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Simulating Tomorrow: Ensuring a Sustainable Future

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Simulation of a Sustainable Civilization:

The Circular Economy

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Based on climate simulations [1] we know that global warming is caused by human activities that produce greenhouse gas emissions (mostly CO_2). Figure 1 shows the results of climate simulations for a "business as usual" scenario, and for the case when the greenhouse gas emissions are greatly reduced. The validation of the models was the historical climate data set. Based on the validated models we know that the warming-up process will not slow down if we don't reduce our CO_2 emissions or extract enormous amounts of CO_2 from the atmosphere.

But even if we were able to extract enough CO_2 from the air in a sustainable way, it would only give us a little extra time before the destruction of the planet becomes irreversible.

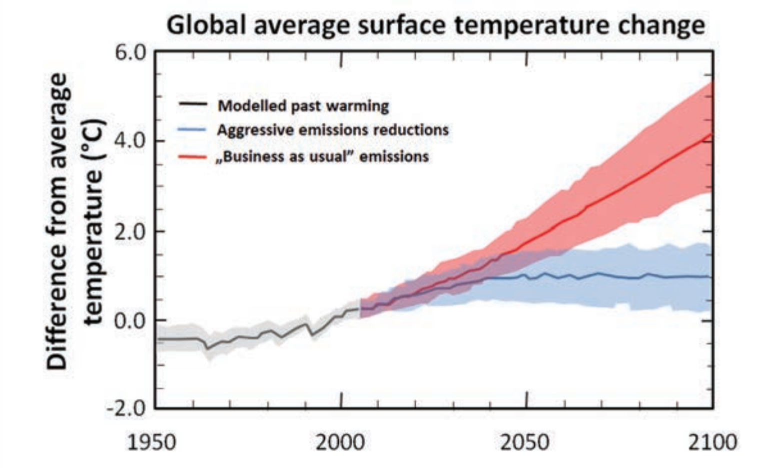

Figure 1: Climate change simulation results [1]

Thanks to increased awareness, today we might be closer to understanding how important it is that we live our lives in harmony with the biosphere if we want to ensure the wellbeing of our offspring. The idea of the Circular Economy (CE) is dedicated to the realization of a harmonious relationship between humanity and nature. This optimized economy system is based on restoration which is depicted in Figure 2, taken from the Ellen MacArthur Foundation report, "Towards the Circular Economy" [2]. As you can see all of the human activities have to be redesigned to become restorative, this is for both technological and agricultural production. To reduce our harmful emissions the processing of materials and that of energy has to be precisely designed to avoid any leakage of resources.

It seems obvious that the design process of the depicted ecosystem has to be supported by virtual testing of the design variants and by the simulation of different scenarios. Just like every other type of simulation method, here too, the global problem can be broken down into smaller sub-problems. It means that we can draw the "V" model also for CE simulations, where on the left side we have the "Idea of the sustainable civilization", and on the right side we have the "Human Civilization based on Circular Economy" as output. The simulation of the whole of civilization seems to be an unrealistic goal, but even the simulations of the subsystems are extremely helpful. The models can be validated of course, comparing the simulation results to acquired data from the economy and from the ecology. The models of these sub problems can be optimized after validation, approaching the realizable global CE as the sum of these sub-processes.

Application of numerical simulation methods in the economy has its own history, and now we can witness its explosion. It was not the technology itself but rather acceptance and acknowledgement of numerical techniques in business that were the biggest obstacles in the way of the method's general popularity. Because we have to deal with the simulation of networks, it was an important milestone when Barabási [3] settled the basics of Network Science in the last decade. Thanks to that, today more reliable network simulations can be performed than ever before and thus the simulation results delivered for decision makers are also much more precise. Basically, three types of simulation techniques are applied to describe economy processes and thus also the highly complex CE system and sub-systems. These techniques are the Discreet Event Simulation method, Agent Based Modelling and, System Dynamics. It is worth taking a closer look at them.

Discrete event method: A lot of processes in business can be modelled as a system of separate discrete events. For example, a customer arrives at a teller, is served, and then leaves. The best way to simulate this is the application of discrete event simulation. Using discrete event simulation modelling, the movement of a vehicle from point A to point B is modelled with two events, namely a departure and an arrival. Discrete event simulation focuses on the processes in a system at a medium level of abstraction. [4]

Agent based modelling: In agent based modelling (ABM) individual active elements of a system are in focus. Using ABM, active entities, the so called agents, have to be identified and their behaviour has to be defined. The "agents" may be humans, equipment, or companies relevant to the system. In the simulation we establish connections between the agents, set environmental variables, and simulations run. The global dynamics of the system is the sum of interactions of the agents. [4]

Systems dynamics: When describing the modelled system in an abstract way we talk about system dynamics. Due to the simplifications, these abstract simulation models can be used for highly complex models for strategic modelling. [4]
The three techniques can even be combined with each other and this way pretty complex system can be described.

In their comprehensive work, Roodt and Dempers also described the doubts related to simulations in their introduction of their modelled CE related "BioHub" problem. To highlight the complexity of the simulation task the authors cited the following: "Circular Economy systems contain people, technology and processes, environmental (including ecological) components and biological systems in the context of cultural, legal, financial and political frameworks. Ilya Prigogine showed that complex systems are subject to temporal behaviour that is not symmetrical [5] . Their past and future states are not interchangeable. Knowing the past trajectory of a system may have no bearing on its future". [6]

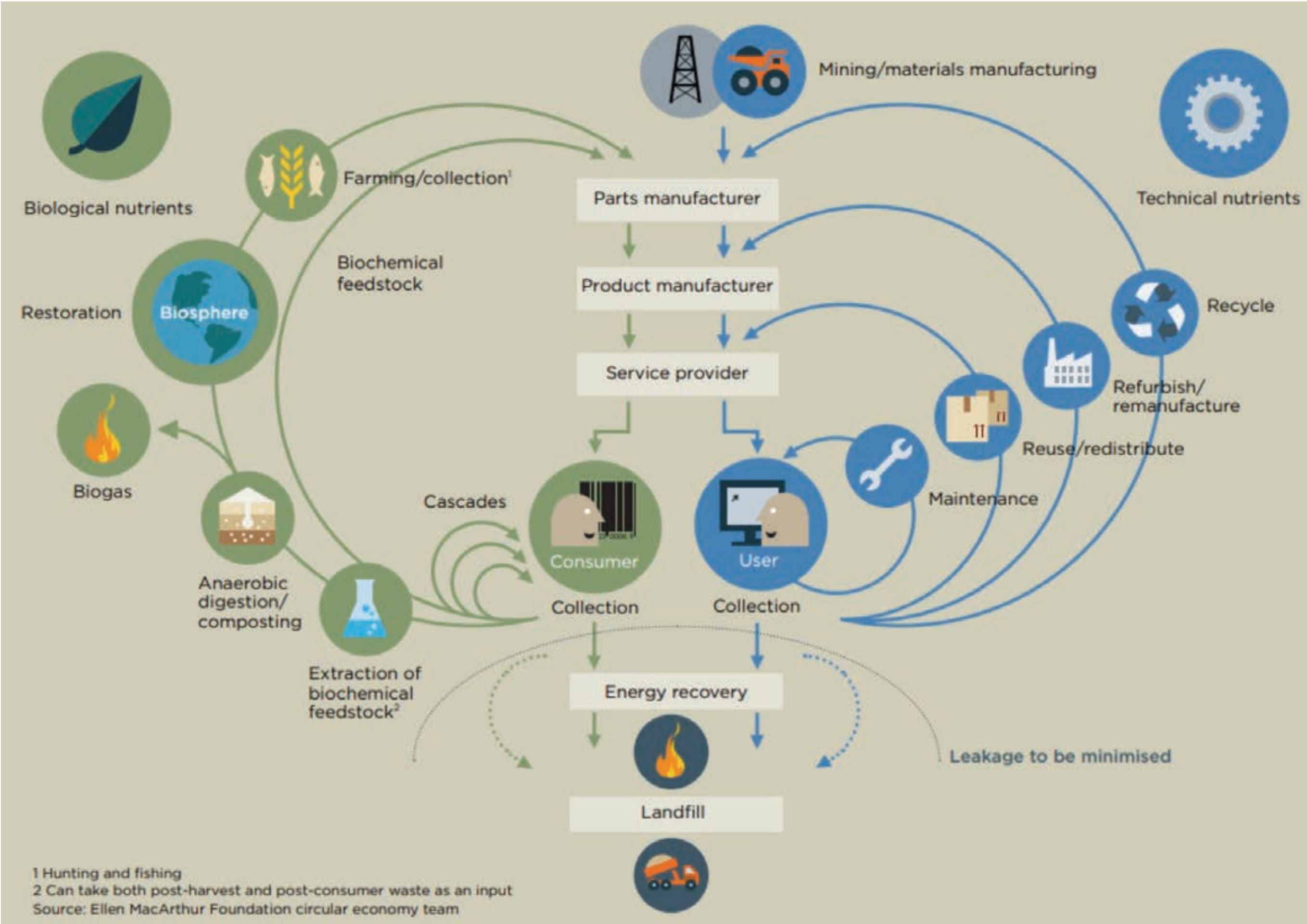

Figure 2: Diagram of the Circular Economy [2]

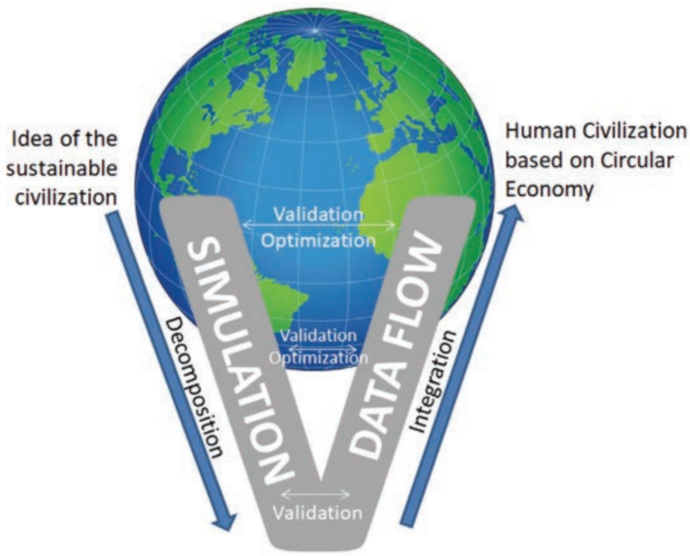

Figure 3: V Model for CE Simulations

Roodt and Dempers also cited the six limits and challenges of the CE concept which were identified in former studies. However, reading the list my doubts about being able to deliver reliable enough simulations in this field increase point by point.

1. Cyclical systems are subservient to the laws of thermodynamics and consume resources and create waste and emissions. The sustainability contribution of CE projects must be assessed on a case-by-case basis.
2. Systems have temporal and spatial boundaries. Care must be taken to ensure that problems are not just shifted along the product and service life cycle, while it must be recognized that the short-term use of non-renewables can support development of long-term renewable infrastructure.
3. The economy (regional and otherwise) dictates the scale of the infrastructure interventions.
4. Lock-in of first technologies and path dependency impose limits on what can be changed.
5. Governance and management impose limits on material and energy flows.
6. Society and culture dictate world views and how waste is defined, managed and handled. These views are fluid and change over time. [7]

Fortunately, you are not helpless when trying to overcome model and simulation building difficulties. Tolk et.al [8]] proposed a development framework to tie together different approaches. It has six steps:

1. Capture the understanding of the situation to be addressed
2. Make assumptions and constraints explicit
3. Construct the agreed upon 'reality' – the reference model
4. Formulate the focus modelling question(s)
5. Create the conceptual model by capturing how we intend to answer the modelling questions
6. Create the simulation model in an appropriate simulator environment.

Being aware of the upper challenges, with the right team one can create useful economy models and simulations. The investigated model by Roodt and Dempers was the BioHub processing plant. For this conceptual model tourists were modelled as agents who generate waste that has to be transported to landfill. They also generate revenue for the region. The tourists will however only be attracted to the region if they can take part in water-based leisure activities (i.e., clean water). If industry pollutes the river, current tourists will leave, and the town will not attract new tourist revenue; the agents will leave as the pollution in the river increases, or move to the region if the water is clean. More tourists mean more revenue, but results in increased landfill that will remain after the tourists leave. Tourists increase pressure on utilities - e.g. electricity consumption. When the waste-to-energy CE BioHub processing plant is engaged, energy is supplied to the town and the grid is disengaged (a simplification for this round). [6]

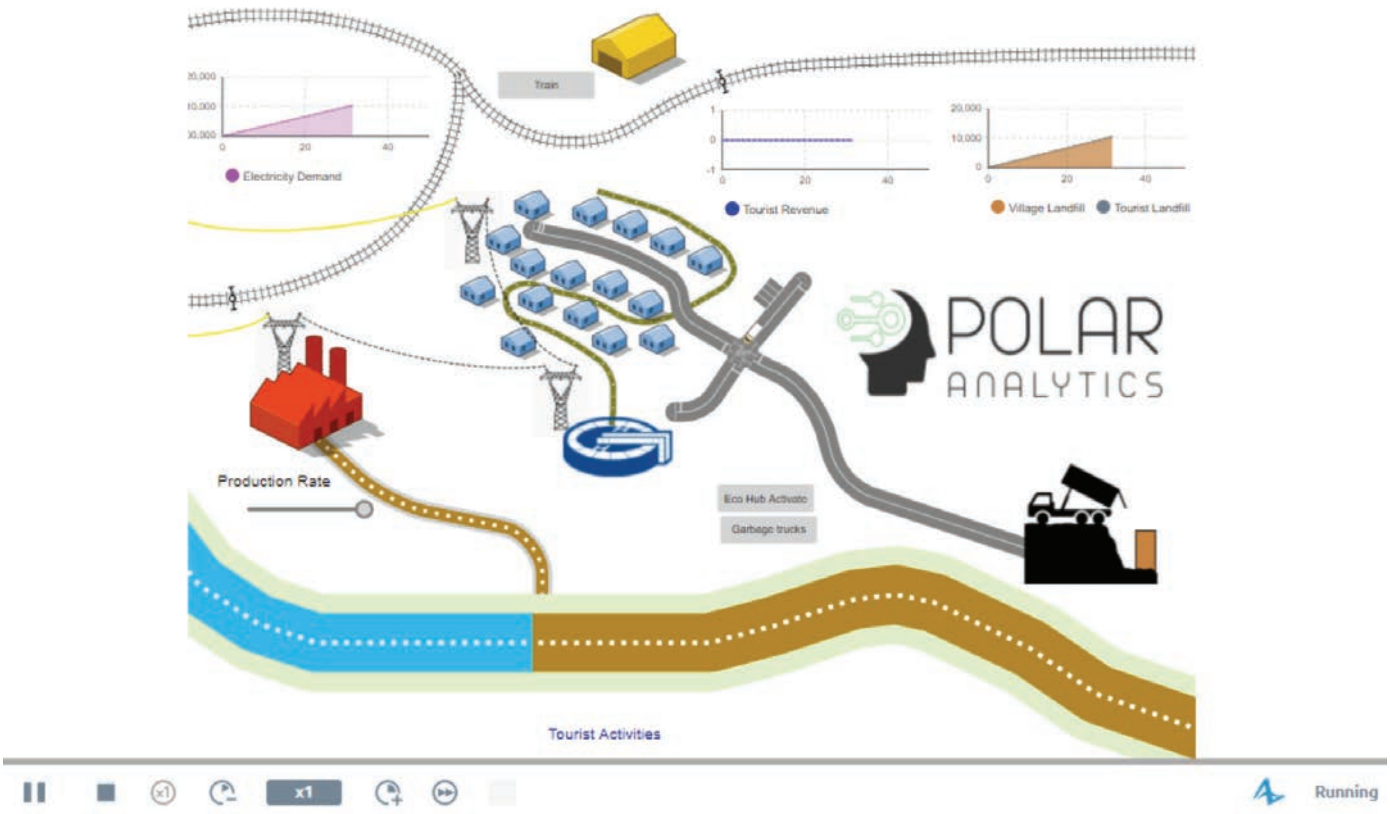

Figure 4: Model of the BioHub problem [6]

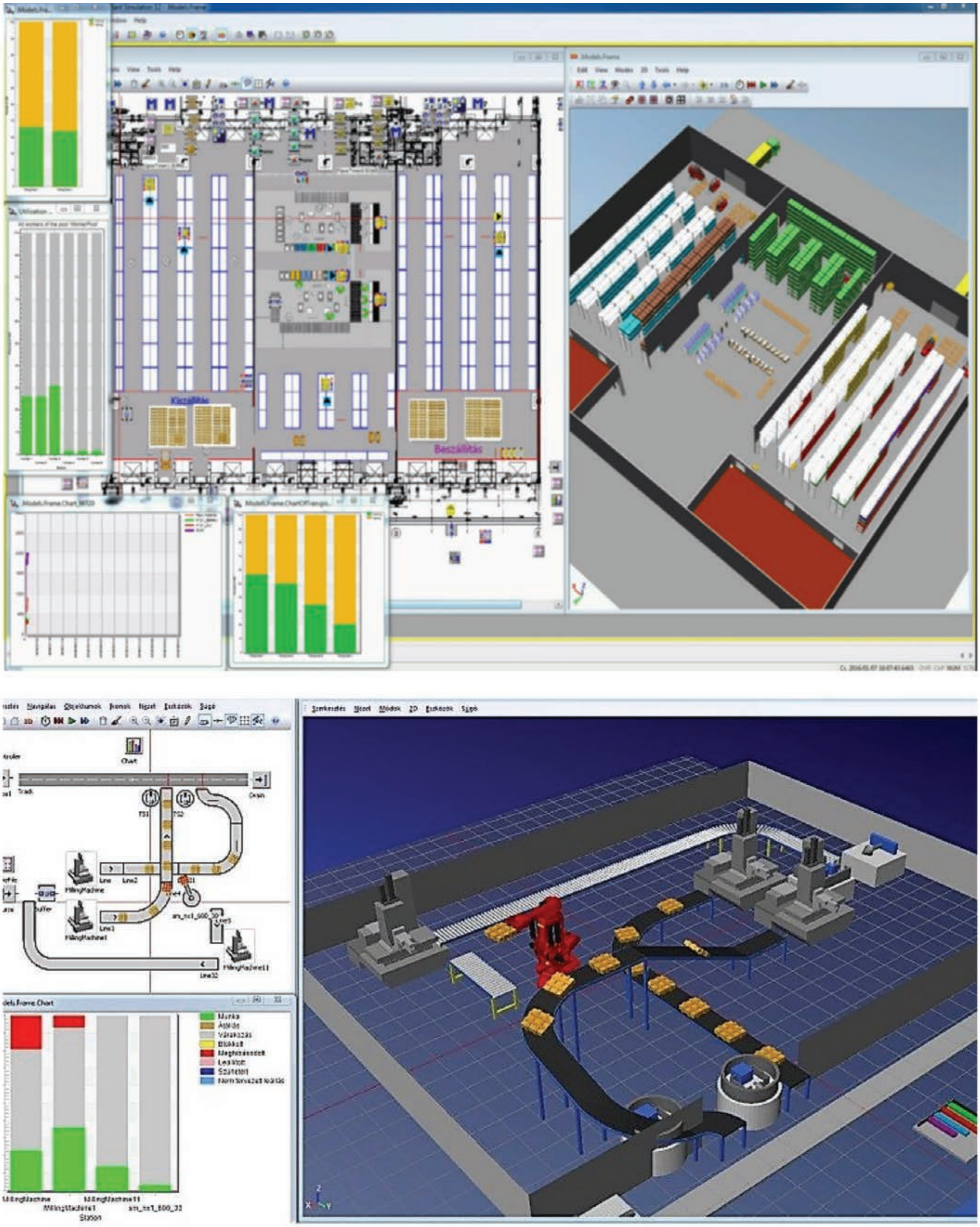

Figure 5: Digital twins in use: modelling and simulation for optimization, improving effectiveness and sustainability (Bay Zoltan Nonprofit Ltd.)

"Simulation models in the context of the circular economy are often used to study "what if" scenarios, and to explore different concepts. These models are used for explorative conceptual work and they are not intended to be accurate digital twins. Nevertheless running the models for a broad spectrum of parameters one can understand the behaviour of the large system and those results are extremely valuable. These are the basis of planning discussions and strategic business decisions." (Clemens Dempers, Polar Analytics Oy)

"The biggest challenge to simulating CE is deciding how to frame the simulation for the particular model, what kind of data and expertise do you have to describe it. Untangle the feedback loops, to find out what drives the system. You need a multidisciplinary team from very different field's including human psychology, industrial psychology and behavioural psychology to find out what the people really like to do, and to know how the individuals can be motivated to change their behaviour. Further on you need expertise to estimate economic impacts. When a recycling loop is realized it will have an impact on the mining industry for example because fewer raw materials are needed. Another important thing that has to be kept in mind is that it is not economically viable to recycle everything. To recycle aluminium is easier than it is to mine it. For other materials it is not always the case. The whole supply chain has to be modelled to capture all the economic and environmental effects." (Clemens Dempers, Polar Analytics Oy)

The growing importance of simulations in the field is also reflected in the increasing industrial simulation needs that are now being fulfilled by specialized research institutions just like the Bay Zoltan Nonprofit Ltd. in Hungary:

"In production, reducing losses and improving performance not only reduces environmental impacts, but also makes management satisfied by eventually reduced costs. Optimization of processes is a primary key. Industry 4.0 highly supports this ambition, relevantly contributing to sustainability. Bay Zoltán Research Institute focuses on specific industrial applications, Industry 4.0 solutions especially for SMEs to collect information on production process at an affordable price. We use event-based simulation tools to develop digital twins for production, simulate processes and identify weak points (i.e. losses or bottlenecks) in the process chain. Ideally this analysis may happen real-time, as an obvious approach, in Industry 4.0. This complex development can support companies to improve their overall resource efficiency increased sustainability. As a result, the ecological footprint of the product by the optimized production process will be reduced." (**Ernő Garamvölgyi**, Logistics Research Group Leader, Bay Zoltan Nonprofit Ltd.)

Research in sustainability related fields is not new. Life cycle assessment (LCA) which is an important issue also in CE has more than a decade of history at the Bay Zoltan Ltd.

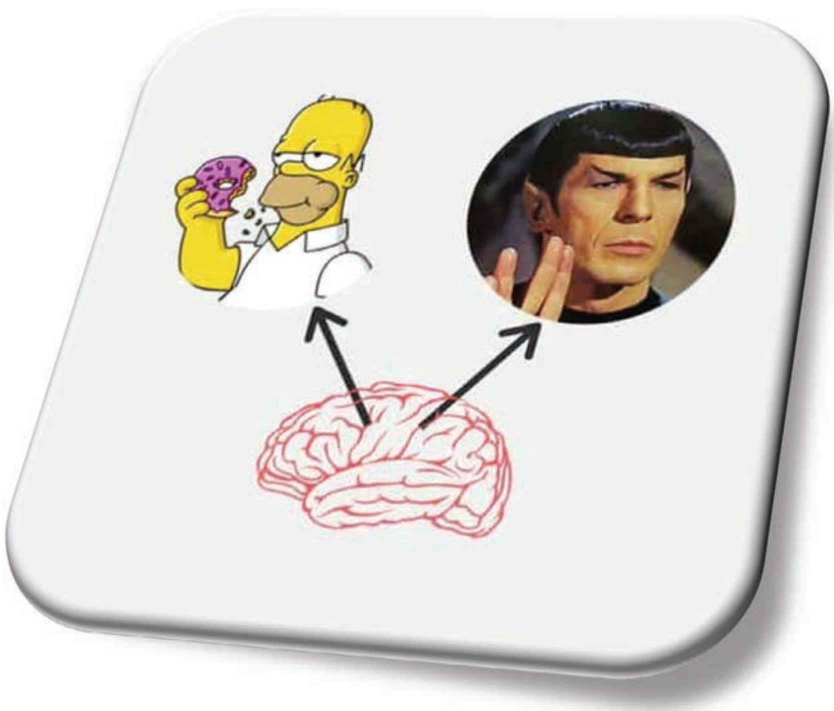

Figure 6: Homer vs. Spock [9]

"Proving *sustainability by minimizing the environmental impacts with feasible financial consequences is always a challenge. For this aim, Bay Zoltán Research Institute uses scientifically proven and acclaimed life cycle assessment (LCA) methodology. The developed models comprise the overall life cycle of the product/service including raw material use (both for primary and secondary), production, use phase and end-of-life actions. The LCA collects all the necessary – mainly on site - information from the production phase to evaluate the emerged environmental impacts, taking into consideration either country and process specific professional databases. Based on the collected information, environmental loads are calculated, assessed, weak points and the potential environmental savings can be detected. This is a comprehensive ecological assessment with the objective to identify changes, at each stage of the life cycle that can lead to environmental benefits and overall cost savings and finding environmentally the most favourable alternative between different scenarios. Bay Zoltán Research Institute has substantial references in environmental Life-Cycle Assessment (LCA) for more than 15 years – LCA of production, EPD (Environmental Product Declaration, Carbon Footprint Assessment, etc.)."* (**Renáta Bodnárné Sándor**, LCA Research Group Leader, Bay Zoltan Nonprofit Ltd.)

The most difficult issue in CE simulations is the reliable prediction of customer behavior when introducing sustainable products. The question is how we behave, are we Homer or Spock? i.e. do we tend to make quick and easy instinctive decisions or are we more inclined to make choices based on reflexive, rational, controlled and time-consuming thoughts? Whatever we may think, one way or another, simulations in CE will help decision makers to save the world from our intrinsic Homer Simpsons.

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