (R1 – R2) trigger when a variation in the Attractiveness of the city causes an increase in population, which generally has a positive effect in GDP; the more the GDP the more the development of industries and services, this generates a twofold positive effect on attractiveness: on the one hand, there is the availability of more services and developed industries; on the other hand, more services and industries means more jobs for inhabitants. The former phenomenon is limited by the balancing feedback loop (B1), which depicts the saturation of jobs in the city. Finally, GDP and Industries and Services are tight together by a simple reinforcing feedback loop (R3).

The second group is composed ofloops which belong to the “environmental” part of the model. Water, waste and transport have direct impacts on the total pollution and, in turn, on the attractiveness of the city.

As opposed to the reinforcing loops met previously, there are two balancing loops (B2 – B3) that stabilize the attractiveness of city through the possible increase in population which cause an increase in waste generation and water consumption, with consequences on pollution and water shortage phenomena.

The reinforcing feedback (R4) describes how traffic congestion has an effect onthe usage of public transport and, in turns, effects on pollution. This loop is balanced by two loops (B4 – B5): on the one hand, the usage of public transport naturally reduces the problem of traffic congestion; on the other hand, external policies could increase the roads’ capacity and length addressing the same problem.
The last group of loops concerns “land availability”. Cities cannot grow indefinitely, above all, it is important to dedicate some space for green areas and parking space, which complete the viability of the city.

The three loops belonging to the third group are balancing loops which limit:

- Roads extension due to congestion (B6);
- Households construction due to population (B7);
- Industries and Services development due to GDP (B8).

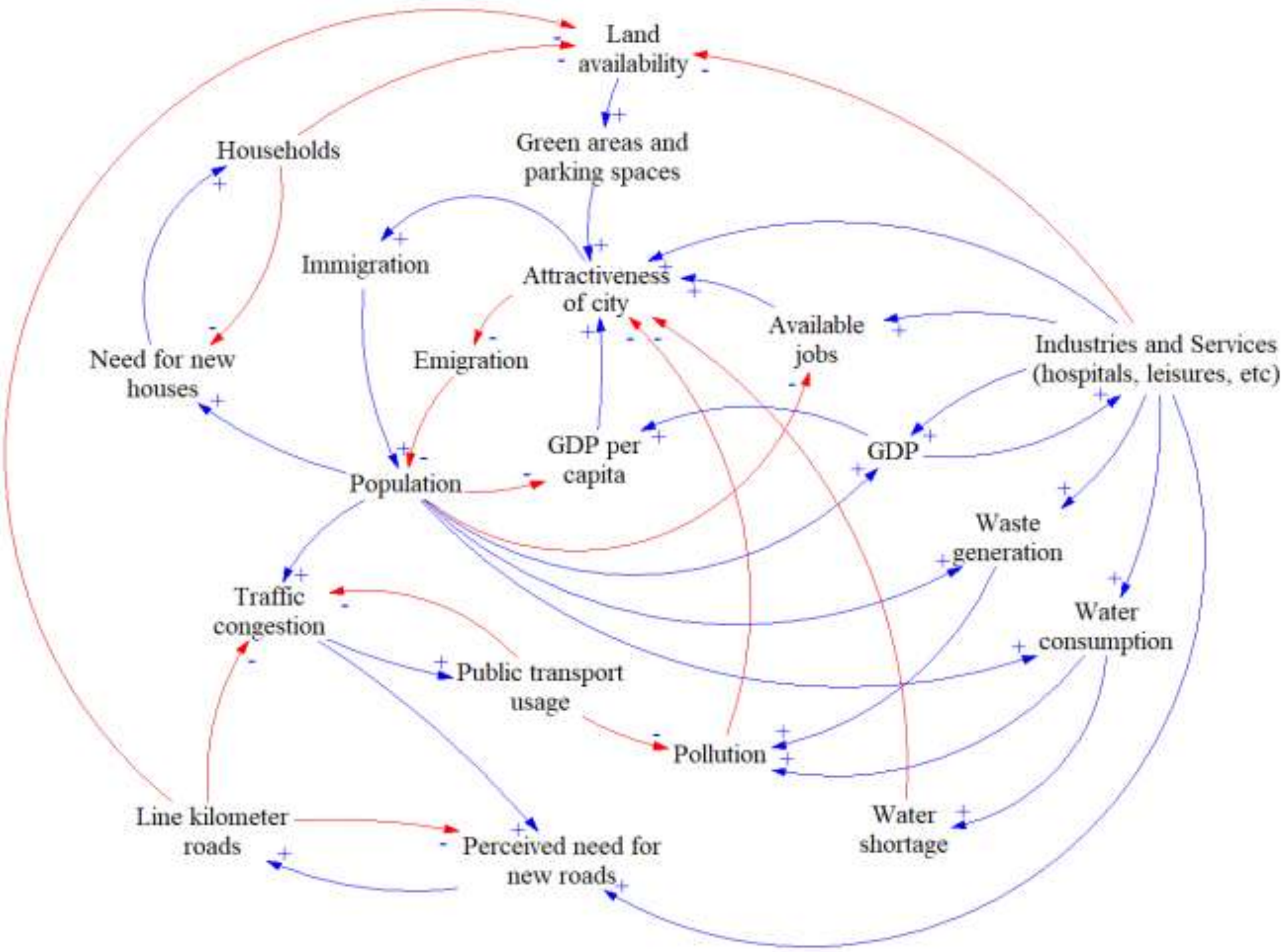

Figure 4. Overall CLD model

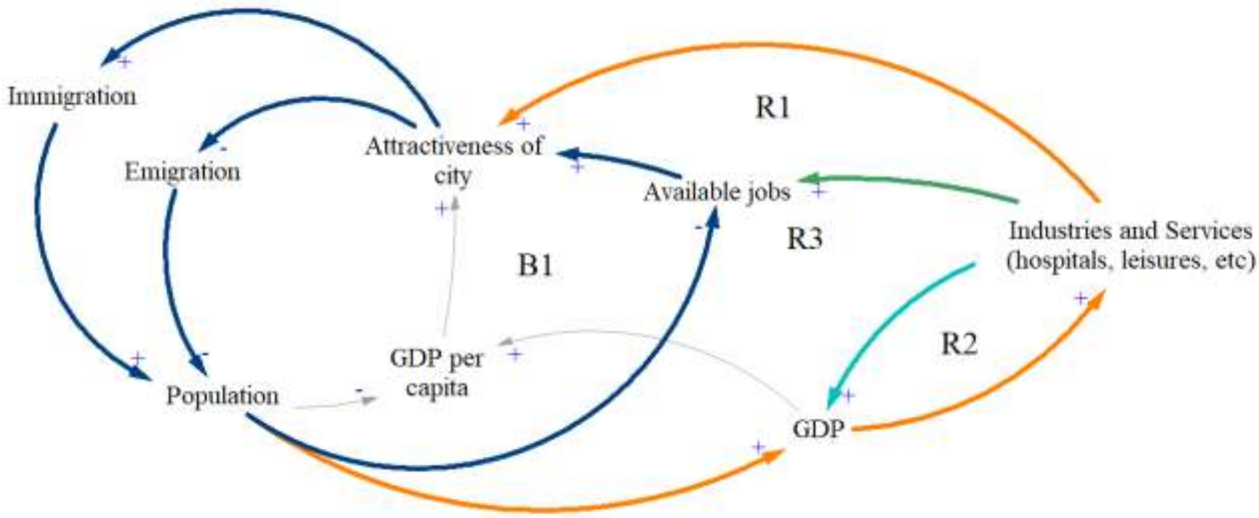

Figure 5. Causal loops part 1

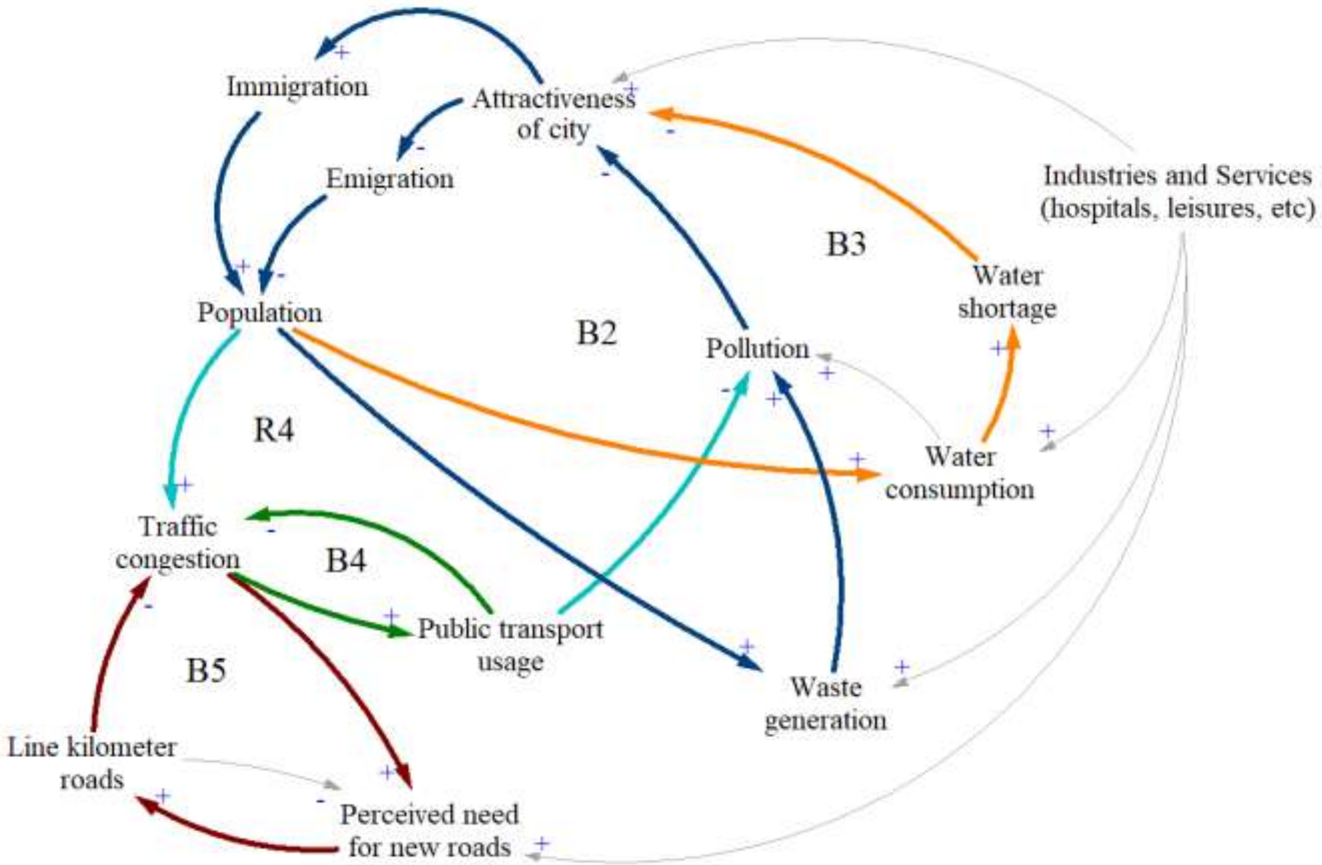

Figure 6. Causal loops part 2

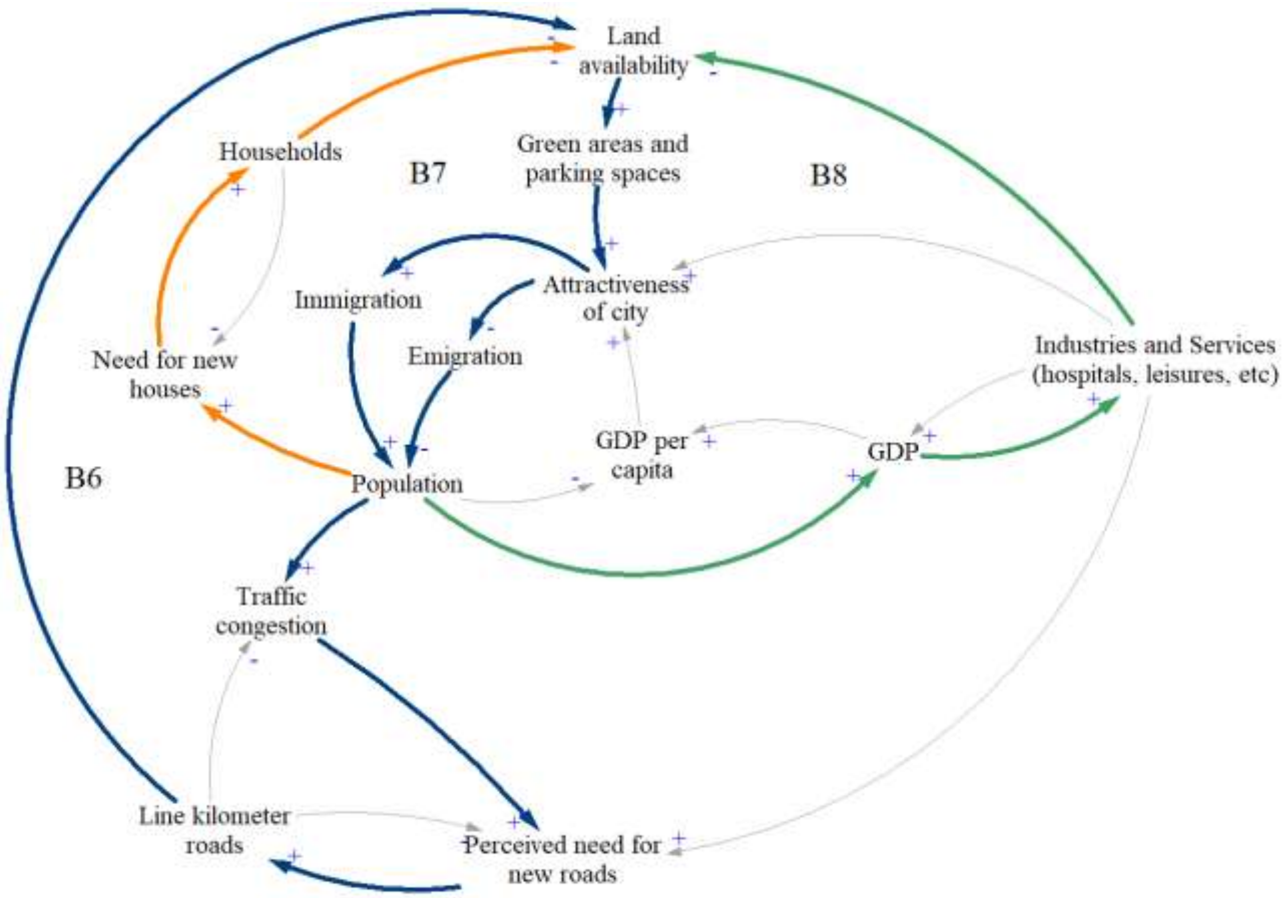

Figure 7. Causal loops part 3

4.2. The Stock and Flow model

The SUSTAIN model that we are going to describe is a Stocks&Flows Diagram (SFD). This delivery intends to convey the structure of the overall model, from which theSUSTAINboardgame can be designed. The small illustrative simulation model will allow for experimentation in a consequence-free environment. The simulation model can be used to identify scenario exemplars on how we can achieve sustainable urban transportation and a balanced societal metabolism, while taking into account formal decision-making process. Thus, greater insights will be provided to the policy makers of the future regarding the complexities of decisions in uncertain issues where many stakeholders are involved.

The wholemodel will be available in the project's website in the form of an Interactive Learning Environment that will allow students (along with existing policy makers and non-experts) to experiment freely before and after playing the game.

Of course, we do not expect that all of the aspects that are included in the simulation model will be implemented/accounted for also in the boardgame; specifically, we have developed the

simulationmodel by focusing on the key elements that were already considered in our preliminary design as well as those provided byrelevant literature (already presented in Section 3 of this report).
The model is divided into several sections:

- Investment-general variables
- Transport
- Waste management
- Water management
- Environment
- Energy
- Urban planning
-

Each of them has its own variables and internal dynamics, but, from a systemic point of view, they can be seen as a whole big system which represents the concept of a "city".
In fact, there are many links and interconnections between variables belonging to different sections.
For example, building a new school has animpact not only at urban planning level (because it occupies a portion of available land), but also on waste and water management and energy (new activities, additional consumption of resources, additional waste).
In order to provide a realistic reference and use real data, we selected Bologna as a representation of a medium-sized city, with 388,000 citizens and a defined use of the territory. Therefore, all the parameters of the model (such population, land covers, etc.) are derived or approximate those of the common statistics of the municipality of Bologna.

Table6. Default city'scharacteristics

	Initial used value
POPULATION	388,000
CITY'S BUDGET	20M €
URBAN PLANNING	
Total area	7.972 ha
Business units	800
Parks	72
Houses (nearZero Houses)	147k (23k)
Hospitals	3
Areas for education (Schools)	100
Leisure & sport areas	250 ha
Total urban roads	1600 km
TRANSPORT	
Private vehicles (electric)	106k (4,3k)
Public vehicles (electric)	300 (70)
% of citizens using public transport	25%
EMISSIONS	
NOx	2,25B g
PM10	200M g
WASTE & WATER	

Waste in Landfill	5M tons
Water (reservoir)	110B liters

The objective

The basic objective of planning and managing a city, here of ILE and board game, can be summarized in trying to increase simultaneously:the population (social aspect), the city's budget (economic aspect) and the environmental well-being (environmental aspect). The success (or failure) will be measured with the following parameters:

1. Population number (maximizing);
2. City's budget(maximizing);
3. NOx and PM10 (minimizing);
4. Water availability(maximizing).
5.

The optimization goal can be reached by investing in specific sectors, but it is also necessary to pay attention to the side effects of each investment. Only by "thinking in the systems" such planning and management of a city can be sustainable.

Investment-general variables

The most important variables of the model as a tool to connect to the board game are the Investments, these represent the decisions of the players in terms of type of investment and amount of money invested.Notably, there are two main kinds of investments. The first group includes investments that will directly affect specific stocks (i.e., resources) and, indirectly, the Attractiveness of the city, these are:

- Investment on Hospitals
- Investment on Schools
- Investment on Business Units
- Investment on Houses
- Investment on nearZero energy Houses
- Investment on Houses conversion to nearZero energy
- Investment on Leisure and Sport areas
- Investment on Parks
- Investment on New Roads
- Investment for new traditional public vehicles
- Investment for new electric public vehicles

The second group of investments is devoted to maintaining the efficiency of existing public equipment and infrastructures at the standard level (i.e., if the players do not invest money in these maintenance activities the efficiency of equipment will be lower than usual). These investments include the following ones:

- Investment to encourage electric vehicles adoption
- Investment on recycling
- Investment forwater purification
- Investment for wastewater infrastructure

Table 7. Available investment for policy-makers

INVESTMENT DECISION	DESCRIPTION	UNIT COST
Investment on Hospitals	All big cities need hospitals. Their number has to be adequate to the size of population. In this model is possible to create new hospitals but this requires time (**4 year**), so it is impossible to fill the gap instantly, but it is necessary to plan accurately.	200M
Investment on Schools	All cities need schools. Their number has to be adequate to the size of population. In this model is possible to create new hospitals but this requires time (**2 year**), so it is impossible to fill the gap instantly, but it is necessary to plan accurately.	3M
Investment on Business units	To develop the economy of city, it is necessary to create new business areas to attract new investors. This will create many new jobs for new potential citizens.	2,25M
Investment on Houses	The citizens need houses to live. If there are no empty houses, there cannot be new citizens.	103k
Investment on nearZero energy Houses	Near-Zero houses have the same function of traditional houses with a higher cost, but the impact of these houses on city's energy consumption is 0 (with benefits for the energy supply system).	140k
Investment on Houses conversion	It is possible to make a conversion of some actual traditional houses into near-zero layout. This is useful when city's energy consumption decrease is needed quickly.	32k
Investment on Leisure and Sport areas	This variable includes all the leisure services, entertainment, recreations and sports that make the city a pleasant place to live.	21M
Investment on Parks	City parks and green areas serve an important purpose: in the midst of the population centers, they provide a sense of peace and relaxation. Their extents must be adequate to the city's area.	8M
Investment on New Roads	When population grows, the number of vehicles grows as well. Increasing the capacity of the vehicle network is one of the potential solutions in the short-term.	20k per km
Investment for new traditional public vehicles	Local public transport of city has its own fleet that could be enforced by increasing the number of buses. This choice gives benefit to the vehicle network because less private vehicles will circulate on roads.	200k
Investment for new electric public vehicles	The purchased buses could be also electric. Their cost is higher, but they guarantee no emissions compared to the "traditional" ones.	400k

Investment to encourage electric vehicles adoption	To tackle the emissions from vehicle traffic, it is possible to push the citizens to purchased new electric cars, for example by delete parking fees for electric cars or to make available more charging centers around the city.	-
Investment on recycling	The waste generated by city activities need to be processed and managed. One of the solutions is to recycle part of the total waste.	-
Investment forwaterpurification	The water is a scares resource that is fundamental for the city life. A percentage of wastewater could be reused as long as sewage treatment plants work well thanks to investments.	-
Investment for wastewater infrastructure	Investments in wastewater infrastructure guarantee that there will be no water losses throughout the network.	-

Beyond these, the most important variables are those forming the core of the model: Population, Attractiveness of the city, Pollution, City Budget.

A city exists, indeed, when some persons live in it. Every aspect of the city is affected by the number of persons that live in the city. The more the persons, the more the resources consumed, activities carried out, waste generated, etc. Population varies over time depending not only on its net birth rate (births – deaths) but also on immigration and emigration.

The Attractiveness of the cityrepresents the “wellness” and the satisfaction of the citizens and is influencedby severalvariables (e.g. number of schools andhospitals, level of pollution in the city, etc.). Notably, all these variables, directly through the Attractiveness of the city, or indirectly in the form of a constraint, influencemigration rates in and out of the city, thus defining thepopulation level.
The level of Pollution is a significant factor that can definitely impact on the life of citizens and also determine their decision of leaving the City. In this model, pollution is considered as the cumulative effect of NOx and PM10 emissions.

The City Budgetrepresents the liquid assets at the city administration’s disposal. Taxes from people and business activities, as well as revenues from public transport and value from recycled materials, increase the City Budget, which is subsequently (based on actualavailability) reinvested in different city sectors.

The section of the SUSTAIN Model that depicts the variables aforementioned is shown below.

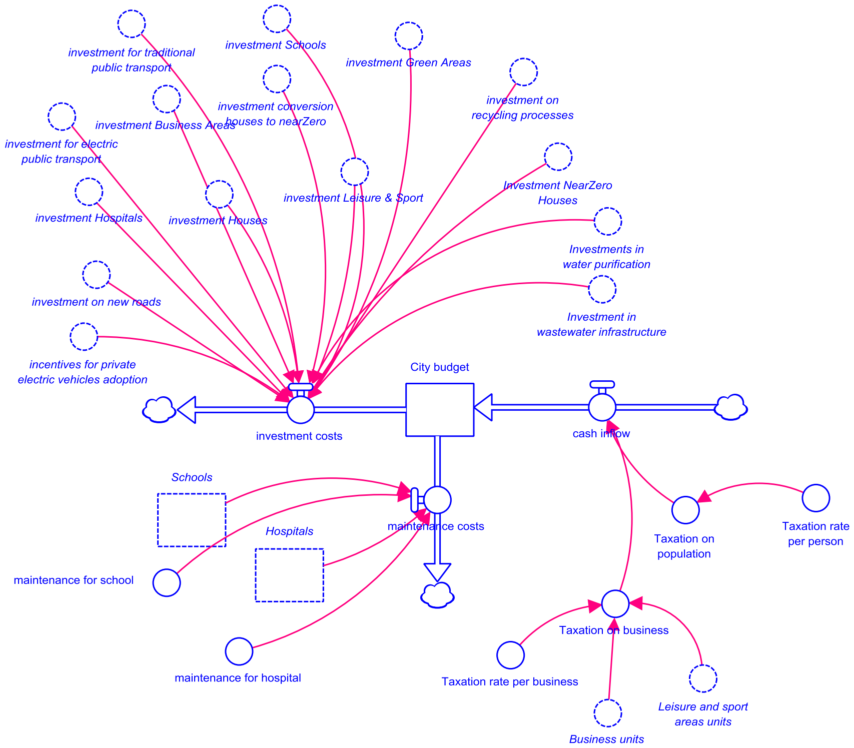

Figure 8. Investment-general variables

Transport

The transport sector in the model reflects a high-level description of transport dynamics inside a city. There are three transport choices for citizens: private vehicles, electric private vehicles or public vehicles. The latter could also be traditional or electric, but this depends on the policy-maker's decision. Based on the usage of one or the other mode there is a variation in the number of private vehicles (i.e. new cars purchase), and therefore the car fleet in the city. There are also other variables outside the transport section which affect this variation (i.e. standard purchase rate or adequacy of charging infrastructure for electric cars). The variation of private vehicles which circulate inside the city produces important feedback at section level as well as at overall model level.

The modal choice is the core aspect in this section, for the reasons explained before, and is defined by two essential factors: Cost and Time.

The cost factor is represented by the cost ratio between the annual cost for private transport and the public one. Each citizen has an annual average kilometer per capita. Private transportation cost results from private car fixed costs (insurance, maintenance, car purchase) and variable cost (fuel) times annual kilometers. While public transportation cost results easily from price per kilometer and annual kilometers.

The time factor is represented by the ratio of time needed to arrive atthe destination with both modes, considering the different mean velocity.

Public transport fleet could be developed by investing both on traditional (e.g. petrol busses) and electric vehicles (e.g. trams). Each of them has different costs of purchase and maintenance, also they have a different impact in terms of GHG/CO2 emissions.

Such sector is controlled by Urban planning sector through the planning of new lane-kilometers.At the same time, investments on roads have an impact also at the urban planning level, because they consume the city's land availability for other buildings and activities.

Another important factor is represented by traffic congestion, which is due to the number of private vehicles, public vehicles and network capacity. The congestion negatively affects the attractiveness of the city indirectly by the related traffic emissions which influence the sector Environment (that in turn has impact on the attractiveness of the city).

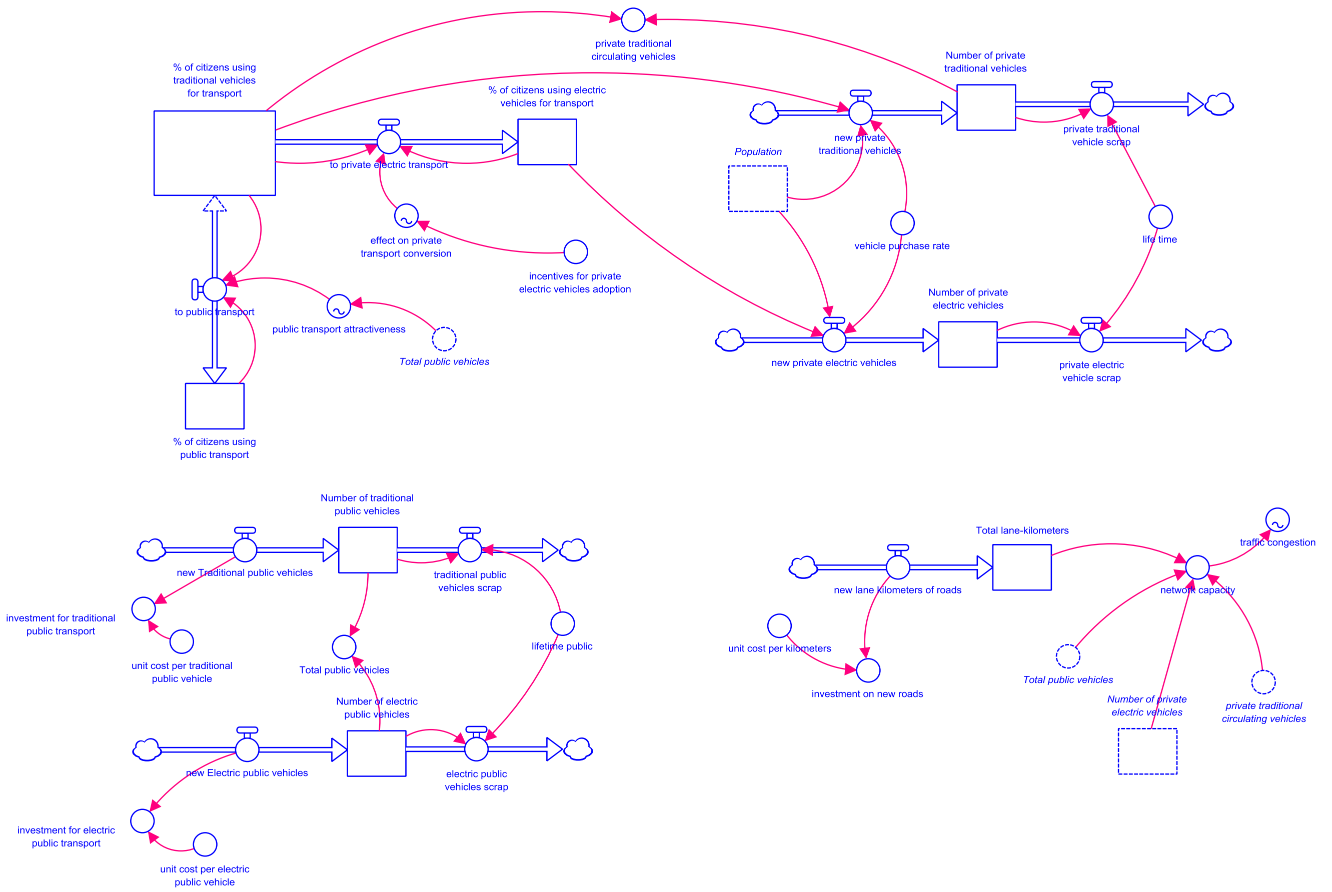

Figure 9. Transport section

Waste management

The Waste Sector is modelled in order to representthe whole cycle of waste from its generation to its disposal, elimination and/or transformation into recycled raw materials. In detail, the supply chain makes clear that waste is first generated (it depends on the number of the various activities in the city and the average waste generated by each class of them) and needs to be managed and processedsubsequently. Three main outputs can be obtained managing the waste generated in the city. First, part of the waste isrecycled; second and subsequently, part of the waste is burnt using the incineratoror sent to the Landfill. These rates depend on the levels of investments carried out in this sector by the players. Specifically, the players have to decide the levels of investments devoted to recycling activities, which are needed to avoid sending a great amount of waste to the incinerator or the Landfill.

Notably, this area impacts on other sectors, since the Landfill generates pollution, the incinerator provides energy but also generates emissions, and recycled materials are worthy.

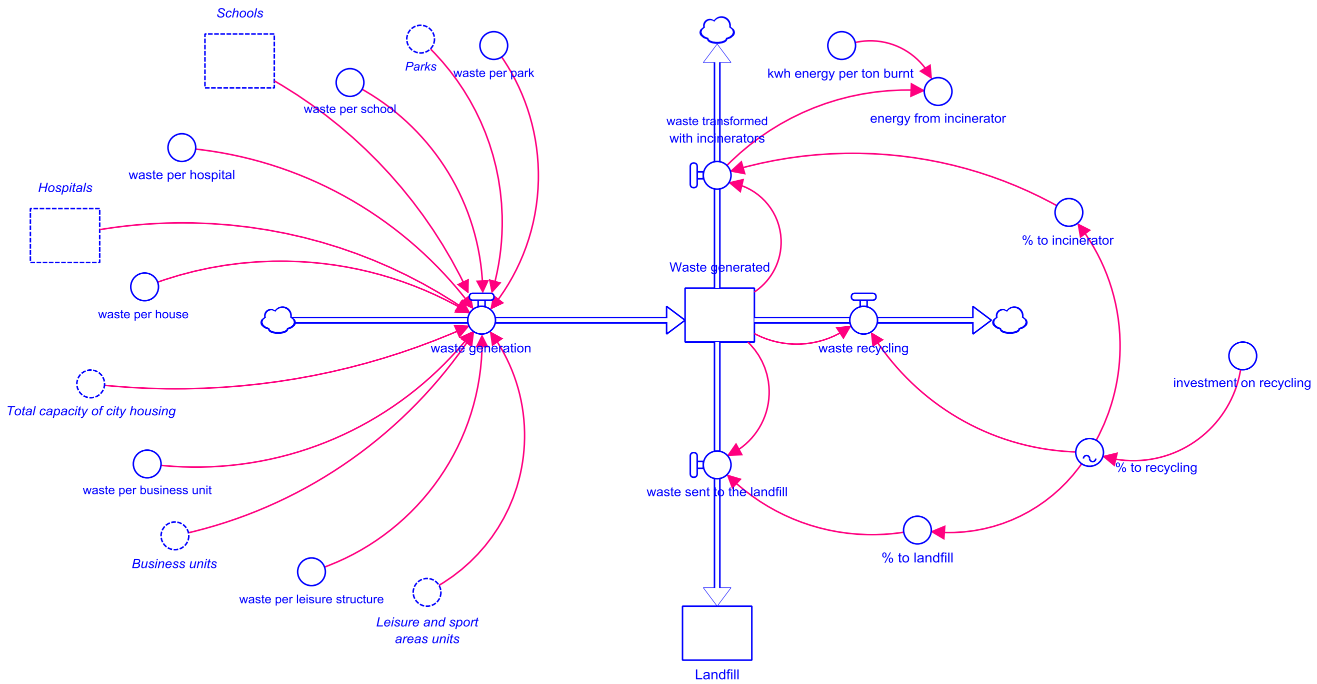

Figure 10. Waste management section

Water management

The Water sector of the model is based on the main idea that any activity in the City consumes water and generates wastewater.Water consumption is modelled multiplying each category of stock for a constant, representing the average consumption of water for that specific class: for example, the total number of hospitals is multiplied by the "Average water consumption per hospital" to define the Water Consumption for this specific class.

Part of the water that is used creates wastewater that needs to be purified and is subsequently treated in an Advanced purification plant). Wastewater going through advanced purification plants is therefore purified and represent an inflow to (pure) Water in the City's Reservoir. The Reservoir is also increased by Rainwater naturally entering in it.

Investments in this area are required to keep the purification plants in order and efficient, otherwise they will underperform, and less water will be purified.

Overall, if the Reservoir will not be high enough in comparison with the City's needs, there will be a water shortage. A specific variable named "Water availability" is calculated in order to inform the players' decision about such a possibility. This variable feedbacks within the system influencing the Attractiveness of the City.

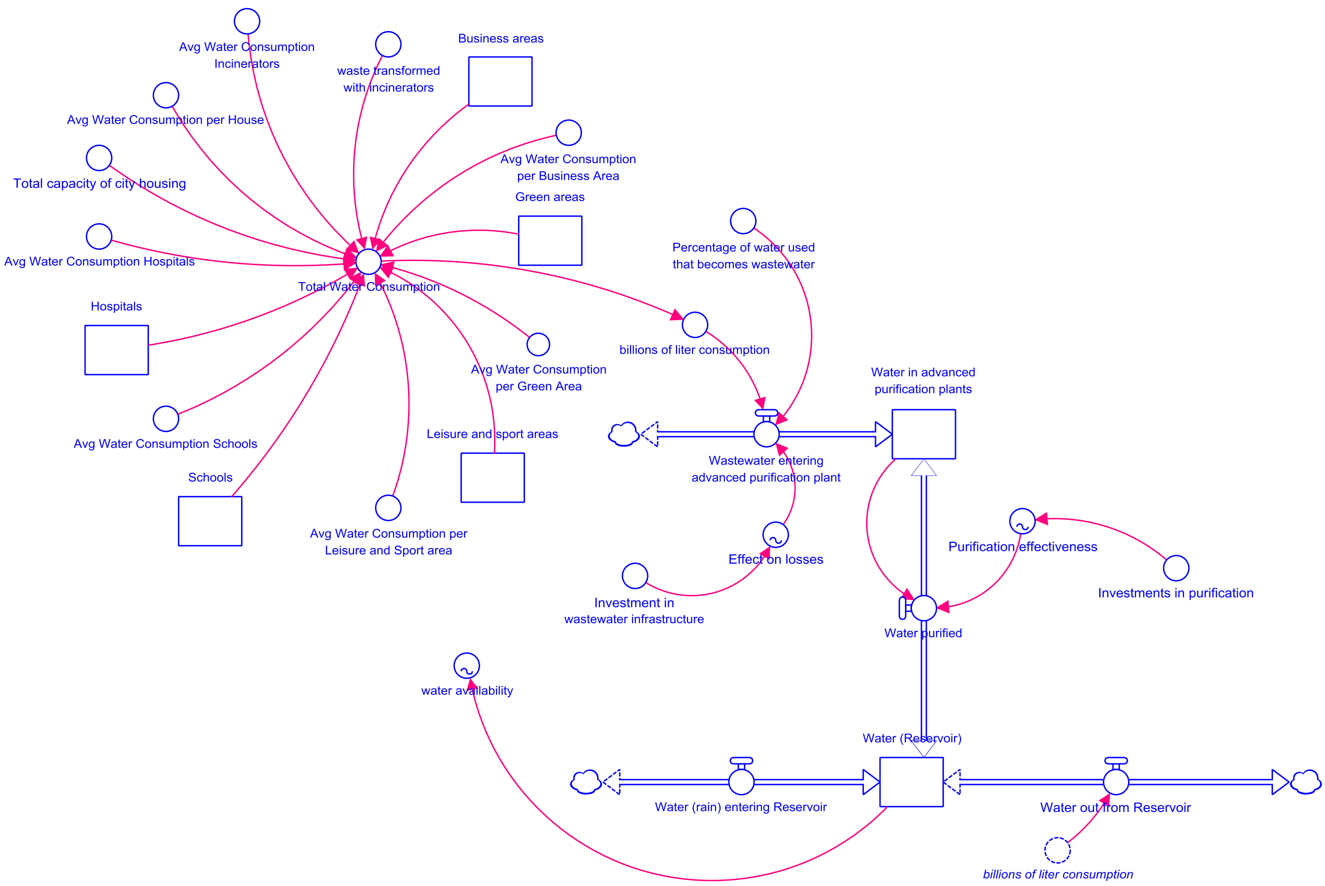

Figure 11. Water management section

Environment

All the activities carried out within the cities produce pollution. In the project we refer to two of the main pollutants in urban areas: NOx and PM10; these are commonly monitored variables and the relative data sets are easy to find. NOx and PM10 are side effects (caused) of different types of activities such as industry, transport and waste management, which is why they form a balancing loop (negative feedback) on the attractiveness of the city with respect to the desirable growth of economic activities.

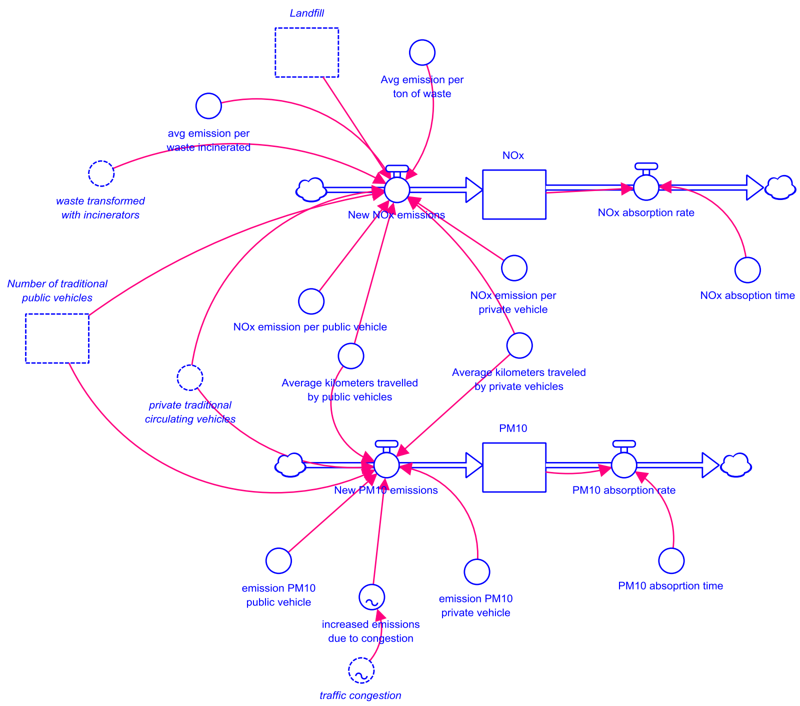

Figure 12. Emissions section

Energy

Cities consume energy based on the number of schools, hospitals, leisure structures, industries and households. The total energy consumption of the city is an important factor to consider, because it defines the capability of the city to meet the need for energy of its citizens and business activities. In fact, a inappropriate level of energy capacity could cause some local blackouts, compromising the livability and so the attractiveness of the city.

This kind of problem could be softened by the use of incinerators during the waste management process. In fact, incinerators provide city with additional energy, lowering the total level of consumption (anyway, incinerators have their own emission to consider).

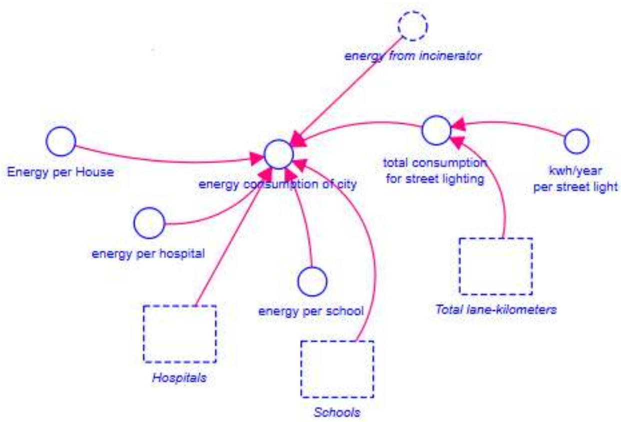

Figure 13. Energy section

Urban planning

The urban planning sector concerns the consumption of available land for functional areas, dedicated to specific purposes (land uses or land covers). The functional areas, for housing (NearZero houses and Classic houses), health services (Hospitals), leisure and recreation (Leisures and Parks), parking (Parking space) and education (Schools), and production or job creation (Industries) increase the Attractiveness of the city, while they exhaust the available land. Each function, once established, also implies negative consequences on the quality of the city itself, in terms of waste, emissions, energy and water consumption, as well as influencing the transport sector. These negative consequences are modelled by other sectors such as Water, Waste and Environment. The distinction between NearZero houses and Classic houses allows to choose different type of buildings with different costs and associated energy consumptions (e.g. for cooling/heating). In the board game,such difference could be played using different actions such as investment in a standard “classic house” or in “near-zero-emission house” (or in investing conversion of standard into near-zero emission house).

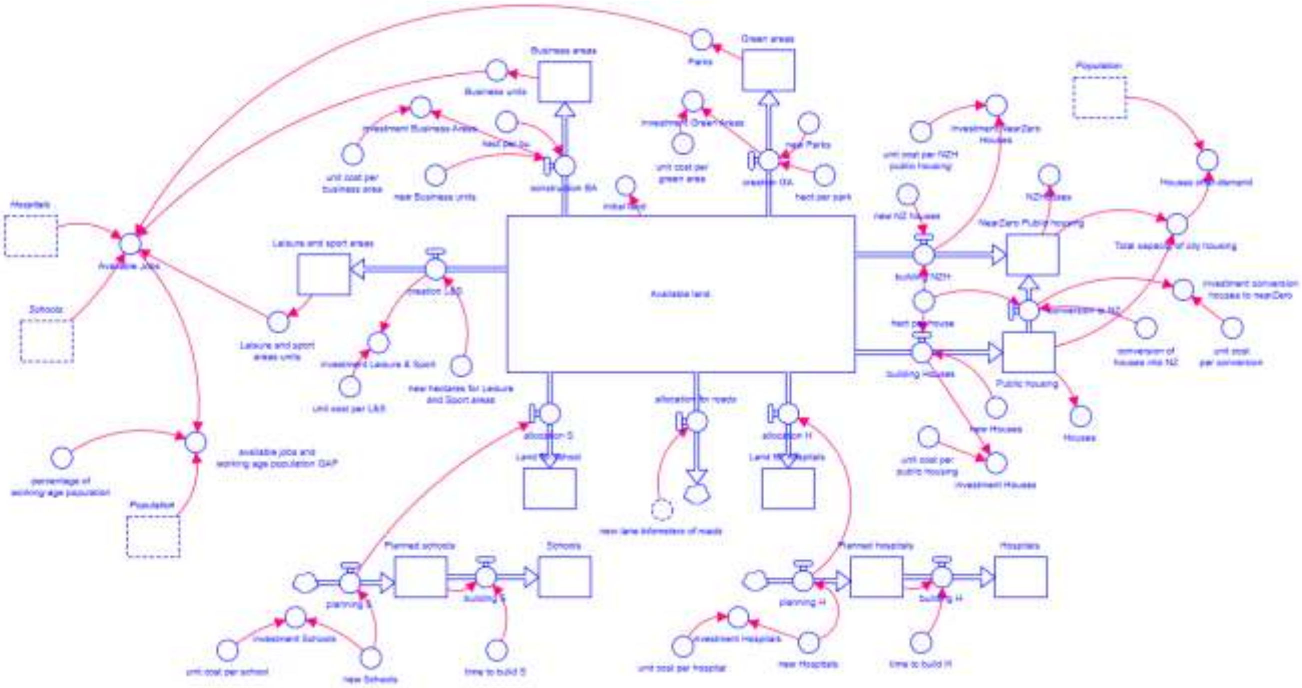

Figure 14. Urban planning section

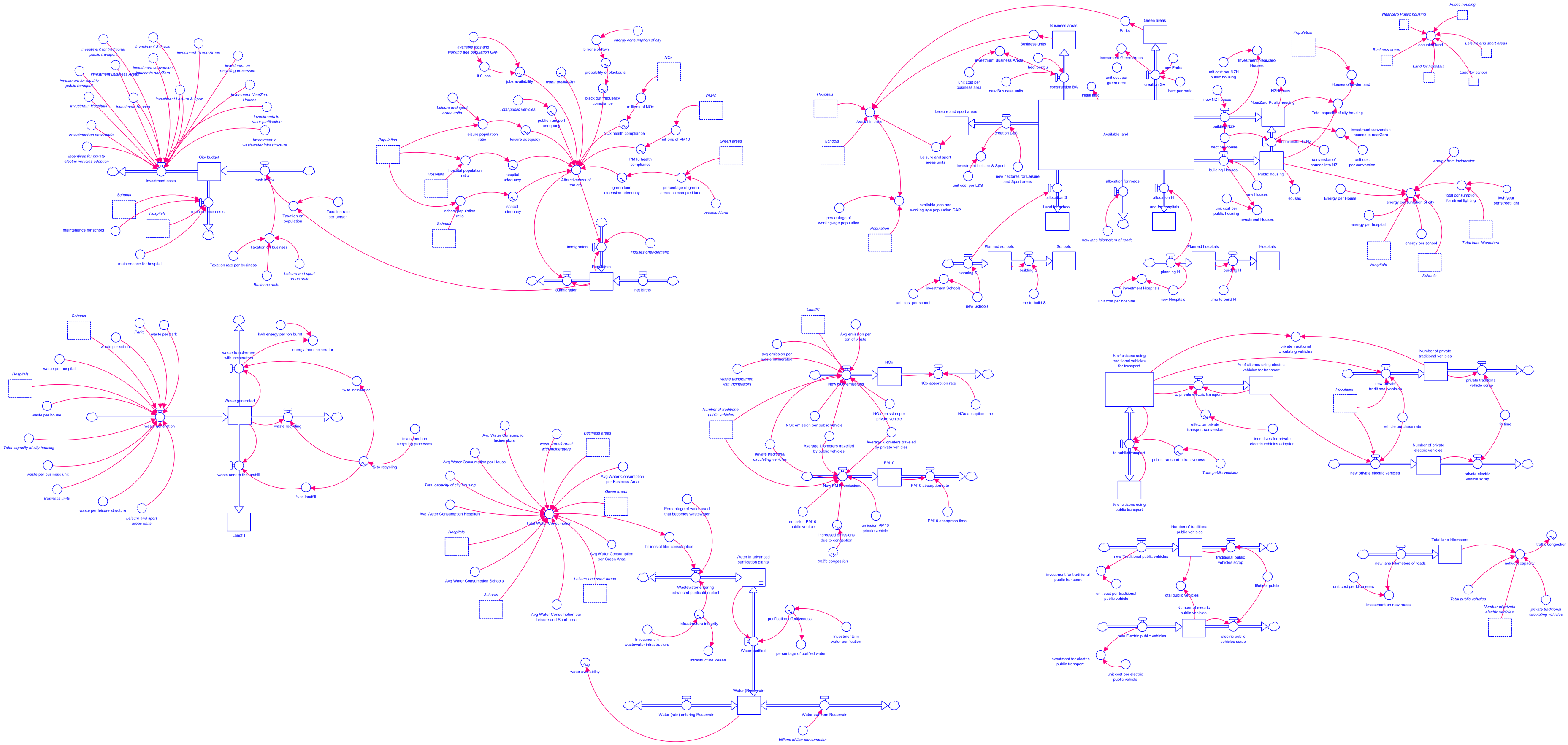

Figure 15. Overall model

4.3. SUSTAIN Scenarios and Simulation results

This section briefly presents the potentials of using *scenarios* to explore how to test or use the model when specific circumstances might occur."Scenario analysis" is a well-known methodology that, building on the use of different hypotheses or decision-making options, allows for the inspection of the outputs and outcomes thereby facilitating a deeper understanding of the consequences stemming from our decisions and actions[2].

It is not a matter of identifying the best-case scenario, rather it is important to compare possible situations (i.e., scenarios) and the results given by the model and the simulator to understand the interested systems and learning about their complexity.

In broad terms, scenarios can be easily created and tested by modifying the inputs to the model (e.g., the value assigned to a constant), making hypotheses about specific dynamics to be subsequently tested (e.g., situations in which we aim to explore "what will happen if… ?")that could be of interest for the learner (e.g., the analyst or the model user).

In this project, the scenarios of interest are decisions in terms of investmentsby which to increase simultaneouslythe population (social aspect), the city's budget (economic aspect) and the environmental well-being (environmental aspect) or the key variable "attractiveness of the city".
Some examplesfollow below.

Example of a Scenario
<u>Title:</u> Garbage everywhere!
<u>Problem:</u> The city is growing very fast and all the new business areas and facilities that we are building are generating a huge amount of waste. The citizens are definitely not happy about this …
<u>Possible policies:</u> the players could invest more money in recycling activities, in order to increase the percentage of waste that is collected and subsequently recycled.

Simulation scenarioscan also be used to challenge the players engaged with a simulator. In reference to the specific situation described by the example above, the scenario is meant to emphasize that a growing City (in terms of population as well as infrastructures and processes) will inevitably lead to an increased generation of waste that will need to be collected and subsequently treated (i.e., recycled, burnt or sent to the landfill). Clearly, if the players will fail to invest enough in waste management activities (notably, in recycling activities), the City will be full of garbage, and this will inevitably impact on other areas and variables (e.g., more pollution and a lower level of Attractiveness). In other terms, playing and experimenting with scenarios, the players have at their disposal the opportunity to test their ideas and policies, at the same time understanding the wide range of consequences that will stem from their own decisions and will impact across the various areas of the model (i.e., the City).

[2]For more details on the use and potentials of scenario analysis see Schoemaker. (1993) and Schoemaker (1995).

By the simulation modelpresentedhere, a number of scenarios can be used to understand the complexity of a city.

Scenario 1
Title: Black-out again!?
Problem: The city consumes too much energy, due to the high number of public structures, roads (street lighting) and houses. This increases the probability of black-outs in the city.
Possible policies: Building new nearZero houses or convert traditional house in nearZero ones.
Or: Taking advantage from waste using the incinerator to gain more energy.

Scenario 2
Title: One bus every half hour…
Problem: The number of bus is too low to cover the city area. Citizens has to wait for long time till a bus comes to the bus station.
Possible policies: Increasing the number of buses (traditional or electric ones)

Scenario 3
Title: Intense traffic all day
Problem: There are a lot of vehicles that circulate inside the city, much more than the network capacity can handle.
Possible policies: encouraging citizens to use public transport by empowering the public transport service
Or, increasing network capacity by making new roads

Scenario 4
Title: The air in this city is unbreathable!
Problem: High level of PM10 make the air unhealthy and oppressive for respiration. PM10 level is due mainly to road vehicles.
Possible policies: Encouraging people to purchase new electric cars through benefits (free parking, subsidies, etc.)
Or: Investing in new electric public vehicles instead of gasoline ones

Scenario 5
Title: Water shortage
Problem: The city is growing fast and this entail a huge increase in the total amount of water being consumed. After a while a water shortage will be evident.
Possible policies: the players need to invest money to keep the water purification plants efficient, thus purifying a high percentage of the water being used within the City and subsequently replenishing the City's Reservoir.
Alternatively, a campaign devoted to increase the citizens' awareness of water consumption-related problems could be discussed.

Scenario 6

Title: Water shortage

Problem: The water shortage may be due to rainfalls lower than expected.

Possible policies: the players need to invest money to keep the water purification plants efficient, thus purifying a high percentage of the water being used within the City and subsequently replenishing the City's Reservoir.

Scenario 7

Title: Garbage everywhere!

Problem: The city is growing very fast and all the new business areas and facilities that we are building are generating a huge amount of waste. The citizens are definitely not happy about this …

Possible policies: the players need to invest money in incinerators to address this issue.

Or, the players could invest more money in recycling activities, in order to increase the percentage of waste that is collected and subsequently recycled.

Scenario 8

Title: What a bad smell

Problem: The city is producing a big amount of waste. Part of it is sent to the incinerator, part is recycled and the remaining is sent to the Landfill. This generates a bad small and the citizens are not happy!

Possible policies: More investments in recycling activities, to increase the amount of waste that is recycled and not sent to the Landfill.

Notably, the results of the decisions taken by the players are visible and displayed throughout the windows of the simulator, being portrayed in various forms and with different tools (e.g., graphs devoted to portraying the simulation results for a specific variable, or data stored in tables).

Scenario 9

Title:Increase the number of happy citizens

Problem:Each citizen requires a space for living, for leisure and recreation, as well as a variety of services (such as education and schools, healthcare and hospitals) and a job. Increasing areas dedicated to that could cause unintended consequences! Side effects of investments on productive, residential o service areas could be an increase in the energy consumption, water consumption, and decreasing of available territory.

Possible policies:Balanced investments in functional areas, monitoring the effects on resources consumption and pollution.

4.4. SUSTAIN strategies and the key learning points

At the end of this report, we would like to emphasize some specific learning points that emerge from the Project and are related to the methodological principles and the simulations tools here employed and suggested.

The starting point is to recognize that urban sustainability is a complex concept which entails the simultaneous management of several variables and policy levers. Stated differently, urban sustainability is a concept that needs to be addressed in – and studied with – a systemic perspective. More in detail, a system perspective implies the existence of interconnected elements to fulfill a function or a purpose over time. Indeed, a systemic and comprehensive approach to "urban sustainability management" is the focal point of this project.

To reach this aim, we focused on System Dynamics (Forrester 1961 and 1968). As mentioned, System Dynamics is a rigorous simulation modelling methodology that provides researchers and learners with a comprehensive set of principles and tools.

First of all, we would like to recall the wide range of tools that we mentioned in this report and are at the researchers' and players' disposal.Those tools are both qualitative and quantitative.Among the qualitative tools, we have shown that causal loop diagrams (CLDs) may help to analyse a complex system since they allow representing the complex hierarchy of the variables existing within that system, and their relationships (identified by causal links among them). Additionally, CLDs make use of polarities to denote the influence between couple of variables (positive for a direct effect, or negative for an indirect effect) and allow identifying feedback loops (reinforcing or balancing) within that system.

Coming to the quantitative tools, System Dynamics is centred on the use of simulation models and interactive learning environments (ILEs, which add a graphical interface atop of the simulation model).

Both these tools generate simulation dynamicsand allow visualizing and analysing the results of the simulation model. In more detail, when players interact with a simulation model or an ILE, they can explore their ideas, develop and test policies and subsequently observe and understand the impacts generated by the decisions being carried out. More specifically, an ILE can be used (and customized) in order to perform scenario analysis, that is to say, to provide and challenge the users with specific problematic situations to be faced and managed. Subsequently, and similarly to what we discussed in the previous section of this report, the players will be required to use the ILE to develop sound policies and take action, thus generating the simulation results that will allow evaluation and learning about urban sustainability.

All the tools aforementioned are key to this specific project.With this said, we can now summarize some specific “learning points” to be considered when facing urban sustainability *and* using the Sustain Model.

1) An urban environment is a complex system where many variables interact at the same time. This entails identifying and focusing on the relationships among the various sectors of that system rather than focusing on single (or small) parts of it (e.g., investing in electric vehicles is a policy that will impact also on the environment and not just on the urban transport system).
2) In such a wide system many variables will co-exist and must be managed simultaneously. This implies not only identifying such variables but also understanding that they will be characterized by multiple trade-offs (e.g., to build new business areas we need to invest money, in this way depleting the City Budget; at the same time, building new business areas will generate more waste and pollution; etc.).
3) Time is a key feature of our systems. It takes time (i.e., there are time delays) to build new hospitals or schools. Stated differently, we need to plan for the future taking into account the time-delays involved by the actions we will be carrying out.
4) Explore your ideas, and test your policies. A simulation model, such as an ILE, allows experimenting with our policies within a safe environment. Simulations can be repeated, different policies can be developed and tested, and fine-tuning is possible through multiple simulation runs.
5) At the same time, do not rush your decisions. Instead, consider carefully which policies could be developed and which investment decisions will be actually applied.
6) Scenario analysis can help challenging your beliefs. The opportunity to perform scenario analysis within an ILE is a fundamental learning point: challenged with problematic situations, the players will speed up their understanding and learning process in order to come up with feasible solutions.
7) Learning comes first. The Sustain Model is not to be used to search for the “best” policy, rather explore the dynamics existing within a complex system and the effect generated by our own policies. Analysing the results, understanding the impacts of investment decisions, spotting the relationships among variables should be our primary targets.

Appendix

Generic case studies using System Dynamics available online

Case	Title	Client	First Author	Sector
60	HIV/AIDS Response Programs	Ministry of Health and Public Hygiene, Republic of Côte d'Ivoire President's Emergency Plan for AIDS Relief (PEPFAR), US Embassy in Côte d'Ivoire	Paulo Gonçalves, SimpliceTakouboKamdem	Health Care
59	Wind Tunneling Business Strategy	Vertex, Inc.	Kevin Boettcher	Computer, Information
58	Dealer Hoarding, Sales Push and Seed Returns	Hybrid seed supplier (e.g., Monsanto, Pioneer, Syngenta)	Paulo Gonçalves	Human Resource Management, Sales and Marketing
57	Attrition of Staff	United Nations Mission in Kosovo (UNMIK)	Paulo Gonçalves	Human Resource Management
57	Hughes Aircraft	Hughes Aircraft Company	Ken Cooper	Aerospace
56	Northrop Grumman	Northrop Grumman	Ken Cooper	Aerospace
55	Recycling Rate	Waste Agency of Oslo, Norway	John EgilNilssen	Waste management
54	Litton	Litton Industries	Ken Cooper	Manufacturing
53	Firm-Level Capability Development Trade-offs	N/A	HazhirRahmandad	Financial Services
52	MasterCard	MasterCard	Kenneth Cooper	Research and Development
51	Anemia Control	N/A	James T. McCarthy	Health Care
50	Oral Health	State Secretary of Health of Paraná	Mitsue Fujimaki	Health Care
49	PRISM	Centers for Disease Control and Prevention (CDC) and National Heart, Lung, and Blood Institute (NHLBI)	Jack Homer	Health Care
048	C-ROADS	You can find a list of funders here, and clients,	John Sterman	Environment

Case	Title	Client	First Author	Sector
		and users here.		
047	Pushing the boundaries of marketing ROI at Coca-Cola	Coca-Cola Inc.	Foresight Associates	Food
046	Data Center Capacity Planning	Telecomputing, Norway	Kaveh Dianati	Telecommunications, Information
045	Keep on rolling – managing a large rail improvement project	London Underground	Steve Curram	Logistics & Transportation
044	Are You vMad To Go For Surgery? Risk Assessment for Transmission of vCJD via Surgical Instruments	UK Department of Health	Curram S	Health Care
043	A case study in strategic human resource management	German service provider in the logistics industry	Andreas Größler	Logistics & Transportation
042	System Dynamics & Agent-Based approaches to face HR constraints	Public ICT company localized in Minas Gerais, Brazil; Primary Hospital Localized in Foz do Iguaçu, Brazil	Passos GF	Multisector planning
041	Children's Oral Health	Colorado Department of Public Health and Environment, New York State Department of Health	Gary Hirsch	Health Care
040	The Organizational Responsibility Model for Public Companies	Brazilian state of Minas Gerais	Passos GF	Other
039	Social Determinants of Health in a Diverse Urban Population	Wellesley Institute (Toronto)	Mahamoud A	Health Care
038	ReThink Health Dynamics	Fannie E. Rippel Foundation (New Jersey)	Jack Homer	Health Care
037	Haaglanden	Housing market	Eskinasi M	Urban planning
036	Managing the Inventory of Test Items used in Computer-Based Educational Testing	Educational Testing Service (ETS), the world's leading developer and provider of standardized educational	Homer J	Education

Case	Title	Client	First Author	Sector
		tests		
035	Projecting Motorcycle Parts and Accessories Sales	A large US manufacturer of motorcycles	Homer J	Manufacturing
034	Analyzing Price Cycles in Commodity Chemicals	A large global chemical company (Dow Chemical)	Homer J	Chemicals
033	Strategies to Improve Freight Railroad Performance	A major freight railway company (CSX Transportation)	Homer JB	Logistics & Transportation
032	Hardware Maintenance Field Service Dynamics	Major producer of diagnostic equipment used in semiconductor wafer fabrication	Homer J	Manufacturing
031	Cocaine Use Prevalence Estimation and Policy Analysis	National Institute of Justice, US Department of Justice	Homer J	Criminal justice
030	Marketing Strategy for a New Cholesterol-Lowering Drug	A large global pharmaceutical company (Sandoz, now Novartis)	Homer J	Health care
029	Antibiotic Resistance Dynamics	Texas Department of Health	Homer J	Health care
028	Hospital Surge Capacity Planning	Health Resources and Services Administration (HRSA), US Department of Health and Human Services	Manley W	Health care
027	Local Strategy for Chronic Disease Management and Prevention	A large hospital in Washington State	Homer J	Health Care
026	Obesity Population Dynamics	Centers for Disease Control and Prevention (CDC)	Homer J	Health Care
025	HealthBound	Centers for Disease Control and Prevention (CDC)	Bobby Milstein	Health Care
024	Medicare Payment Rate	Government	Jack Homer, Gary Hirsch	Health Care
023	Cement industry price dynamics in Iran	Cement Investment and Development Company	Ghaffarzadegan N	Chemicals
022	National airspace	US Federal Aviation	Ventana Systems	Logistics

Case	Title	Client	First Author	Sector
	system	Administration		&Transportation
021	Logistics support system for the US coast guard	US coast guard	Ellis RE	Defense
020	Monetary policy	Central Bank of Colombia	Arenas F	Financial Services
019	Spatial planning in Indonesia	Ministry of Human Settlements and Regional Infrastructures Development, Indonesia	Radianti J	Urban planning
018	Health and social care policy in the UK	UK Government	Wolstenholme E	Health Care
017	Energy policy analysis in Mauritius	Ministry of Renewable Energy and Public Utilities, Mauritius	Bassi AM	Energy
016	Climate change and energy	National Commission on Energy Policy, Environmental Defense Fund, WAI	Bassi AM	Energy
015	Urban dynamics	UK local authorities	Swanson J (Sdgworld; Steer Davies Gleave)	Urban planning
014	International Council on Systems Engineering (INCOSE)	INCOSE	Warren K (Strategy Dynamics)	Engineering
013	Supply chain options in pharmaceuticals	Anonymous pharma co	Jones L (Ventana Systems UK)	Health care
012	State planning in Sarawak	Sarawak State Planning Unit	Brian Dangerfield	Multisector planning
011	Medical Device Company	ALK-Abello, Denmark	Kim Warren (Strategy Dynamics)	Health care
010	Pharmaceutical product life-cycles	Anonymous pharma co	Jones L (Ventana Systems UK)	Health care
009	Sustainable water management in Laikipia District (Kenya)	CETRAD	Gallati J	Water
008	Maintenance improvement at ONEgas	ONEgas	Venderbosch T	Chemicals

Case	Title	Client	First Author	Sector
007	Criminal justice	Ministry of Justice, the Netherlands	Rouwette EAJA	Criminal Justice
006	Project management at Fluor	Fluor	Kenneth Cooper	Engineering, Construction
005	Process innovation at Du Pont	Du Pont	Repenning NP	Chemicals
004	Diabetes	CDC	Jones AP	Health Care
003	Polio eradication	World Health Organization (WHO)	Thompson KM	Health Care
002	Pharmaceutical Product Branding Strategies	Numerous Pharmaceutical Companies	Mark Paich	Health Care
001	General Motors OnStar	General Motors	Vince Barabba	Logistics & Transportation, Information

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