Chapter 9
The System Dynamics Model for the Impact Assessment of Project Management on Circular Economic Processes

Ekaterina Andreevna Khalimon, Irina Stanislavovna Brikoshina, and Mariya Nikolaevna Guseva

Abstract The study tested the scientific hypothesis about the possibility of creating a neural recurrent model of the circular economy for an adequate representation of its key processes. To develop such a model, various conceptual models, mathematical descriptions of certain circular economic processes, and approaches were taken for analysis. Next, the parameters and indicators used by some groups of researchers to measure indicators of the circular economy were reviewed. Simulation modeling based on system dynamics and deep recurrent neural network modeling based on the multilayer feed-forward neural network configuration were used to build a model containing many deep multi-level feedbacks. The simulation and neuronet tools not only allowed to work with quantitative data obtained during the simulation model run, but also to evaluate the information suitability of the constructed model. The results confirmed the scientific hypothesis and permitted to make conclusions that should form the basis for further research of circular economy processes, apply project management tools at the level of public administration and corporate governance to address the identified threats when planning strategic development programs for countries, regions, cities, industries, and companies.

Keywords Circular economy · System dynamics · Simulation modeling · Recurrent neural network · Project management

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9.1 Introduction

The linear economy paradigm, based on the use of fossil raw materials, has provided significant global socio-economic and technological development, but this has come at the cost of escalating resource use, global environmental degradation, and an unprecedented scale of anthropogenic impact on the climate. The industrial age brought about global economic convergence, but at the risk of sacrificing the safe working space of our planet.

As a result of research conducted in 2015 that identified nine planetary boundaries to ensure a safe working space for humanity, it was concluded that four of them are crossed: climate change, loss of integrity of the biosphere, changes in the land use system, and changes in biogeochemical cycles (phosphorus and nitrogen) (Steffen et al., 2015). Two of them – climate change and the integrity of the biosphere – are "fundamental boundaries", meaning that changing them will bring the Earth's system into a new state that can no longer support our current economic system.

In the transition from a fossil-based economy to a low-carbon economy, the focus of politics and the media tends to be on the energy sector. However, it has been estimated that 60–65% of environmental damage is related to the production of materials, while only 35–40% is related to energy (UNEP, 2017). This fact highlights the need to develop a closed-loop economy (or even closed-loop Bioeconomy (Hetemäki et al., 2017).

No country in the world today can be described as a country with a circular economy, but most countries are ready for transformation and are already on the threshold of a different world order. In order for the implementation of the strategic plans to be successful and the expectations of the country's leaders to be met, it is necessary to develop a full-fledged model of the closed-loop economy, which can be detailed, scaled, and adapted to any country. Such a model should not be conceptual, but live, and the best means for this is neural networks with reverse cycles.

The use of neural networks will not only allow to build a model and to determine the relationships between variables and resulting indicators but also to evaluate their suitability for further practical use.

Because of the absence of actual retrospective data from countries with circular economies (as they do not exist nowadays), adaptive learning should be used by training neural network. In this regard, from 100 to 500 experiments should be performed on the constructed model and the results obtained could be used as the input data for training the neural network and checking its characteristics. Based on the neural network's powerful ability to learn and integrate a variety of data from various factors, more accurate values can be obtained at the output.

9.2 CE Models, Concepts, and Approaches

The scale of the problems (environmental, economic, social, etc.) facing humanity in recent time makes it increasingly necessary to refer to the concept of CE or "closed-loop economy". It involves moving from linear systems to cyclical (or closed) systems by promoting Resource Economics and increasing resource productivity at all stages of production, distribution, and consumption.

In most scientific sources that write about this topic, it is customary to point to the 60 s of the twentieth century, as the period when the first theories on the problems of conservation of natural resources and the imperfections of the existing linear economic model appeared. However, it is worth noting that in the Soviet Union, the problems of rational use of resources, across the entire economic system of its countries, were the subject of close study, and many of these developments (delivery of used containers for reuse, collection of waste paper and recyclables, a developed system of rental points, the rejection of disposable tableware, increasing the service life of products) have not lost their relevance to this day. Studying the experience of the USSR in creating partially closed chains, creating products with an extended service life, and so on, can be the subject of a separate study. Moreover, many of the principles implemented in the USSR formed the basis of the basic principles of the circular economy.

Today there are many models of the CE and approaches to the description of its main processes. Next, some basic ones will be considered that will form the basis for creating a generalized model for its construction in terms of system dynamics and neural modeling.

1. The basis of the CE approach are 10 principles also called "types of activities" (Allwood et al., 2011; DenHollander & Bakker, 2012) or "10R", and they have gone through stages of development and transformation during their existence from 3 to 10 "R". The letter "R" is not a random choice. This is the letter with which many words begin, indicating the repeated use of the subject. "10R" at the present stage includes the following elements, principles, and activities:

    1. "Rethink" – make the use of the product more intensive (e.g. by sharing the product)
    2. "Reduce" – increase the efficiency of production or use of products by reducing the consumption of natural resources and materials
    3. "Reuse" – reuse by another consumer a product that is not needed by the original consumer, but is still in good condition and performs its original function; active development of resale processes among consumers, especially using popular Internet sites, online auctions, and stores (eBay, Amazon, etc.)
    4. "Repair" – repair and maintenance of a broken product so that it can be used with its original functionality
    5. "Refurbish" is to restore the old product and bring it to a modern state, for example, repair of buildings and structures, heavy equipment, etc.

6. “Remanufacture” – use of the unwanted/broken product to a new product with the same features
7. “Repurpose” – to use the unwanted/broken product for a new product with other functions
8. “Recycle” – recycle materials to get the same high-quality or lower-quality product
9. “Recover” – the burning of material with energy recovery
10. “Refuse” – offer the same product functionality using a different approach/materials/tools.

   It was noted by Reike D., Vermeulen W.J.V., and Witjes S. after having reviewed 69 contributions that they all summarized imperatives for reuse as a certain number of Rs (Reike et al., 2018). It seems obvious why this is popular: the “re-” in Latin means “again,” “back,” but also “afresh,” “anew,” fairly well expressing the essence of CE (Sihvonen & Ritola, 2015). However, the simplicity that makes such terminology attractive may simultaneously have contributed to confusions in CE literature and its related literature strands (Reike et al., 2018). The authors proposed their vision of a CE model based on the 9 “R” approach (Fig. 9.1).

2. A closed-loop economy, as defined by the Ellen MacArthur Foundation (Fig. 9.2), shows how technological and biological nutrient-based products and materials cycle through the economic system, each with their own set of characteristics (EMF, 2013).

   In their study, the authors also developed a high-level value driver tree (Fig. 9.3) that contains the input values of the CE model and the likely levers for improving the resulting indicators based on the described assumptions about what a circular CE system will entail in terms of collection and reverse processing for each of the products under study. The tree represents the architecture of the CE model.
3. Another point of view on CE was given through the creation of Bioeconomy by Hetemäki L., Hanewinkel M., and others in 2017 (Fig. 9.4). The authors agree with the model and the definition of CE made by Ellen MacArthur Foundation, and they suggest that the Bioeconomy is restorative and closed in nature and aims to ensure that products, components, and materials always remain as useful and valuable as possible, taking into account the differences between technical and biological cycles (Hetemäki et al., 2017). It’s important they note that the Bioeconomy and the CE do not per se imply sustainability, they have to be made sustainable (Hetemäki et al., 2017).

Summarizing all the concepts, the CE is a new stage, the next stage in the development of economic relations in society. The approaches and principles implemented within this paradigm, in contrast to the linear economy, seem to be more integral, and systematic, with a plan of action and value from the moment the idea arises to the end of the product’s operating cycle.

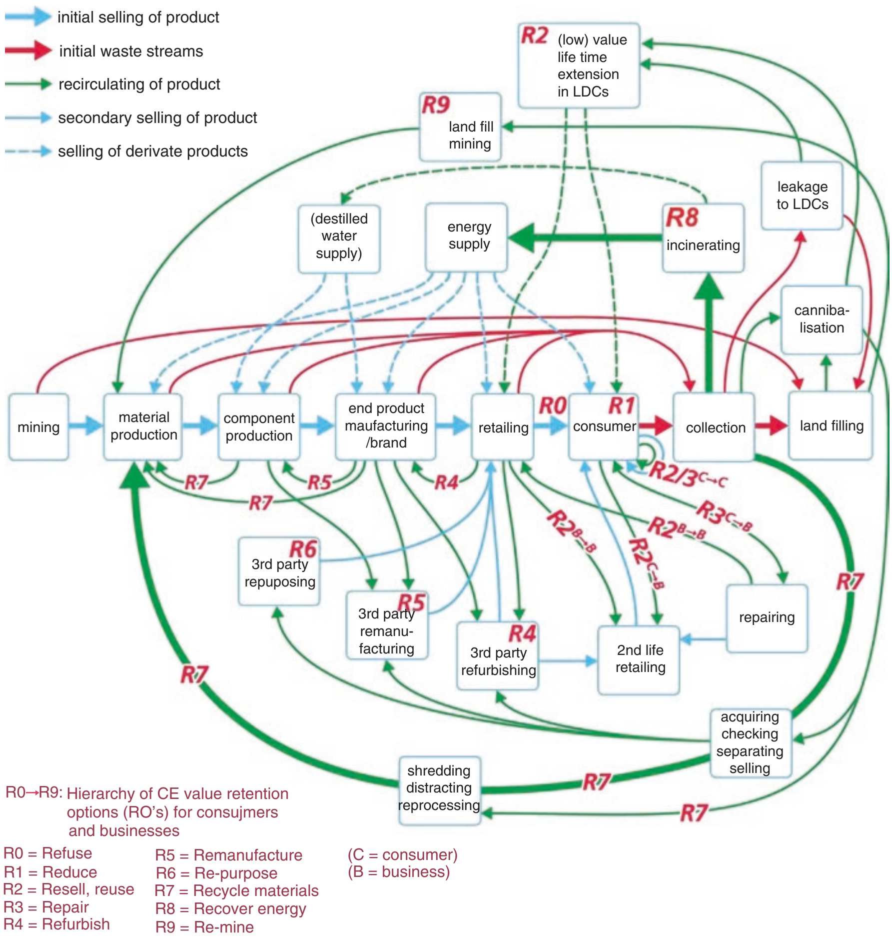

Fig. 9.1 Mapping circular economy retention options: The life cycle of production and use of the product. (Source: Reike et al., 2018)

9.3 Parameters and Indicators Measuring CE

In order to estimate the economic and environmental benefits of circularity interventions, it is important to assess their cost-effectiveness. Such an attempt was done through the application of analytical methods that assess the impact of particular policies (Elia et al., 2017). However, there is no recognized framework for measuring how effective a country is in making a transition to circularity. Such an approach needs to integrate indicators with a clear understanding of the circularity mechanism influencing multiple economic activities and their environmental performance (Aguilar-Hernandez et al., 2018).

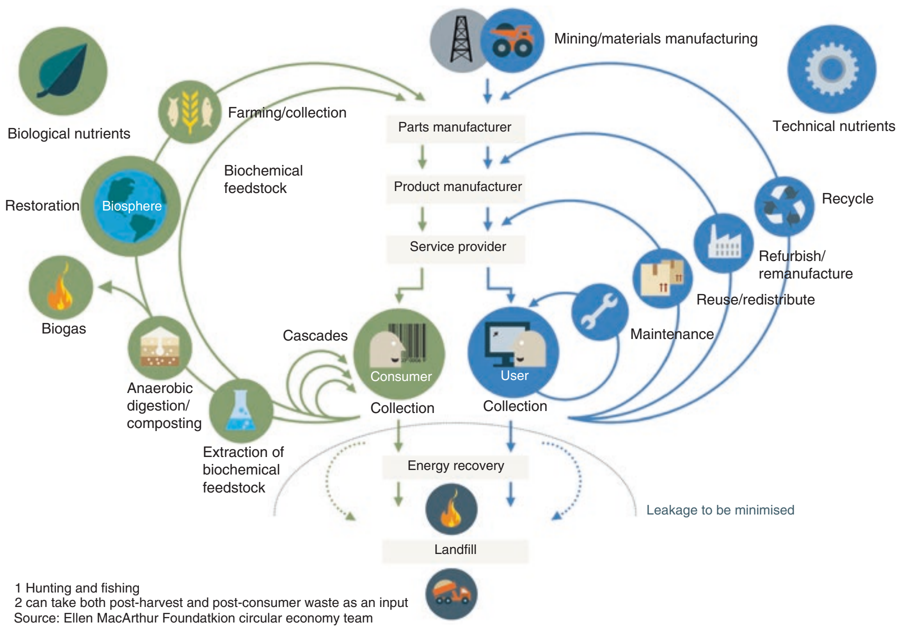

Fig. 9.2 The circular economy – an industrial system that is restorative by design. (Source: EMF, 2013)

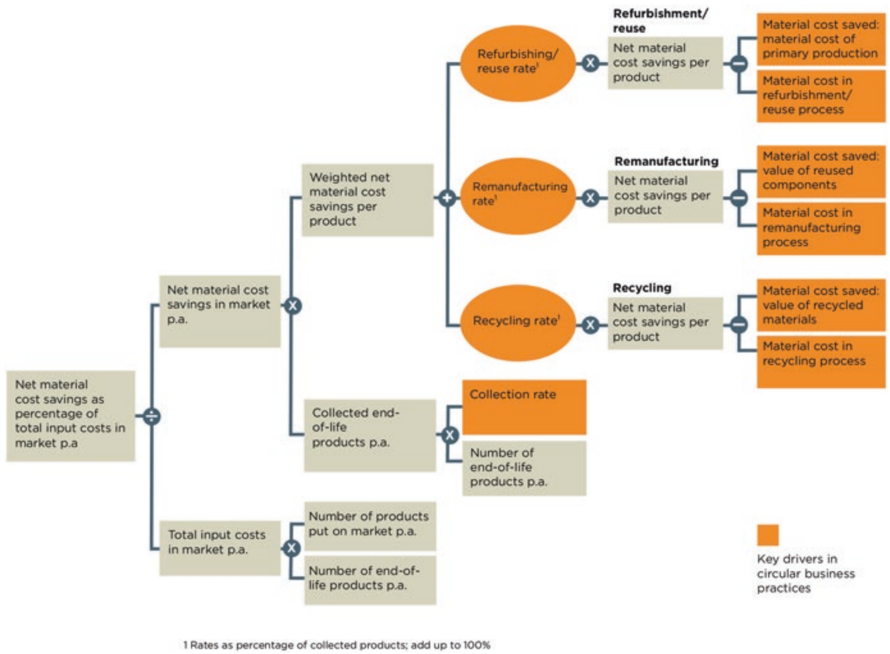

Fig. 9.3 Driver tree: factors affecting net material cost savings as a percentage of total input costs. (Source: EMF, 2013)

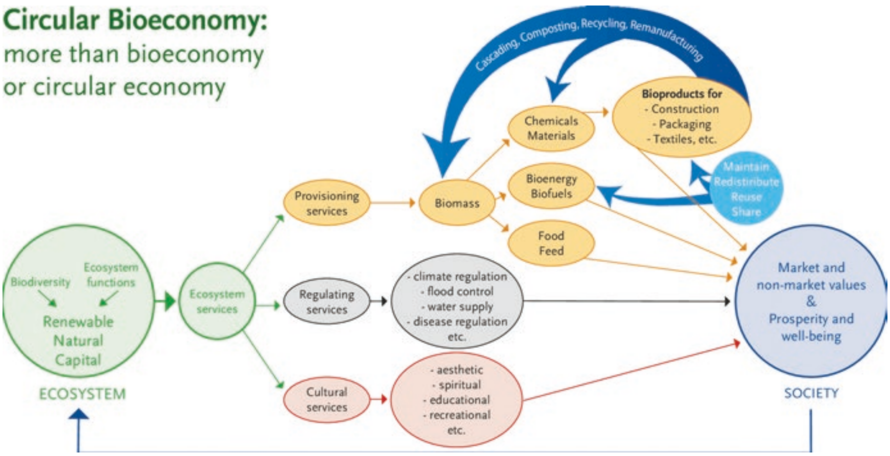

Fig. 9.4 Illustration of circular bioeconomy flows. (Source: Hetemäki et al., 2017)

It was pointed out by the group of researchers (EASAC, 2016) that GDP was not for measuring social well-being: on the basis of market transactions, it provides a monetary measure of the value of all final goods and services produced in a given period of time. It does not take into account social costs, environmental impacts and income inequality, as recognized by many environmental economists and politicians. Despite this, GDP remains the headline indicator against which economies' performance tends to be assessed (EASAC, 2016). Many alternative measures of progress have been devised. Some of them – the Index of Sustainable Economic Welfare (ISEW) and the Genuine Progress Indicator (GPI) – adjust GDP to incorporate social and environmental factors, for example the benefits from volunteer work, the costs of divorce, crime, and environmental pollution. Comparing these indicators with GDP the researchers (EASAC, 2016) revealed that none has yet succeeded in systematically repairing the shortcomings of GDP, and that an ideal indicator of social welfare has yet to be developed.

The recent research (Moraga et al., 2019) illustrates the classification framework with quantitative micro-scale indicators selected from literature and macro-scale indicators from the European Union's 'CE monitoring framework'. It was concluded that most of the indicators focused on the preservation of materials, with strategies such as recycling. However, micro-scale indicators focused on other CE strategies considering Life Cycle Thinking (LCT) approach, while the European indicators mostly accounted for materials often without taking LCT into account. Furthermore, none of the available indicators can assess the preservation of functions instead of products, with strategies such as sharing platforms, schemes for product redundancy, or multifunctionality (Moraga et al., 2019). Finally, the authors suggested that a set of indicators should be used to assess CE instead of a single indicator.

In another research, the authors (Qing et al., 2011) used the reference to the "Evaluation index system of circular economy (macro)" issued by China's National

Development and Reform Commission, which selects four factors: the resource consumption, resource recycling, environmental protection, and economic development as the main classified indexes to evaluate the circular economy development situation of China's western provinces.

9.4 Simulation Modeling

Simulation models are a combination of traditional mathematical modeling with computer technologies (Filyak & Zolotarev, 2015). The goal of building simulations is to bring the model as close as possible to a specific object and achieve maximum accuracy of its description. Simulation modeling is used when conducting experiments on a real system is impossible or impractical, most often due to their cost or duration. In various fields of Economics, business, and science, simulation helps to find optimal solutions and provides a clear understanding of complex systems. In addition, the simulation model can be analyzed in dynamics, as well as view animation in 2D or 3D, which allows to study the processes and make changes to the simulation model during its operation, better analyze the system, and quickly solve the problem.

In this research we'll follow the stages of simulation modeling presented below:

(a) Understanding the system: understanding what is happening in the system that is being analyzed, what its structure is, and what processes are taking place in it.
(b) Formulation of the system modeling goal: a list of tasks that are supposed to be solved using the future model. List of input and output parameters of the model, list of source data, criteria for completion of future research.
(c) Development of the conceptual structure of the model: the structure of the model, the composition of the essential processes to be displayed in the model, the fixed level of abstraction for each subsystem of the model (list of assumptions), the description of the control logic for the subsystems.
(d) Implementation of the model in the modeling environment: implemented subsystems, their parameters and variables, their behavior, implemented logic, and connections of subsystems.
(e) Implementation of the animation representation of the model: animated representation of the model, user interface.
(f) Checking the correctness of the model implementation: the belief that the model correctly reflects the processes of the real system that need to be analyzed.
(g) Model calibration: fixing the values of parameters, coefficients of equations, and distributions of random variables that reflect the situations that the model will be used to analyze.
(h) Planning and conducting a computer experiment: simulation results – graphs, tables, etc., giving answers to the questions.

There are four quite different systems of views: dynamic systems, system dynamics, discrete-event modeling, and multi-agent models (Karpov, 2005). These paradigms differ not so much in their areas of application, but in their concepts and views on the problem and approaches to solving the problem.

9.4.1 Dynamic Systems

Static models operate with characteristics and objects that do not change over time. In dynamic models, which are usually more complex, the change in parameters over time is significant. Static models usually deal with steady-state processes, balance-type equations, and limiting stationary characteristics. Dynamic system modeling consists of simulating the rules for a system's transition from one state to another over time (Karpov, 2006). The state of a system is defined as a set of values for its essential parameters and variables. A change in the state of a system over time in dynamic systems is a change in the values of system variables in accordance with the laws that determine the relationships of variables and their dependencies on each other over time.

Real physical objects function in continuous time, and to study many problems of physical systems, their models must be continuous. The state of such models changes continuously over time. These are models of motion in real coordinates, models of chemical production, and so on. At a higher level of abstraction, for many systems, models are adequate in which the transitions of the system from one state to another can be considered instantaneous, occurring at discrete moments of time (Karpov, 2006). Such systems are called discrete. An example of an instant transition is a change in the number of bank customers or the number of customers in a store. It is obvious that a discrete system is an abstraction, processes in nature do not happen instantly. At an even higher level of abstraction, continuous models are also used in system analysis, which is typical for system dynamics.

When modeling complex real-world systems, researchers often encounter situations in which random influences play a significant role. Stochastic models, in contrast to deterministic ones, take into account the probabilistic nature of the parameters of the simulated object. For example, in the oil port model, the exact time when tankers arrive at the port cannot be determined. These moments are random variables, because this model is stochastic: the values of the model variables that depend on the realizations of random variables themselves become random variables (Karpov, 2006). Analysis of such models is performed on a computer based on statistics collected during simulation experiments when the model is repeatedly run for different values of the initial random variables selected in accordance with their statistical characteristics.

Taking into account the complexity of the created model of the circular economy and the level of abstraction at which it is necessary to work, it can be stated that the developed CE model will be dynamic, continuous, and stochastic.

9.4.2 System Dynamics

The paradigm of computer modeling, in which graphical diagrams of causal relationships and global effects of some parameters on other parameters over time are constructed for the system under study, and then the model created on the basis of these diagrams is imitated on a computer, is called system dynamics (Karpov, 2006). Complex relationships and mutual influences of processes are often found in business, ecology, social systems, urbanism, and so on.

System dynamics is suitable for modeling complex systems at the highest level of aggregation. It is based on the idea of a system as a set of interdependent flows (money, products, human resources, etc.) that change over time. When constructing such models, a number of assumptions and simplifications are made. First, models of system dynamics abstract from individual characteristics and behaviors of system objects, and even from individual objects themselves (whether they are documents, personnel, animals, etc.). Second, these models usually depend on the physical characteristics of the environment in which the processes take place. Third, all variables, even if they characterize discrete quantities (e.g. population or number of customers), are considered continuous. Finally, individual events in the system are not highlighted here; all processes are considered to take place in continuous time (e.g. generational changes in the population or days for product sales are not highlighted).

Despite these simplifications, system dynamics models have proven to be very productive for investigating many complex problems. A small number of relatively simple structural elements, the repeated use of which allows to build models of business processes and city development, models of production and population dynamics, models of ecology and epidemic development. All this allows us to talk about system dynamics as a very effective, universal paradigm for studying complex systems using simulation.

From the mathematical point of view, models of system dynamics have variables and constants, differential equations, and functional dependencies. Therefore, formally, for the development of such models, there are enough tools that allow you to build models of dynamic systems, with the ability to represent formulas, algebraic and differential equations, as well as various functions (both built-in computer programs and user-defined). However, there is a significant difference in approaches to developing models of system dynamics and models of dynamic systems. This difference is that developers of system dynamics models do not think in terms of differential and algebraic equations, but in terms of graphical representations of flowcharts, in terms of functional dependencies of variables, the structure of variable relationships, and do not use the terminology of differential equations.

In addition, from the point of view of system dynamics, all systems, no matter how complex they may be, are built on closed feedback loops of dependencies of system variables. Therefore, graphical representation of flow diagrams, as well as relationships of variables that can be used to analyze cycles of parameter dependencies, is an essential requirement for system dynamics.

It should also be mentioned about the model that represents complex mutual dependencies of variables – the E. Lorentz model, which was originally created to simplify the description of processes that occur in the atmosphere and determine the weather.

From a formal point of view, the Lorentz model is not complicated: it is just three variables that are mutually connected by a system of differential equations. However, it has three different feedback loops, which makes the system difficult to understand and analyze. Despite the apparent simplicity of the system, it does not have an analytical solution. Complex relationships between variables make the model dynamics very interesting. First, under certain initial conditions, the model describes a so-called deterministic chaos – a deterministic model whose variables behave extremely chaotically (another name for the model is the Lorentz attractor). Second, this model demonstrates high sensitivity to initial conditions. For example, for certain parameter values, minor changes in the initial conditions significantly change the trajectories of variables. One of the experiments (Fig. 9.5) shows that sometime after the start, the values of x_i begin to differ significantly from the values of x. Lorenz interpreted this effect as follows: “even the flapping of a butterfly’s wing somewhere in the forests of Brazil can cause a hurricane in Texas in a month” (Lorenz, 1963). Lorenz called it “the butterfly effect”. Another conclusion from this model is that it is impossible to rely on the accuracy of long-term weather forecasts: all measurements are made with a certain error, within which processes in the atmosphere can develop over time in completely different directions. In other words, the accuracy of weather forecasts is objectively limited.

System dynamics models that are built to analyze the real economic and business processes, urbanization processes, population dynamics, and so on are usually much more complex than this Lorentz model. The cross-mutual influence of processes in them can sometimes cause completely unexpected effects, similar to the effect of deterministic chaos described by the Lorentz model. J. Forrester writes (Forrester, 1969) that a large corporation, a city, an economy, or a government are all examples of complex systems whose behavior is radically different from what we usually assume from the experience of observing simple systems. The Lorentz model demonstrates the possibility of chaotic behavior in such systems, in which there are cross-causal relationships of variables. One of the tasks of modeling is to introduce a managing mechanism that prevents the chaotic development of processes and directs them in the desired direction.

The most important practical value of system-dynamic models is that they provide a preliminary quantitative representation of the processes under study. The parameters used in them (e.g. the product usage index or production speed) have a certain meaning, and this allows you to check whether the model corresponds to the actual process that it describes. Based on the data obtained, the model can be calibrated — calculate the values of the model parameters and then use this model as a basis for further research. Moreover, feedback loops are the basic concept of system dynamics.

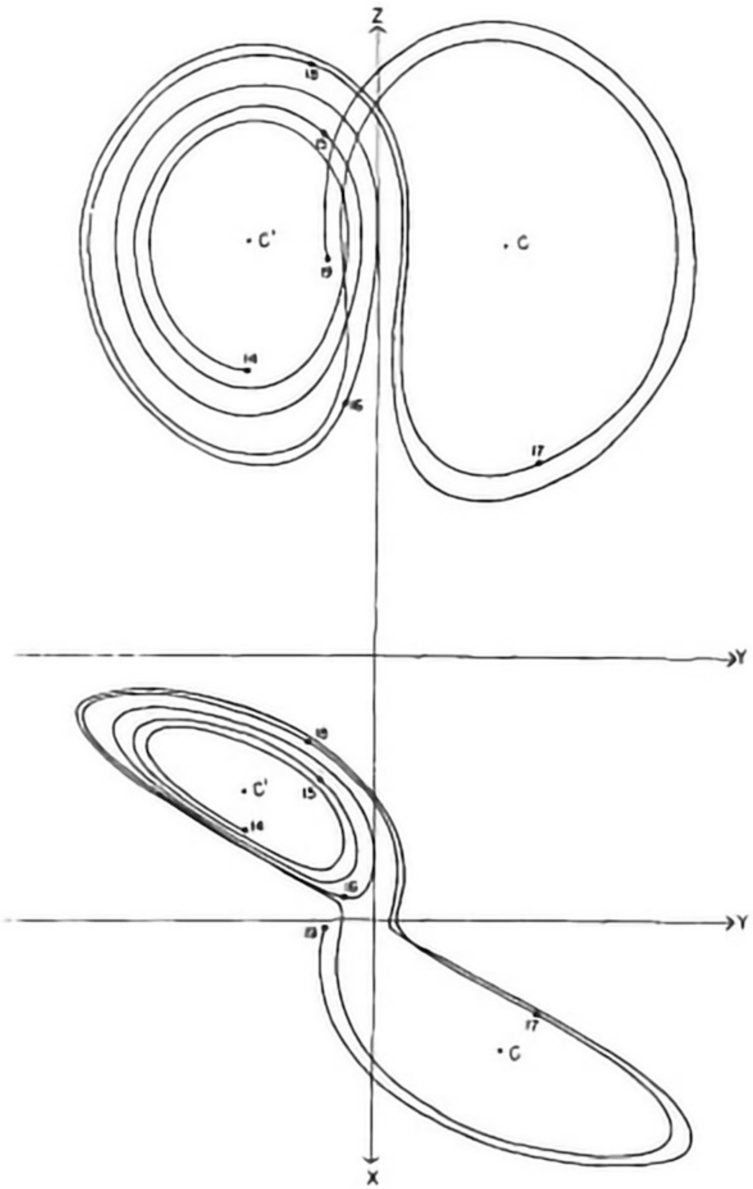

Fig. 9.5 The experiment demonstrates the influence of the weather, “the flap of a butterfly wing”. (Source: Lorenz, 1963)

System dynamics is supported by several software products that are similar to each other, but AnyLogic (Source: AnyLogic) will be chosen to build a CE model, since:

– It supports development and modeling in terms of system dynamics.
– It presents all the advantages of an object-oriented approach in system dynamics. Complex models can be multi-level, created using objects connected by interface variables. System dynamics diagrams in this case are hidden inside objects. A user can create his own libraries from these objects, which are system-dynamic templates, and use them in other models. (www.anylogic.ru).
– It allows to export models, run them in the cloud, animate them, and integrate them with other software tools.
– It is the only tool that allows to combine the method of system dynamics with agent-based and discrete-event modeling (if needed).

In addition, in 2019. an attempt has already been made to prove the interdependence between people and their environment and how the development of a circular economy can affect energy use and the environment. The conceptual simplified model was developed by Clemens Dempers in AnyLogic simulation software (Source: Circular Economy Concept) and is a subject of discussion for further transdisciplinary research and development. The purpose of the conceptual model was to consider several factors that are minimally necessary and contribute to community prosperity in an urban environment: energy demand, jobs, tourism, transport, and the impact of waste on water and land (landfills). As the study continues, not only life-support factors should be added, but also the effects of carbon mitigation and climate change.

9.5 Neural Network Modeling

Artificial neural networks (ANN) are a family of statistical learning models based on how biological nervous systems, such as the brain, process information. By mimicking brain functions, they can detect patterns in data and then extrapolate predictions when they get new amounts of information. Neural networks can learn complex relationships in data. They process records and "learn" by comparing their developed system with a known actual classification record. Errors from the initial classification of the first record are fed back to the network and used to modify the network algorithm a second time, and so on for a large number of iterations in the training process to predict reliable results from complex or inaccurate data. The typical architecture of a neural network structure is shown in Fig. 9.6.

It consists of connected blocks called "nodes" or "neurons". There are three types of neurons in ANN: input nodes, hidden nodes, and output nodes. Neurons are arranged in layers. Input layer neurons receive input data for calculations. These values are passed to the neurons of the first hidden layer, which perform calculations on their inputs and pass their outputs to the next layer. This next layer can be another hidden layer, if there is one. The outputs from the neurons in the last hidden layer are passed to the neuron or neurons that generate the final outputs of the network.

Neural networks are used in a wide range of areas, including stock market forecasting, credit and loan risk allocation, credit fraud detection, sales forecasting,

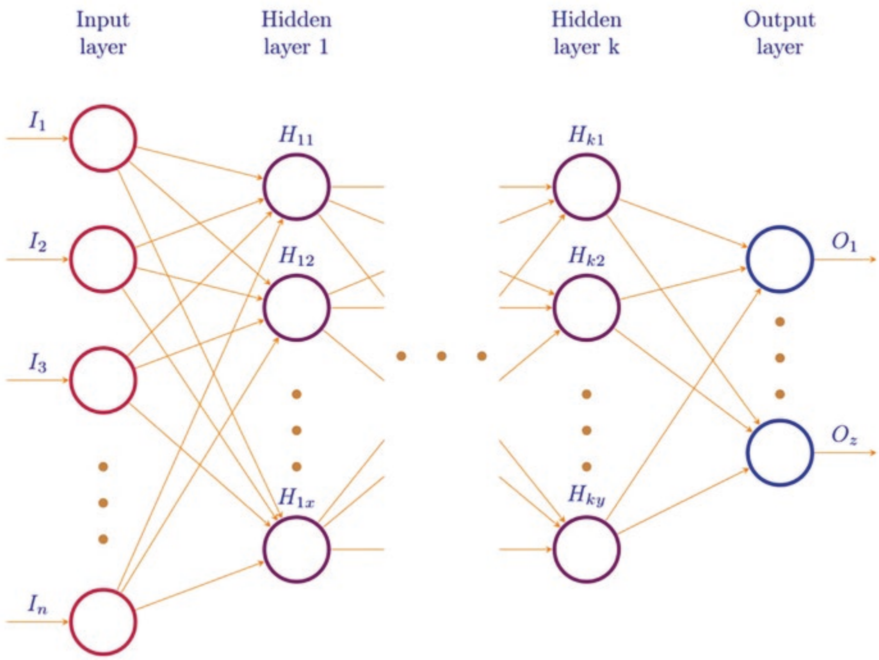

Fig. 9.6 The architecture of an ANN structure. (Source: Aqib et al., 2019)

general business forecasting, investment risk assessment, medical diagnostics, research in scientific fields, and management systems.

There are cases (Azadeh et al., 2014) of successful application of ANN to forecasting the completion dates of projects at oil refineries. There is an example (Cheng et al., 2011) of using a fuzzy hybrid neural network (HNN) to enhance project cash flow management and improve the performance of contractors in the construction industry, which is crucial in terms of providing the project manager with information about the progress of contractors, as well as for selecting appropriate contractors for a specific current or future project need. ANN in project management is used to identify factors and assess their impact on the effectiveness of project management (Wanyin, 2015). A study conducted by the American institute of project management PMI (Vargas, 2015) provides a detailed example of modeling the costs required for project management using ANN.

Recurrent neural networks (RNN) or feedback neural network is another kind of ANN model, in which the outputs from neurons are used as feedback to the neurons of the previous layer (Tarun & Khalid, 2019). In other words, the current output is considered as an input for the next output. In our research, RNN is introduced as an extension to feedforward networks, in order to allow the processing of variable-length sequences, and some of the most popular recurrent architectures in use, including long short-term memory (LSTM). The typical architecture of an RNN structure is shown and described in Tarun and Khalid (2019).

RNN architecture can be further extended to a deep recurrent neural network (DRNN) – another type of neural networks – with multiple layers between the input and output layers, presented and described in (Kong et al., 2019).

There are numerous examples of successful use of such deep multilayer recurrent networks for analyzing the processes of complex economic systems, presented in (Herbrich et al., 1999; Masloboev et al., 2014; Verstyuk, 2018).

Three stages are used to develop and test neural networks:

1. Preparing a basic data set to be used as a template for the neural network's "learning process". It is important to emphasize that usually, a correct data set is expensive and time-consuming to build. In most practical research works on the use of neural networks, the preprocessing technique is reduced to normalization, scaling, and initial initialization of weights. If the factor space is small, the specifics of the source data distribution should be taken into account for effective training of the neural network. With a large number of factors, this can be difficult to do. In this case, it is advisable to use clustering to form a training set of examples of features that are most unique in the aggregate. One of the most effective clustering methods is the use of self–organizing Kohonen maps (Pastukhov & Prokofiev, 2016). Clustering of the factor space makes it possible to form a representative sample containing the most unique training examples for training the neural network.

   The most common types of variables are dependent and independent ones, whose possible values are taken from a set of categories. If they are expressed qualitatively, they are yes or no, red, green, or blue values, and if they are expressed quantitatively, they are numeric values.
2. Training (the neural network is trained to understand the logic of the output values of available historical data). When the data was set, the network is ready for training. There are two approaches to learning: supervised learning and adaptive learning.

   In supervised learning, both input and output data are provided, and the network compares the results with the provided output data. This allows to control how well the ANN is configured to predict the correct answer.

   For adaptive learning, only input data is provided. Using self-organizing mechanisms, neural networks benefit from continuous learning to face new situations and environments.

   One of the biggest challenges of the training method is to decide which network to use and how to configure the program execution process. Some networks can be trained in seconds, but in some complex cases with multiple variables and cases, it may take hours just for the training process.

   The results of the learning process are complex formulas that relate input or independent variables to output (dependent variables).
3. Testing (the trained neural network is tested to check the quality of prediction) and sensitivity analysis (to determine the stability of results with different random selections of test cases). After training the network, an image that was not previously presented is submitted to the input, which belongs to the same set of

categories as the set of images used in training (Strokova, 2014). Thanks to the information extracted from the training data, the network can assign the presented image to a specific category (Haikin, 2006).

After training and testing, the neural model is ready to predict future results. The most important information that should be the subject of our research is the contribution of each individual variable to the predicted results and its impact on the reliability of the model.

Let's take a closer look at some of the available neural network configuration models: probabilistic neural networks (PNN), multilayer feed-forward neural network (MLFN), and Best Net Search (Mossalam & Arafa, 2018).

1. PNN are statistical algorithms in which operations are organized into multilayer direct networks with four layers (input, pattern, summation, and output). Training is fast, but it requires a large amount of memory. These networks always have two hidden layers of neurons, with one neuron in the case of training located in the first hidden layer, and the size of the second layer is determined by some facts about the training data. This allows to make the prediction process fast. When an object/phenomenon is presented to the network, each neuron in the template layer of the model calculates the distance between the training object / phenomenon represented by the neuron and the input object/phenomenon. The value passed to the summation layer neurons is a function of the distance and smoothing factors (Mossalam & Arafa, 2018). Each input has its own smoothing factor; these factors determine how quickly the significance of training cases decreases with distance. The summation layer has one neuron per dependent category; each neuron summarizes the output values for the neurons corresponding to the training objects/phenomena in this category. The output values of the summation layer neurons can be interpreted as probability density function estimates for each class (Mossalam & Arafa, 2018). The output neuron selects the category with the highest value of the probability density function as the predicted category.
2. MLFN are the most popular neural networks that are trained using a "backward propagation of errors" learning algorithm, they have one or two hidden node layers. This method is more reliable than PNN, and is usually used if there is not enough time to apply the Best Network Search.

   When training a neural network using the "backward propagation of errors" algorithm, the responsible stage is the formation of the factor space, which is subject to the following requirements:

   - Consistency of the data involved in training is required.
   - The most unique features of the examples that make up the training set should be present.
   - A sufficient amount of training data for the network of the selected architecture is needed (Pastukhov & Prokofiev, 2016).

   To meet the first requirement, the training set should be analyzed for contradictions, it is necessary to find out the causes of errors (the error appeared when entering data or, more seriously, as a result of using an insufficient number of features of the factor space) and, if possible, eliminate them (Pastukhov & Prokofiev, 2016). The second requirement must be met in order to use the training sample as efficiently as possible. The amount of data used for training a neural network is often small, so it is extremely important to correctly form a training set containing data that is most unique in terms of the set of features. The third requirement is to achieve the specified accuracy of training the neural network in a finite number of steps.

3. Best Net Search is the most reliable method in which various neural network configurations are trained and tested, including PNN and MLFN, to generate the one that gives the best predictions for the data.

   Neural networks allow accurate decision-making without an algorithm or formula-based process. To do this, there are various information systems that allow to work with neural networks, create them and adapt them to specific research goals. Among them are, for example, Palisade Neural Tools, Deep Learning Toolbox, Microsoft Power BI, Oracle Crystal Ball, Neural Network Toolbox (MATLAB). For our research, the choice of software product using the neural network method was made based on the following criteria: the ability to process data online, ease of use, speed of operation, availability of output results, and availability for use (price). And as a result, Palisade Neural Tools was selected for future use.

   With the recent development of software tools, the process of building and training neural networks becomes very simple and clear. However, the biggest problem in getting reliable results is the quality of the input information. The whole process is based on real results, and most of the time, labor, and budget require getting enough reliable data to train and test the neural network.

9.6 Different Models of CE

9.6.1 Simulation Model of CE

The model presented in Fig. 9.7 was built using simulation modeling tools, namely, based on the concept of system dynamics and in the AnyLogic program. The model is based on the 6R concept, which includes such resulting indicators as Recycle, Rethink, Reduce, Reuse, Repair, and Recover. In our model, Reduce also includes Refuse, while Repair includes Refurbish, Remanufacture, and Repurpose.

This flow model uses four types of graphic objects that are basic for system dynamics: drives (levels, state variables, parameters containing something), flows (connections between drives, gates that regulate flows), and functional dependencies (determining the mutual influence of flows). The drives are marked by rectangles, flows as arrows, and the auxiliary variables by circles. All arrows indicate cause-and-effect relationships in the model. Streams (green, red, and gray arrows)

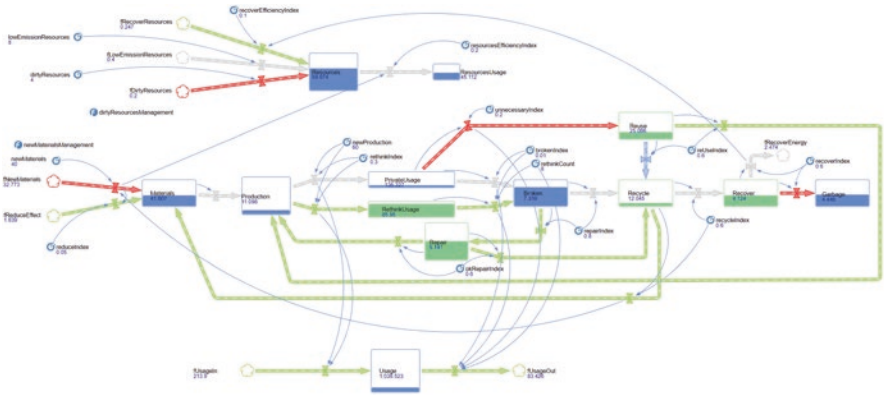

Fig. 9.7 The CE model with recurrent links in the concept of system dynamics. (Compiled by the authors based on the research results)

are the continuous movement of content between drives. Accumulators and flows influence each other through connections that can form chains of positive and negative feedbacks. Auxiliary variables denoted by circles were used to set the effects of parameters. Loops of causal relationships reflect the influence of processes on each other both directly and indirectly (through a long chain of causal relationships).

Thus, the purpose of constructing this model is not to search for a predictive value or identify a single indicator that describes the entire system, but to study the dynamics of the entire CE model with all its connections and parameters, which can lead to a correct understanding of the development processes of the entire system and identify control variables to adjust its operation. This is the main idea of system thinking.

Karpov Y.G. directly linked system dynamics with system thinking in the economy, social sphere, and ecology (Karpov, 2006). Complex models of system dynamics clearly show one of the main reasons for modeling: the direct impact of each specific process on other processes can be understood, analyzed, described, and graphically depicted. However, a person cannot understand the mutual influence of many processes. Only simulation and computer experiments make it possible to understand and evaluate the mutual influence of each process on any other, even if they are not directly related, as well as the influence of process parameters on important system characteristics.

The model consists of a large number of system parameters, drives or processes, flows, and control functions. Let's look at each of the blocks in more detail.

9.6.1.1 System Parameters

A system parameter is a metric or index that is set at the system input. The behaviour of the system can be analyzed with different options for the initial parameters set.

- brokenIndex (0–1) – the percentage of products that fail during a single model cycle.
- dirtyResources (0–100) – the number of newly produced resources that release harmful substances into nature. For example, energy extraction by burning coal or without using sufficient filtration of exhaust or wastewater; open-pit mining in polar regions; mining by explosions or other methods that destroy the structure of the soil.
- lowEmissionResources (0–100) – the number of newly produced resources that do not release harmful substances into nature in significant amounts. Production of electricity and heat by burning natural gas, use of various types of renewable energy (sun, water flow, tides, thermal springs).
- recoverEfficiencyIndex (0–1) – the conditional ratio of the useful volume of incinerated, processed, recoverable waste as a resource to their total amount.
- resourcesEfficiencyIndex (0–1) – the conditional share of material resources (energy, oil, petroleum products, metals, plastic, wood, water, etc.) in the creation of a new product.
- newMaterials (0–100) – the number of newly created materials using certain material resources.
- reduceIndex (0–1) – a conditional value that sets an indicator of resource efficiency, i.e. if earlier 100% of the resource was spent on creating a product, then in the next period it decreases by a specified share. I.e. the amount of metal, paint, and petroleum products decreases, and the cost of processing materials decreases.
- newProduction (0–100) – the number of products that are available for use.
- rethinkIndex (0–1) – the percentage of products that are actively shared. For example, car sharing, public transport, dormitories, and city communications.
- unnecessaryIndex (0–1) – the percentage of products that are out of use because they are not needed. In other words, they remain fully functional, but are not used.
- reUseIndex (0–1) – the percentage of products that were sent for reuse by sale, donation, or other methods. Goods that are not needed but are not used are considered waste and sent for further disposal. Goods that are not used or sold are also considered waste.
- brokenIndex (0–1) – the percentage of products that lose their functionality for various reasons.
- rethinkCount – (0–100) is an indicator of the intensity of product sharing. In other words, the car is used much less in private use than in car sharing, taxi or public transport. At the same time, the load on the product also increases many times, i.e. wear and early failure or loss of product presentation increases.
- repairIndex (0–1) – the percentage of products that lost their presentation or broke down, aimed at repair or restoration. Accordingly, the remaining part of the broken goods is sent for further disposal.
- okRepairIndex (0–1) – percentage of products that were repaired or restored. They are directed to reuse. Items that cannot be repaired or cannot be used to repair any other item are sent for further disposal.

- recycleIndex (0–1) – the percentage of products that were recycled. Recycled goods are materials and are entered into the system. Part of the goods that are not recyclable and cannot be used for further production is sent for further disposal.
- recoverIndex (0–1) – incineration of material with recovery of electrical and thermal energy. As well as reuse of biomaterials and other elements as a resource. The remainder of these processes is transferred to non-recyclable waste.
- resourcesEfficiencyIndex (0–1) – the index sets the effect of increasing the efficiency of using resources to create new materials. For example, if previously 100% of the resource was needed to create a unit of goods, now 98% of the resources are needed to create a unit of goods. That is, increasing the strength of alloys reduces their amount in the final product.
- recoverEfficiencyIndex (0–1) – transfer index for converting processed, recovered goods into resource units.
- lowEmissionResources (0–100) – this parameter sets the amount of use of resources with low emission of harmful substances.
- dirtyResources (0–100) – this parameter specifies the amount of use of resources with a high emission of harmful substances.

9.6.1.2 Drives or Processes

- Resources – resources necessary for the production of materials for production (ore, oil, water, energy, fertile soil, fertilizers, etc.).
- ResourcesUsage – the process of using resources, i.e. this is the part of the resources that really went to the production of any materials.
- Materials – materials that are used for the production of products. This is a generalized indicator of all the material means of production used to create a product. It consists of newly created materials, materials from various parts of already used products, as well as from recycled materials.
- Production – ready-to-use products. It includes all possible variants of products: new, restored, used, etc.
- PrivateUsage – products used for private purposes. They are characterized by a large number, but a small amount of use. On the one hand, the useful life of such products is much higher, but on the other hand, these products do not bring benefits and often clutter the space.
- RethinkUsage – products that are shared. I.e. the product can be rented, public or open for free use. Such products are characterized by increased wear and tear, resulting in faster failure.
- Broken products that have lost their product functions or appearance, i.e. they can no longer be used for their intended purpose.
- Repair – repair and maintenance of a broken product so that it can be used with its original functionality.
- Recycle-recycle materials to get the same high-quality or lower-quality product.
- Recover – the amount of incinerated, recycled, and recoverable waste as a resource.

- Garbage – non-recyclable garbage, from which it is impossible to extract useful properties and must be buried in a specialized landfill.
- Reuse – reuse by another consumer a product that is not needed by the original consumer, but is still in good condition and performs its original function; Active development of resale processes among consumers, especially using popular Internet sites, online auctions, and stores (eBay, Amazon, etc.).
- Usage-a conditional indicator of the use of the entire mass of products. This metric includes personal use products with a weight of one, and shared use products with a weight equal to rethinkCount. In case of failure, the indicator also decreases in accordance with rethinkCount. It shows that when the same product is used together, much more consumers use it. Also, more expensive products can be used by consumers who previously could not afford it, for example, using a car in car sharing and renting complex construction tools or equipment.

9.6.1.3 Flows

Flows show the movement of a resource or product over the network. Each stream has a formula or rule, a direction, and a beginning and end. If there is no initial process in the stream, it is a generator, if there is no final process-a terminator, i.e. the element as a result of the process completely loses its previous functionality and is removed from the network.

$$\text{fNewMaterials} = \left(\text{newMaterials} - \text{fRecycleMaterials}\right) * \text{newMaterialsManagement}\left(\ \right)$$

Flow of production of new materials. The growth of recycled materials reduces the production of new ones. The quantity of materials is also affected by the newMaterialsManagement control function, which suspends the production of new materials when products that are available for consumption but not used exceed a certain limit.

$$\text{fReduceEffect} = \text{fNewMaterials}^{*}\text{reduceIndex}$$

The flow reflects increased efficiency in the use of materials in the production of new products. The flow depends on the actual release of new fNewMaterials materials and the reduceIndex performance index.

$$\text{Materials}-> \text{Production} = \text{Materials}$$

Flow of materials into the production process. The model assumes that all manufactured and recycled materials are transferred to the production process.

$$\text{Production}->\text{PrivateUsage}=\left(\text{newProduction}-\text{uniform\_discr}\left(1{,}15\right)\right)^{*}\left(1-\text{rethinkIndex}\right)$$

The flow shows the movement of goods from production to private consumption. It depends on the total demand for the product with the addition of a random uniform_discr component, and also decreases depending on the rethinkIndex sharing index.

$$\text{Production}->\text{RethinkUsage}=\left(\text{newProduction}-\text{uniform\_discr}\left(1{,}15\right)\right)*\text{rethinkIndex}$$

The flow shows the movement of goods from production to joint consumption. It depends on the total demand for the product with the addition of a random uniform_discr component, and also decreases depending on the rethinkIndex sharing index.

$$\text{PrivateUsage}->\text{Broken}=\text{PrivateUsage}^{*}\text{brokenIndex}$$

The flow reflects the movement of a product that is out of order. The flow rate depends on the quantity of the product that is in private use, as well as the brokenIndex reliability index.

$$\text{PrivateUsage}->\text{Reuse}=\text{PrivateUsage}^{*}\text{unnecessaryIndex}$$

The flow of movement of a product that has ceased to be used by consumers and is leaving the process of private use. Depends on the total quantity of the product actually used and the unnecessaryIndex.

$$\text{RethinkUsage}->\text{Broken}=\text{RethinkUsage}^{*}\text{brokenIndex}^{*}\text{rethinkCount}$$

The flow reflects the movement of a product that is out of order. The flow rate depends on the quantity of goods that are shared, the brokenIndex reliability index, and the rethinkCount utilization rate.

$$\text{Broken}->\text{Repair}=\text{Broken}^{*}\text{repairIndex}$$

Products aimed at repair, restoration or reconstruction. Depends on the repairIndex.

$$\text{Repair}->\text{Production}=\text{Repair}^{*}\text{okRepairIndex}$$

Products that have actually been repaired or restored to a state where they can be used either for their original purpose or for other functions.

$$\text{Repair}-> \text{Recycle} = \text{Repair}^{*}\left(1-\text{okRepairIndex}\right)$$

Items that cannot be repaired, or waste that appeared during the repair process. The flow depends on the number of items being repaired and the okRepairIndex.

$$\text{Broken}-> \text{Recycle} = \text{Broken}^{*}\left(1-\text{repairIndex}\right)$$

The flow of products that are not initially repairable. They are sent for recycling. The flow depends on the number of items being repaired and the repairIndex.

$$\text{Reuse}-> \text{Recycle} = \text{Reuse}^{*}\left(1-\text{reUseIndex}\right)$$

The flow of products that for some reason cannot be sent for reuse to other owners. Such goods are sent to the processing process. The flow depends on the total number of unused items and the reuseIndex.

$$\text{Recycle}-> \text{Recover} = \text{Recycle}^{*}\left(1-\text{recycleIndex}\right)$$

Goods that can no longer be extracted for reuse in production are sent for incineration, recycling, and recovery as a resource. The flow depends on the total number of products processed and the recycleIndex.

$$\text{Recycle}-> \text{Materials} = \text{Recycle}^{*}\text{recycleIndex}$$

The flow reflects the movement of materials extracted from non-working and unused goods, which are returned to the production of new goods. The flow depends on the total number of processed goods and the recycleIndex.

$$\text{fRecoverEnergy} = \text{Recover}^{*}\text{recoverIndex}$$

The flow shows the recovery process, as a result of which the volume of recovered goods is withdrawn from the system, but at the same time, the amount of resources for the production of new materials increases. The flow depends on the recovery volume and the recoverIndex.

$$\text{Recover}-> \text{Garbage} = \text{Recover}^{*}\left(1-\text{recoverIndex}\right)$$

The amount of waste from which it is no longer possible to extract useful properties is sent for disposal in specialized landfills. The flow is based on the total amount of waste in the recycling process and the recoverIndex.

$$\text{fUsageIn} = \text{fPrivateProduction} + \left(\text{fRethinkProduction}^{*}\text{rethinkCount}\right)$$

The flow of increasing the utilization rate of manufactured goods. Shows how much real consumption increases among users. This flow depends on the volume of private use with a weight of one and on the flow of shared use with a coefficient of intensity of operation rethinkCount

$$\begin{aligned}\text{fUsageOut} &= \text{fPrivateProductionBroken} + \text{fUnnecessary} \\ &\quad + \left(\text{rethinkCount}^{*}\text{fRethinkProductionBroken}\right)\end{aligned}$$

The flow of reducing the indicator of use of goods as a result of breakage or refusal to use. The flow depends on the failure of products in private and shared use, as well as on the volume of products that retain their functionality, but for some reason go out of use.

$$\text{fRecoverResources} = \text{fRecoverEnergy}^{*}\text{recoverEfficiencyIndex}$$

Flow of recovered resources. Depends on the flow of waste received for recovery and the efficiency index of this process recoverEfficiencyIndex.

$$\text{fLowEmissionResources} = \text{lowEmissionResources}^{*}\text{dirtyResourcesManagement}\left(\ \right)$$

The flow of resource development with insignificant content of toxic substances released into the atmosphere. This flow is regulated by the nature clogging control function dirtyResourcesManagement (), which reduces or completely stops the use of such resources in production.

$$\text{fDirtyResources} = \text{dirtyResources}^{*}\text{dirtyResourcesManagement}\left(\ \right)$$

The flow of resource development with a significant content of toxic substances released into the atmosphere. This flow is regulated by the nature clogging control function dirtyResourcesManagement (), which reduces or completely stops the use of such resources in production.

$$\text{Resources}- > \text{ResourcesUsage} = \text{fNewMaterials}^{*}\text{resourcesEfficiencyIndex}$$

The flow of resources. Depends on the release flow of new materials and the resourcesEfficiencyIndex resource efficiency index.

9.6.1.4 Some Control Functions

dirtyResourcesManagement – a control function for nature clogging that reduces or completely stops the use of such resources in production, depending on the need for resources at a certain point in time.

```
if ((Resources/ResourcesUsage)<0.25) return 0.75;
else if ((Resources/ResourcesUsage)<0.5) return 0.5;
else if ((Resources/ResourcesUsage)<0.75) return 0.25;
else if ((Resources/ResourcesUsage)>1) return 0.05;
return 1;

newMaterialsManagement
if (Production/(PrivateUsage+RethinkUsage) <0.25) return 0.75;
else if (Production/(PrivateUsage+RethinkUsage) <0.5) return 0.5;
else if (Production/(PrivateUsage+RethinkUsage) <0.75) return 0.25;
else if (Production/(PrivateUsage+RethinkUsage)>1) return 0.05;
return 1;
```

9.6.2 Deep Recurrent Neural Network Model of CE

After the CE model in AnyLogic was constructed, we set ranges of numbers and the stochastic order in which the model selected variable values from it. Despite the randomness of the variable values, after the model was launched it became clear that the model stabilizes by the 200th time period (Fig. 9.8) and the indicators tend to constants. Accordingly, 200 data on the following 5 "R" indicators were selected for testing and training the neural model: Reuse, Recover, RethinkUsage, Recycle, and Repair. The 6th "R" – Reduce – could not be taken for training and testing the neural network model as it was used as a function fReduceEffect=fNewMaterials*reduceIndex. Another five parameters are presented in Table 9.1.

Based on the goal of creating a neural network not to make a forecast, but to track the behavior of the system and its stability, the MLFN configuration model and the adaptive learning were used to build and train the RNN. It took some hours for the training process. The results were complex formulas that relate the input or independent variables with the output (dependable variable) (Tables 9.2 and 9.3).

Thus, using RethinkUsage as a dependent variable on 9 independent parameters (Table 9.1), the neural model showed a linear relationship (direct and inverse) between the parameters and calculated their coefficients to determine the regression

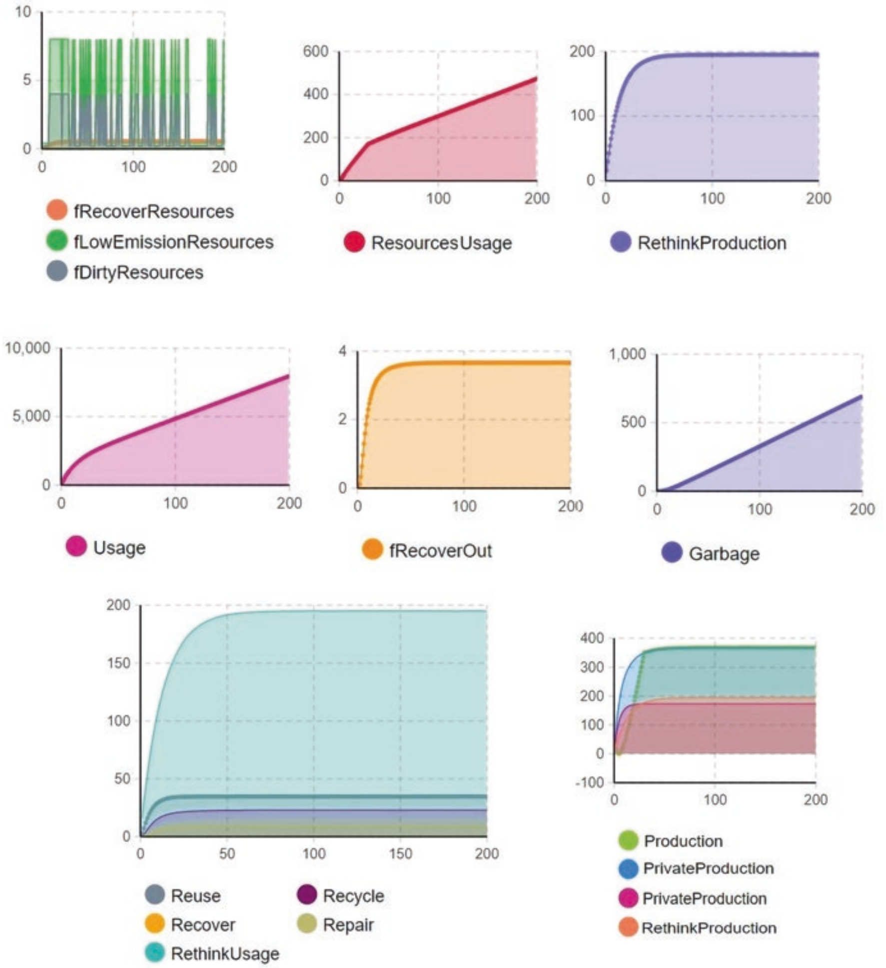

Fig. 9.8 Values of some variables and functions of the model on a time scale (200 time periods). (Compiled by the authors based on the research results)

function (Table 9.2). From the entire set of parameter values over 200 time periods, the neural model itself randomly selected 160 data packets (rows in Table 9.3) for training and 40 data packets – for self-testing. According to the indicators of information suitability of the model based on training and test samples – root mean square error, mean absolute error, and standard deviation of absolute error – it was concluded that the model is suitable for analyzing and explaining economic phenomena and processes (Table 9.3).

Table 9.1 Some of the data used for training and testing the RNN (Palisade Neural Tools software)

Number of cases	Resources Usage	Rethink Production	fRecover Resources	Flow Emission Resources	fDirty Resources	Reuse	Recycle	Recover	Repair	Rethink Usage
1	0.072	15.879	0.002	0.4	0.2	2.61	0.36	0.03	0.15	15.82
2	7.956	29.624	0.017	0.4	0.2	7.23	1.73	0.29	0.69	29.57
3	15.632	42.374	0.05	0.4	0.2	11.89	3.76	0.83	1.50	42.37
4	23.048	54.087	0.095	0.4	0.2	16.01	5.99	1.59	2.41	54.07
5	30.2	64.91	0.145	0.4	0.2	19.48	8.13	2.42	3.32	64.90
6	37.108	74.935	0.194	0.4	0.2	22.35	10.06	3.23	4.19	74.92
7	43.798	84.186	0.239	0.4	0.2	24.69	11.75	3.99	4.99	84.16
8	50.3	92.713	0.279	0.4	0.2	26.60	13.20	4.66	5.73	92.70
9	56.642	100.639	0.314	8	4	28.13	14.43	5.24	6.40	100.60
10	62.848	107.859	0.344	8	4	29.37	15.48	5.73	7.01	107.82
11	68.936	114.628	0.369	8	4	30.37	16.38	6.16	7.57	114.55
12	74.924	120.81	0.391	8	4	31.18	17.14	6.52	8.07	120.74
13	80.827	126.52	0.41	8	4	31.84	17.79	6.83	8.54	126.44
14	86.657	131.809	0.426	8	4	32.39	18.36	7.10	8.97	131.74
…										
198	470.237	194.834	0.549	0.4	0.2	34.68	22.88	9.15	13.87	194.85
199	471.992	194.904	0.549	0.4	0.2	34.68	22.88	9.15	13.86	194.82
200	473.989	194.923	0.549	0.4	0.2	34.68	22.88	9.15	13.86	194.86

Table 9.2 The fragment of a table with the training and testing results (Palisade Neural Tools software)

Tag used	Prediction	Good/Bad	Residual
Train			
Train			
Train			
Train			
Train			
Test	74.90	Good	0.02
Train			
Train			
Train			
Train			
Train			
Train			
Train			
Train			
Train			
Test	141.08	Good	−0.13
Train			
Train			
Train			
Train			
Test	158.81	Good	−0.03
Test	161.64	Good	−0.01
Test	164.21	Good	−0.05
Train			

9.7 Results and Discussion

The results of the analysis of processes in the developed circular economy model can be divided into two groups: positive and negative effects (Table 9.4).

As can be seen from the table, the number of negative factors greatly exceeds the positive ones. Therefore, it is already necessary to develop programs and projects to prevent the occurrence of negative events or minimize the effect of their occurrence. Without a project-based approach at the level of government and at the level of companies, it will be impossible to move painlessly from a linear to a circular economy. The following factors should also be taken into account when planning state transition programs and projects for restructuring production processes:

- The share of “Re”-processes in production is growing, which leads to a shortage of recyclable materials (the volume of flows in reverse loops). If all the return loops are well-defined, the volume of renewable resources and materials is not so large, and competition for the right to use recyclable materials will grow strongly.
- The production of new goods strongly decreases. For the conservation and sustainable development of technologies, the share of scientific and engineering

Table 9.3 The Palisade Neural Tools summary table

Linear function	
	Intercept/coefficient
Intercept	5.809
ResourcesUsage	0.00009995
RethinkProduction	0.1842
fRecoverResources	−23.81
flowEmissionResources	0.2451
fDirtyResources	−0.4914
Reuse	3.064
Recycle	−9.383
Recover	6.072
Repair	15.81
Net information	
Name	Net trained on data set #1
Configuration	Linear predictor
Location	This workbook
Independent category variables	0
Independent numeric variables	9 (Resources usage, RethinkProduction, fRecoverResources, flowEmissionResources, fDirtyResources, reuse, recycle, recover, repair)
Dependent variable	Numeric Var. (RethinkUsage)
Training	
Number of cases	160
Training time	0:05:00
Number of trials	0
Reason stopped	Auto-stopped
% bad prediction (30% tolerance)	0.0000%
Root mean square error	0.05008
Mean absolute error	0.03998
Std. deviation of Abs. Error	0.03015
Testing	
Number of cases	40
% bad prediction (30% tolerance)	0.0000%
Root mean square error	0.04962
Mean absolute error	0.03617
Std. deviation of Abs. Error	0.03397
Data set	
Name	Data set #1
Number of rows	200
Manual case tags	NO

Table 9.4 Positive and negative effects when switching to a CE model

Positive effects	Negative effects
Reduced number of extracted resources and landfills	
Increase the population density without reducing the quality of life	
Decrease the number of credits of the population	Increase the number of regular monthly payments
Increase accessibility to technology	Reduced life cycle of products due to the intensity of their use
	Decrease the number of products
	Increase the intensity of circulation of money in the economy
	Increase competition
	Reduced the number of producers
Increase the services market	Reduce the production market
	Resource-Oriented economies will face inflation due to a decrease in household incomes and a decrease in the number of products sold
	Developed countries with non-resource-oriented economies will face devaluation due to a drop in the competitiveness of manufactured goods in foreign markets

research in production costs grows gradually, but intensively, which leads to a strong increase in the cost of the final product for the consumer. That means that the consumer becomes more profitable to participate in the sharing system and doesn't have a certain product in the property.

- The need for continuous large consumption of new resources and products decreases. There may be an intense drop in demand for primary resources, which may lead to a decrease in their cost on the market. At the same time, resource recycling technologies cannot become cheaper. How can this process be regulated? By setting limits of production? Then countries that do not participate in the recycling process will have a strong competitive advantage, since they will not have restrictions on the use of resources that have fallen in value.
- The actual consumption of various products can afford a much larger number of the population without an increase in production, which means the growth of consumption is not due to an increase in production, but due to more frequent use of the product already produced.
- The reduction of burden on the environment. As a result, the living environment of a large number of people becomes better. Tourist and recreational activity is increasing.
- The emergence of a new technologically intensive and financially active industry for processing waste from industrial and consumer human activity.
- The possibility of closer living of the population without reducing the quality of life. It is important for countries with an existing overpopulation.

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