SZENT ISTVÁN UNIVERSITY

DOCTORAL SCHOOL OF MANAGEMENT AND BUSINESS ADMINISTRATION

CIRCULAR ECONOMY MODELS AND THE MEASUREMENT OF THEIR EFFICIENCY

THESIS STATEMENTS OF THE DISSERTATION

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1. RATIONALE OF THE RESEARCH, RESEARCH GOALS

The choice of the topic derives from the recent decision of the European Union to make the implementation of “Circular Economy” a strategic goal of the community. (EC 2015). The initiative is basically designed to transform the currently dominating economic system, based on the principle of “take-make-dispose”, into a resource-efficient system (EMF 2013). This approach sounds simple, but experience has shown that there are many interpretations of the circular economy. These include correct and incorrect, asymmetric information-based trends. Uncertainty is due to the fact that the circular economy – in contrast to the environmental initiatives so far – represents not only one ecological aspect (e.g. climate protection). Rather, it means a new development paradigm with a holistic vision that integrates the various subsystems of sustainability pillars (economy, society and environment) in a versatile manner.

In the dissertation, the anomalies arising in the interpretation of the circular economy are listed under one topic. This area has been defined in my research work as the “contradictions of practical implementation of the circular economy”, so I refer to it in the dissertation in the same way. In connection with this, I have defined two objectives that are designed to avoid misapplication of the concept.

My primary goal (G1) is to discover the paradoxical effects of creating closed material cycles. This topic discusses the issue of “closed loops” that is a widely used term in a circular economy. The literature reveals that material flows can not only be closed, but extended and narrowed. So instead of recycling waste, it is best to avoid creating it (CRAMER 2017). This can be achieved by extending the life cycle of products or reducing consumption.

Therefore, in my first hypothesis (H1), I state that developments focusing on the closure of material cycles lead to contradictory results. Mechanisms to ensure the efficiency of the material cycle do not necessarily reduce the environmental burden of production and consumption activities sufficiently.

My next goal focuses on the contradictory phenomenon that exists between the useful life of the products and their ecological efficiency. In this topic, the lifecycle extension mentioned above plays an important role. This means, that a product should have the longest possible useful life - ahead of the production and consumption of new ones (BAKKER ET AL. 2014). However, the literature also points out that the products produced should be kept on the highest utility level throughout their lifetime. This, on the one hand, means intensive use, which results in rapid depreciation and reduced product life. On the other hand, the utility can be identified by the fact that a product is resource efficient, so it requires less energy – and other materials – during its operation (EMF 2015a).

And the latter can be achieved by the replacement of old products with new, energy-efficient and material-efficient versions. So, the useful life and the maximum benefit are apparently in opposite directions.

For this reason, as my second goal (G2), I set out to analyze the trade-off between the useful lifespan and the utility below it through a case study. I chose the sample of the modernization of the Hungarian building stock, which has been on the table for both the profession and the policy makers for years. The point of the ongoing debate is to decide whether it is worthwhile – from an economic and environmental point of view – to invest in the renovation of existing buildings nearing the end of their life cycle, or to start building new, modern structures instead?

Based on the literature reviewed in this topic, in my second hypothesis (H2) I assumed that the renovation of buildings is a more efficient way – in economic and environmental means as well – to modernize the Hungarian building stock than replacing it with new buildings. The long-term EU climate goals can be achieved through a modernization strategy based on renovation.

These two goals so far have adequately covered the range of contradictions perceived regarding circular economy in recent years. After their fulfillment, I will focus on finding the place of this concept in the field of sustainability. This research area will be treated as a separate topic in my work which I call "Sustainability Issues".

In this area, I will first examine the perception of global supply systems in a circular economy. Since the concept aims to efficiently manage resources and recycle them into production, it prefers systems which makes it easier to track them. Therefore, it considers the closure of material cycles to be not only a technical but also a regional matter (DE WIT ET AL. 2016; KRAAIJENHAGEN ET AL. 2016). Although it admits that the total self-sufficiency of local communities cannot be an option anymore, it places great emphasis on defining the territorial boundaries of supply chains and criticizing intensive production on global markets (FOGARASSY ET AL. 2016). The decisive role of localization is not surprising in the circular economy, as this issue has always been a fundamental problem in the field of sustainability.

Therefore, my third goal (G3) will be to analyze how the environmental and economic efficiency of large-scale production systems correlates with local supply patterns. As this is a rather broad topic, I will limit the quantitative analysis to energy production systems. One of the reasons for this is the key role of energy flows in the circular economy. On the other hand, this topic is also relevant from a social point of view, since local energy production based on community involvement has many social values.

Based on the professional experiences of such initiatives, I state in my third hypothesis (H3) that the use of decentralized energy production systems offers more favourable environmental and economic conditions than the currently used system in Hungary.

This topic covers one of the two main aspects of circular economy, which is the emerging scarcity of resources. This phenomenon makes it increasingly important to develop efficient production and consumption systems with minimal energy and material losses. Another determining factor behind the emergence of the circular concept is that current consumer societies seem to be running out of actors who would manage their waste. The best example of this is China's recent decision to no longer accept more plastic waste. Since this country has been the most influential figure in the global market over the past 25 years, its exit will have a significant impact on nations that are intensively using plastics (BROOKS ET AL. 2018).

Considering the importance of this topic and its role in circular economy, my fourth goal (G4) is to examine how the international trade of waste can be reconciled with the concept of closed loops.

In my fourth hypothesis (H4) on the subject, I assume that the international trade of waste is not an appropriate way to close material flows if the importing countries have a developing status. These players usually do not have the sufficient capacity to recycle the materials.

The latter two goals have identified directions that affect the impact of globalized market mechanisms on society and the environment. However, exposure to global processes is also present among business actors. In the past, companies attempted to respond to these challenges by conducting product development, as the launch of novelties was a determining factor in competitiveness. However, by now the development of communication technology has exceeded the importance of product development. This has led to an evolutionary step in business where it has become more important to transform marketing and sales mechanism than developing new products. The literature describes this phenomenon as business model innovation (CSATH 2012). Considering that today this process has become a determining factor of market competitiveness, I pay special attention to it.

With my fifth goal (C5), I try to prove that circular transformation has already started in business and this phenomenon can be traced back to the development of business models.

For the case study conducted in the research, I chose the business models of a sector that – according to the literature – is one of the most innovative industries in the world and is one of the firsts to respond to changing economic circumstances.

Thus, in my fifth hypothesis (H5), I assumed that the emergence of circular economy principles can be observed in a key business sector, such as pharmaceutical biotechnology. The industry's new generation business models are expected to include design elements that meet the market expectations of the circular economy paradigm.

After the presentation of the goals and hypotheses of the dissertation, the following chapter outlines the methodologies that I used in my research.

2. Materials and Methods

The following chapter presents the scientific methodologies needed to examine the previously presented hypotheses.

2.1. Statistical analysis of material flow relations

The analyzis covers the countries of the European Union, since the realization of circular economy has become a top priority within this community over the last 3 years. The Ecological Footprint plays an important role in the research, as this indicator gives an indication of the nature of their use of resources. First, I will perform a cluster analysis based on the relationship between the countries' footprint in comparison with their bio-capacity. This ecological grouping criteria will help to assess the research results regarding the material flow indicators.

For the analysis of the Member States' material flows, I use the Eurostat (2018), which has indicators that have been recently developed to measure circular economic performance. These are the followings:

- Domestic Material Consumption (DMC – tonnes)
- Resource productivity (1 EUR/kg)
- Waste/DMC (%)
- Waste/GDP (%)
- Recycling rate (%)
- Circular Material Use (CMU – secondary raw material use/total material use – %)

The indicators listed above provide information about the input and output side of economic material flows as well as information on the type of treatment that closes material cycles. The analysis will be on 2014, because this is the last time all indicators are available for all countries. On the basis of the data of the given year, the study shows the correlation and the strength of the relationship between the individual indicators by means of correlation analysis. This methodology is suitable for drawing attention to the logical relationships between the different phases of the material cycle.

The following chapter presents the method for examining the second hypothesis.

2.2. Cost-benefit analyzis to monetize environmental externalities

The applied cost-benefit analysis (CBA) model is based on the financial accounting of the greenhouse gas (GHG) emissions from the projects. Thus, besides economic aspects, it pays attention to the management of environmental damage and benefits. In connection with the modernization of the Hungarian building stock, I consider two scenarios (renovation of old buildings or construction of new ones), for which I set two different versions. The first case uses a trend-based mechanism to determine the direction of future processes, taking into account current regulations. This version is labelled as "BAU" (as Business-As-Usual) because it does not contain any new regulatory tools. However, in the second case, I assume the implementation of a particular climate-friendly scenario. In the end, it is possible to distinguish between how the sector emits GHG emissions without intervention and building modernization. The inclusion of externalities is the financial accounting of each scenario’s GHG balance, which is based on the price forecasts of the European Union Emissions Trading Scheme.

Formula 1 below shows the applied cost-benefit analyzis mechanism.

$$EI_{pv} = -\underbrace{(IC - DI)}_{\textbf{Development decision}} + \underbrace{(SR - EC}_{\textbf{Operational effects}} \pm \underbrace{IE \pm GHG_q}_{\textbf{Indirect effects}})_{pv} \qquad (1)$$

where:
EI_{pv} = the present value of the excess income (HUF),
IC = the extra investment cost of the equipment to be procured (HUF),
DI = possible subsidies, discounts (HUF),
SR = the surplus revenue resulting from the excess yield and the quality improvement effect of the application of the given technology (HUF/year),
EC= the balance of the extra costs of the given technology and the possible savings (HUF/year),
IE = indirect economic effects of the application of the given technology (environmental effects, social impacts) and value of GHG reduction (HUF/year),
GHG_q = the indirect emission effects of the application of the given technology, the value of the GHG reduction based on the EU ETS quota forecast (HUF/year),
pv = present value.

Source: Self-made based on Kovács (2014)

In terms of the temporal and structural framework of the analyzis, the time interval of the study comes first. Given that the European Union's climate policy framework plays an important role in the analyzis, it is better to adapt to the Community's regulatory mechanisms. Therefore, the CBA model will predict possible changes in the time horizon between 2020 and 2030. The result of the cost-benefit analyzis suggests two main aspects to decision-makers: the first is the financial measures of the scenarios; the second is the environmental impact.

The following chapter presents a methodology that allows measuring the circular economic performance which is in the main focus of the dissertation.

2.3. Measuring circular transitions – The Circular Economic Value (CEV)

The following methodology takes into account two main focus areas of the circular economy, energy and material flows, along an input-output perspective. Thus, it examines how the use of energy and materials can be evaluated from the beginning to the end of each process from a circular point of view. The mechanism of the calculation method is represented by Formula 2.

$$CEV\% = 100 - \left(\frac{\left(\overset{M_{lin}\,\downarrow}{\frac{M_p}{M_p + M_s}} + \overset{M_{lout}\,\downarrow}{\frac{M_d}{M_r + M_d}} \right) + \left(\overset{E_{lin}\,\downarrow}{\frac{E_f}{E_s + E_f}} + \overset{E_{lout}\,\downarrow}{\frac{E_l}{E_c + E_l}} \right)}{4} \right) \times 100 \tag{2}$$

where:
CEV%: Circular Economic Vaue,
M_{lin}: The input side of the material flow (linear),
M_{lout}: The output side of the material flow (linear),
M_p = The amount of primary raw materials used to create the product,
M_s = The amount of secondary raw materials used to create the product,
M_d = The amount of non-recyclable materials after the use of the product (linear),
M_r = The amount of recyclable materials after the use of the product (circular),
E_{lin}: The input side of the energy flow (linear),
E_{lout}: The output side of the energy flow (linear),
E_f = The amount of non-renewable energy used to create the product,
E_s = The amount of renewable energy used to create the product,
E_l = Energy used to displace the product after use (linear),
E_c = Energy used for recycling after the use of the product (circular).

The description of the formula contains a universal pattern that can be translated to analyze any cases. The essence is that it handles the energy and materials that flow in and out of the systems separately. As the description shows, the key point is that the given indicators always express the ratio of linear and circular processes on the input and output side.

The following two subchapters show how CEV can be interpreted to examine the third and fourth hypotheses.

2.3.1. The application of the CEV in decision-making between decentralized and centralized energy production systems

Since this is a comparative analyzis, CEV should be calculated for both cases. Like the cost-benefit analysis, this process will handle each scenario as "BAU" and "Project". The centralized energy supply mechanism will be the BAU case, as it characterizes current trends in domestic energy production. The Project version considers the circular characteristics of a local energy community. The following description shows which indicators will be used in some parts of the CEV:

Material side indicators:

- Input: Ratio of non-renewable (linear) energy sources
- Output: Ratio of energy losses at the power plant

Energy side indicators:

- Input: Ratio of power plant self-consumption from the generated energy
- Output: Ratio of energy grid losses

2.3.2. The interpretation of the CEV to the examination of international waste trade trends

Generally, the topic of international waste trade is too broad to provide a comprehensive picture of it with just one hypothesis of the dissertation. The focus is more on the extent to which the importing countries are able to close the material loops. In order to conduct the investigation, the situation of the plastic flow in Kenya served as a case study. The selection of the sample comes from the fact that this country introduced the first strict regulation against the use of a plastics.

The challenge of using CEV is that no energy data is available for the Kenyan waste management infrastructure. Therefore, the focus of this research will be on the material flow. In such cases, a material flow analysis is usually performed, but this is not sufficient to measure circular performance. The focus of such analyzes is to track down given material stream. In the present case, however, a method was needed to determine the input and output side deficiencies of the systems that handle the plastic stream. Formula 3 presents a customized CEV methodology designed for this purpose.

$$CEV\% = 100 - \left(\frac{\left(\overset{MIM}{\overset{\Downarrow}{\frac{IM_{rm}}{T_{rm}}}} + \overset{MEX}{\overset{\Downarrow}{\frac{EX_{mo}}{T_{mo}}}} \right) + \left(\overset{LCM}{\overset{\Downarrow}{\frac{NR_{pw}}{T_{pw}}}} + \overset{CML}{\overset{\Downarrow}{\frac{NR_{rpw}}{T_{rpw}}}} \right) + \left(\overset{WCL}{\overset{\Downarrow}{\frac{NC_{pw}}{T_{pw}}}} + \overset{WPL}{\overset{\Downarrow}{\frac{NR_{cw}}{T_{cpw}}}} \right)}{6} \right) \times 100 \qquad (3)$$

ahol:
CEV%: Circular Economic Value,
MIM: Share of imported raw materials in plastic production,
IM_{rm}= Amount of imported raw materials in plastic production,
T_{rm}= Total amount of raw materials in plastic production
MEX: Share of exported plastic products in the manufactured products,
EX_{mo}= Amount of exported plastic products,
T_{mo}= Amount of manufactured plastic products,

LCM: Ratio of linear plastic to total plastic waste,
NR_{pw}= Amount of non-recyclable plastic waste,
T_{pw}= Total amount of plastic waste,
CML: Consumption losses from recyclable plastic waste,
NR_{rpw}= Amount of non-recycled recyclable plastic waste,
T_{rpw}= Total amount of recyclable plastic waste,
WCL: Ratio of collection losses to the total amount of plastic waste,
NCpw= Amount of non-collected plastic waste,
WPL: Ratio of processing losses to the collected amount of plastic waste,
NRcw= Amount of non-recycled but collected plastic waste,
Tcpw= Total amount of collected plastic waste.

The next chapter presents a qualitative methodology that is suitable for the circular evaluation of business models which is the main aspect of the fifth hypothesis.

2.4. The evaluation of business models according to the principles of circular economy – The ReSOLVE framework

One of the main lessons learned from the literature was that not only the circular economy has different interpretations, but also what we can understand under the so-called "Circular Business Model". LEWANDOWSKI (2016) therefore highlights that any business structure that is based on the principles of the circular concept can be considered circular. In his work, he introduces a theoretical framework to facilitate circular business model development. His work is based on the "ReSOLVE" framework (Table 1) that has been difened by the ELLEN MACARTHUR FOUNDATION (2015b).

Table 1: The ReSOLVE framework

Activity	Description
Regenerate	use renewable energy and materials
	reclaim, retain and regenerate health of ecosystems
	return recovered biological resources to the biosphere
Share	enhancing product utility by sharing the use, access or ownership
	extending product life through reuse, maintenance (e.g. repair, refurbish) or design for durability
Optimize	optimisation of resource use through increasing performance or outsourcing activities
	remove waste in production and supply chain
Loop	close material loops by remanufacturing, repurposing, recycling or recovering
Virtualize	dematerialize products or services through digital appliances
Exchange	employ new technologies, materials or processes

Source: LEWANDOWSKI (2016, p. 8-9.) and ELLEN MACARTHUR FOUNDATION (2015b, p. 9.)

The table shows that the ReSOLVE acronym is composed of the initials of the names of the activities supported by the circular economy. In this structure, the ELLEN MACARTHUR FOUNDATION (2015b) summarized the most important principles of the circular concept and the processes that contribute to its implementation. LEWANDOWSKI (2016) designates this structure as a benchmark for the evaluation/construction of circular business models. Therefore, the dissertation uses this method in the analyzis to evaluate the business models of the pharmaceutical biotechnology sector. Due to its qualitative nature, the method provides an appropriate tool for analyzing individual business structures.

After presenting the materials and methodologies of the upcoming research, the following section presents the results of the case studies.

3. Results

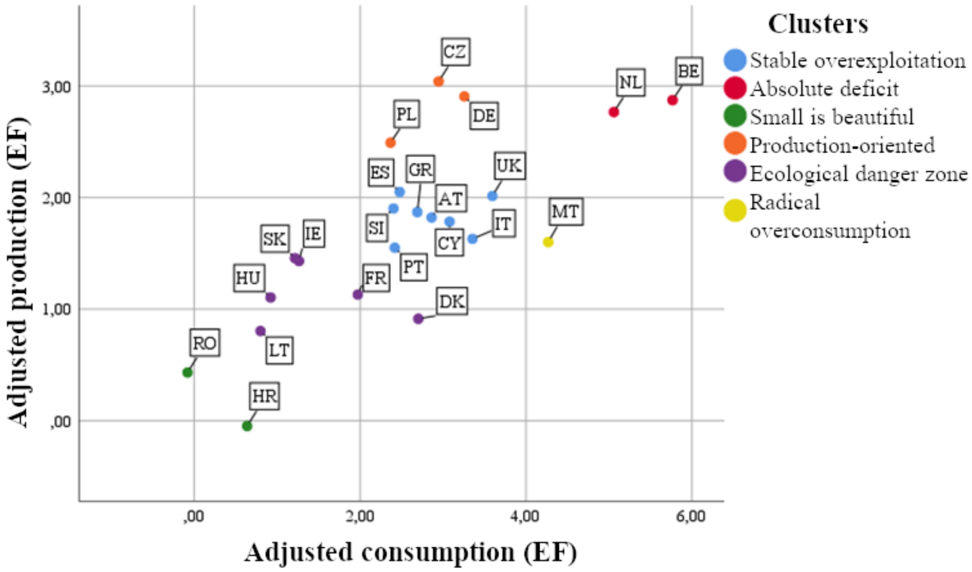
The following section presents the results of examining the hypotheses of the dissertation. The five hypotheses are discussed in five separate sections, and the sixth subchapter summarizes the most important scientific results of the analysis.

3.1. Analyzing the material flow relations of EU Member States

The primary focus of the dissertation is on the contradictions that arise during the practical implementation of the circular economy. The first hypothesis of this thesis (H1), which deals with the circular transformation of material use systems, is connected to this. The relevant analysis seeks to find out whether the capacities created for the efficient use of materials and the closure of material flows are working properly or anomalies may be observed in these systems.

I started the analysis by filtering out items with extreme values, after which 22 EU Member States were left inside the study. These countries were organized into clusters according to the extent to which resources are used for production and consumption purposes compared to the available ecological capacities (Figure 1).

Figure 1: Results of the cluster analysis based on corrected EF indicators



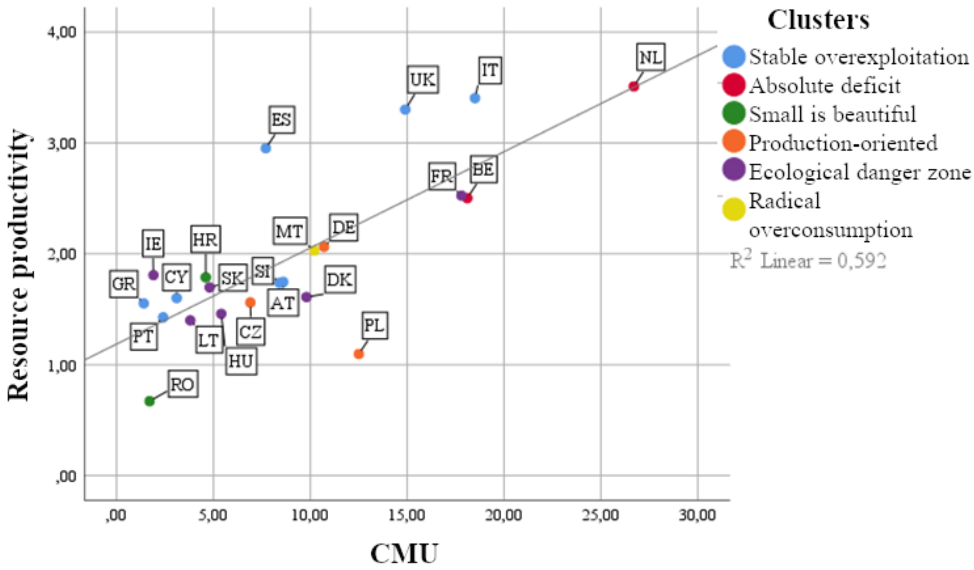
Source: Own calculation based on a Global Footprint Network (2018) data

The figure shows that the existence of ecological deficit is a common feature among EU nations. Going to the right and up from the zero of the matrix, this deficit is getting bigger.

The first conspicuous result from the correlation analysis of material flow data was the per capita raw material consumption of the countries and share of the generated waste in this amount. The relationship between the two indicators is negative (r: - 0.57; p <0.01), which means that with increasing use of materials, countries are producing less waste. A similar correlation can be observed between the same waste ratio and the resource productivity of the countries (r: 0.82, p <0.01). This correlation suggests that most waste is produced in the most resource-efficient countries.

Although these two correlations suppose contradictory relationships, in a circular economy, these processes can be considered obvious. The intensive recycling of waste can reduce the use of primary raw materials, which also improves productivity. The role of this recycling volume is illustrated in Figure 2.

Figure 2: Relationship between resource productivity and circular material use in the examined countries



Source: Own calculation based on GLOBAL FOOTPRINT NETWORK (2018) and EUROSTAT (2018) data

The figure shows that another important criterion for resource productivity is the use of recycled materials. So, while some countries produce a lot of waste, they are still able to operate efficiently because they free up primary raw materials by recycling secondary ones. Thus, at first glance, the results of the correlation analysis show that there are no such development anomalies in material use as the rebound effect in energy use.

However, it would be hard to state by the figure that the most effective countries are examples to follow. The predefined clusters show that countries with efficient material flow have the greatest ecological deficit. Despite the fact that recycled materials prevent the use of primary ones, the former is still overexploited. This correlation suggests that the consideration of the proportion of secondary raw materials is not sufficient to assess the sustainability of material material flows, because the ecological constraints must be also taken into account.

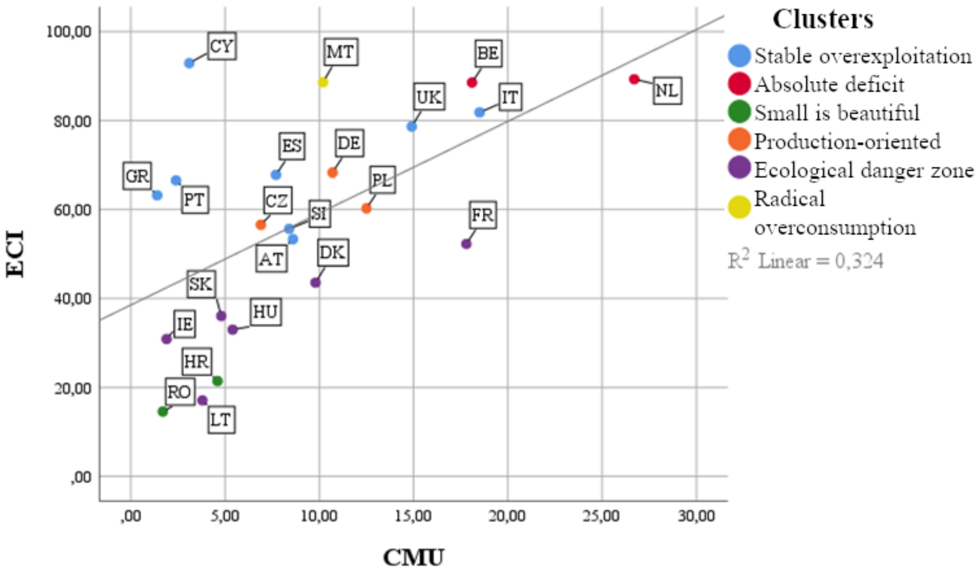
Therefore, I have created an indicator that shows the ideal ratio of primary and secondary raw materials in a country's total raw material use to remain within its bio-capacity. The name of the indicator is Ecological Circulation Index (ECI) and its calculation mechanism is shown in Formula 4.

$$ECI = \frac{U + \left(DMC - \left(\frac{BC}{EF}\, x\, DMC\right)\right)}{M} \tag{4}$$

where:
ECI: Ecological Circulation Index,
U: Secondary raw material use,
DMC: Domestic material consumption,
BC: Bio-capacity,
EF: Ecological Footprint,
M: Total material use.

Based on the formula, I calculated the ECI values of the countries which I compared with their current CMU. The relationship between the two indicators is illustrated in Figure 3.

Figure 3: The statistical correlation between the CMU and the ECI values of the countries



Source: Own calculation based on GFN (2018) and EUROSTAT (2018) data

The results show that the countries leading in recyclable material use are still far below the expected level. In contrast, the EU Member States underestimated by the CMU indicator are not nearly as far from their ideal performance as other nations. This trade-off can be considered general as there is a moderate, highly significant positive statistical correlation between the Eurostat CMU data and the ECI values obtained in the analysis (r: 0.56; $p < 0.01$). So the better the countries' CMU value is, the more of a resource deficit they have.

Based on the results, it can be stated that the first hypothesis (H1) of the dissertation has been confirmed. It is not enough to consider efficiency indicators in circular developments, as this one-plane focus leads to false conclusions. When measuring the performance of a material cycle, it should be taken into account to what extent a system has resources and how it is used.

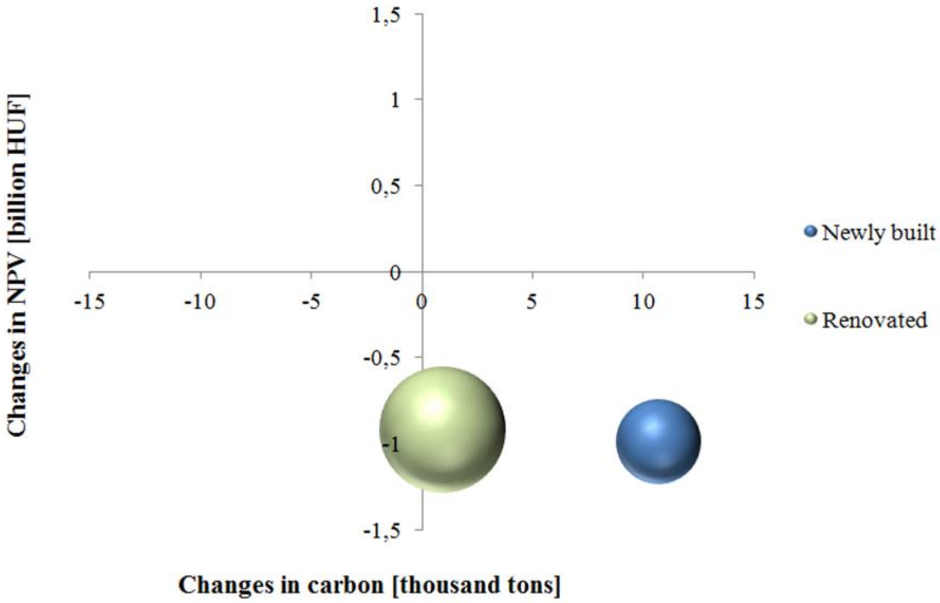
After summarizing the results of the first hypothesis, the following chapter presents the analysis of Hypothesis 2.

3.2. The assessment of the Hungarian building modernization strategies from and economic and environmental perspective

The environmental and economic analysis of modernizing the building modernization strategies is based on the question of whether it is worthwhile to follow the Western European building renovation trends in Hungary. The second hypothesis (H2) of the dissertation assumed that the renovation scenario would be more effective in achieving long-term environmental objectives. Considering that the applied CBA model was able to monetize externalities through GHG emissions, it was possible to assess the economic benefits of the strategies.

The "relative carbon cost matrix" illustrated in Figure 4 enables comparisons of "Renovation" (green bubble) and "Newly built" (blue bubble) scenarios through their financial (X axis) and climate (Y axis) aspects. According to the positioning logic of the matrix, moving from left to right on the X axis means an improvement in financial returns, while on the Y axis the upward downward shift indicates a reduction in GHG emissions. The size of the bubbles shows the resource requirements of the projects, as the cost of saving 1 tonne of CO_{2e} or generating excess emissions in the 2020-2030 period. So, the larger size refers to higher costs. Based on the results, the newly built scenario clearly indicates more favorable values, both from an economic and environmental perspective. The renovation version requires more specific investment, while its return is significantly lower than in the case of the other project. Moreover, the size of the bubbles shows that the degree of carbon efficiency is more than two times better in case of the new buildings.

Figure 4: Relative carbon costs of the scenarios



Source: Own calculation based on NÉS (NFM 2015) data

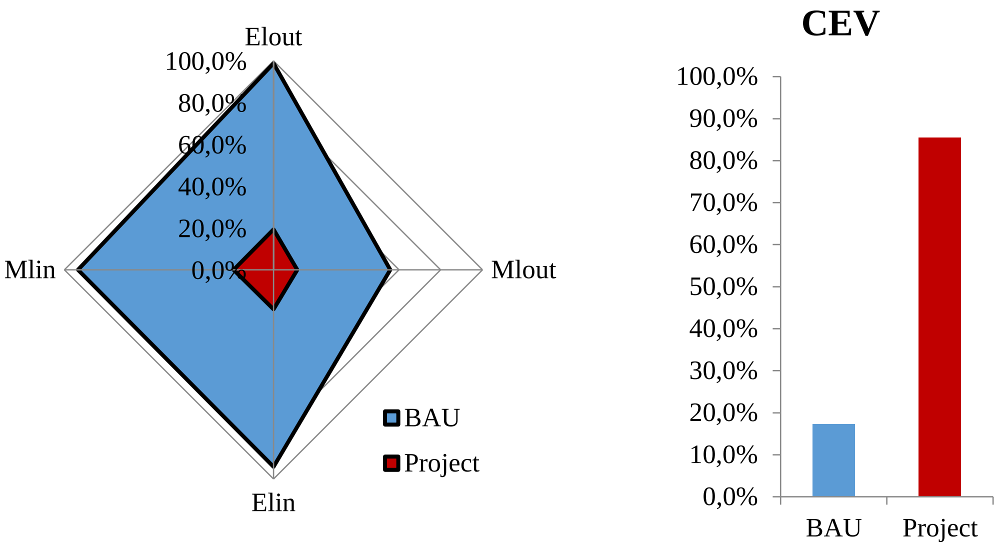
So, according to the reults, it can be concluded that the second hypothesis (H2) of the dissertation is incorrect. The energetic renovation of the Hungarian building stock does not prove to be a more cost-effective solution for achieving long-term environmental goals compared to the strategy for rebuilding buildings.

After the evaluation of the hypothesis, the following section presents an analysis of the third hypothesis.

3.3. The circular economic assessment of energy production systems

The third hypothesis (H3) is based on the assumption that the energy supply should be implemented by using decentralized, smaller power plants instead of centralized production systems. Of course, this also includes the local preference for renewable energy sources. The evaluation of the two production systems in terms of circularity is shown in Figure 5.

Figure 5: CEV values of BAU and Project variants and illustrations of their components



Source: Own calculation based on REKK (2009) and MAVIR (2014) data

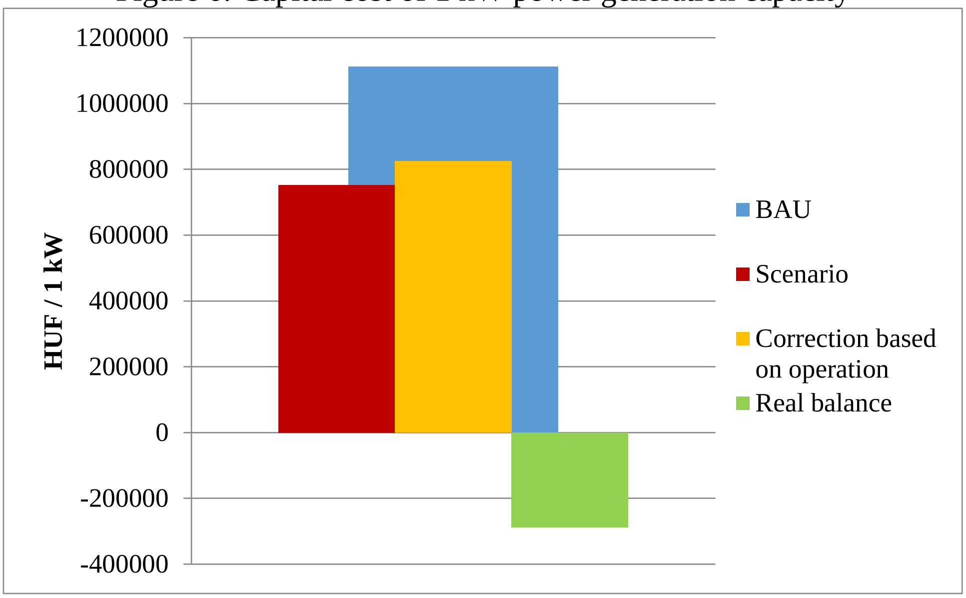
The comparative analysis considers two cases. The first one involves a 20 MW solar park and is responsible for 80% of the energy supply of a hypothetical sample community. This version will be referred to as "Project". In the other version, the renewable energy park will not be commissioned and the sample community will rely entirely on the Hungarian energy mix (49% fossil, 43% nuclear, 8% renewable). The description will refer to this as "BAU". An important requirement is that the BAU energy mix should be taken into account in the Project version as it covers 20% of the energy demand. For this reason, the project requires weighting of the values in the linear-circular ratio calculation of the CEV components, as the share of energy sources changes.

The figure shows that the energy mix represented in BAU has a weak circular performance (CEV = 17.3%). This is not surprising, as only 8% of electricity generation comes from renewable energy sources that could improve these values. In contrast, the project version based on the solar park stands at a high degree of circularity (CEV = 85.5%). The small shortage is due to the fact that the solar energy park is not suitable for the entire energy supply, so it uses 20% share of the BAU energy mix. However, the results of the CEV analysis does not show a complete picture of the sustainability differences between renewable and non-renewable energy sources. Another aspect is the efficiency of production, which in case of centralized systems is significantly reduced by major self-consumption and gird lossess. This phenomenon applies to both energy and material cycle issues.

Besides the circular examination, the aspect of financial returns is also and important part of the research. Thus, the study employs a cost-benefit analyzis which shows the cost-efficiency per 1kW of power generation in both cases. The energy prices used in the calculation are based ont he related studies of NREL (2012) and MAVIR (2014).

As a first step, the CBA focuses on the average cost of 1 kW energy produced by the Hungarian energy mix (BAU). Based on the characteristics of the domestic capacity, this value is approximately 1 112 740 HUF. For a solar park operation, this amount would be 752,250 EUR, but this value should be corrected by using the 20% BAU energy mix. Thus, the capital cost associated with the energy supply of the sample community will be 824 348 HUF. Thus, the cost-efficiency measures indicate that the energy production would by more favourable by using the solar energy park. A comparative illustration of the listed values is shown in Figure 6.

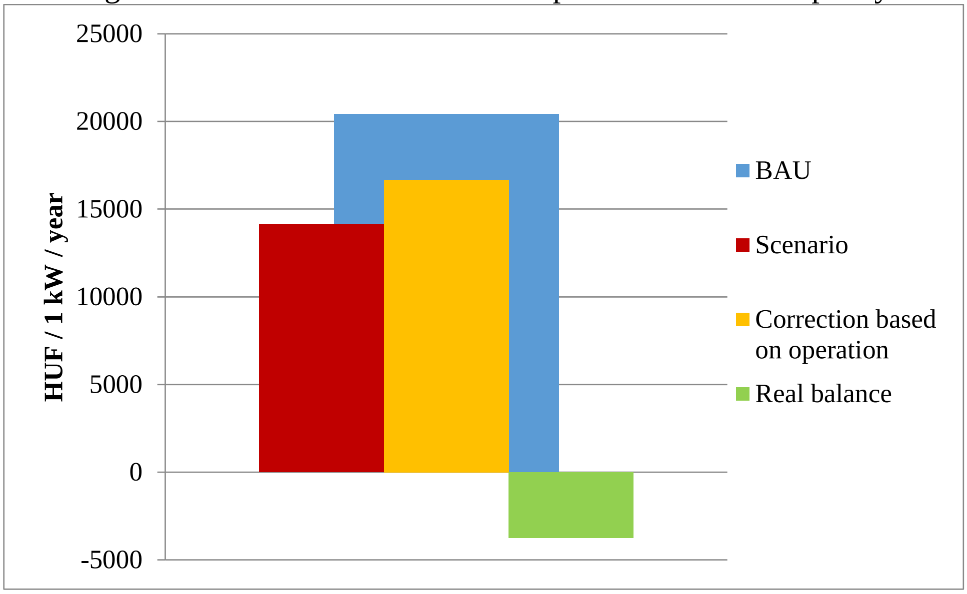
Figure 6: Capital cost of 1 kW power generation capacity



Source: Own calculation baased on NREL (2012) and MAVIR (2014) data

According to the previously applied logic, Figure 7 illustrated the maintenance and repair costs of 1 kW power generation capacity.

Figure 7: Annual maintenance and repair cost of 1 kW capacity



Source: Own calculation baased on NREL (2012) and MAVIR (2014) data

In the BAU version, this value is 20 427 HUF, while in the Project case it is 16 667 HUF. Thus, the energy generated by the sample project offers annual savings of 3,761 HUF per unit compared to the current conditions. Therefore, for investment and maintenance aspects, it can be concluded that the energy park would be 25.9% more efficient in terms of capital cost and 18.4% in the case of operating costs than the currently applied energy system.

The environmental analyzis showed that the comparison of centralized and local energy supply systems goes beyond the differences between renewable and non-renewable resources. Centralized energy production can be considered disadvantageous in many other respects according to the principles of circular economy. The cost factors based on efficiency indicators show that local initiatives produce more economic values besides the environmental ones. Thus, according to the results, the third hypothesis (H3) is accepted.

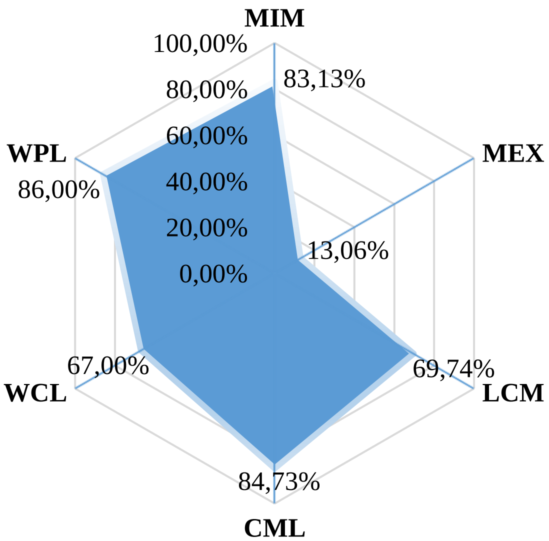
Then, the next chapter will elaborate on the research regarding the fourth hypothesis.

3.4. Analyzing the role of international waste trade in circular economy

The international waste markets have played a significant role in sustaining consumer societies in the developed world. This is due to the fact that the initiators of these processes were usually countries with high income levels, while the importing actors are mostly states that are lagging in development. The circular economy, according to some, is becoming increasingly important not only in the fight against resource scarcity, but also because of the collapse of these waste markets (RAMKUMAR ET AL. 2018). However, the fourth hypothesis of the dissertation (H4) goes beyond the current processes and assumes that the international trade in waste does not correspond to the principles of circular economy regardless of the expected market collapse.

In order to prove this assumption, the calculation of the circular economic value is required, which will focus on the Kenyan capital, Nairobi. The study determines the efficiency of local waste management systems based on the city's plastic material flow. The results of the CEV calculation are shown in Figure 8. The partial values of CEV show that the system produces large amounts of material leakage at almost every point. The average of these linear processes is 77.28%, which means that the system has a circular economic value of 32.72%. These results prove that local technological conditions are unsuitable for creating sustainable material flows.

Figure 8: Circular economic characteristics of the plastic stream in Nairobi



where:
MIM: Share of imported raw materials in plastic production,
MEX: Share of exported plastic products in the manufactured products,
LCM: Ratio of linear plastic to total plastic waste,
CML: Consumption losses from recyclable plastic waste,
WCL: Ratio of collection losses to the total amount of plastic waste,
WPL: Ratio of processing losses to the collected amount of plastic waste,
Source: Own calculation based on the data of WANJIKU MUKUI (2015)

The low CEV result is not surprising considering the poor performance of each pillar. Plastic production relies heavily on the import of external resources (MIM: 83.13%), though internal material flows provide relatively many secondary raw materials. The only positive aspec is that there is only a small amount of spatial leakage, as only 13.06% of the manufactured plastic products (MEX) are exported.

Another problem is that 69.74% of goods on the market (LCM) are not suitable for post-consumer recycling. In this case, local authorities should assess whether this is due to their use (e.g. food contamination, etc.), or to the quality of the raw materials. Creating a database covering this aspect would show whether it is necessary to change the purpose of use or the production process. However, it is even more problematic that most of the recyclable materials (CML=84.73%) leak from the system.

The WCL and WPL values indicate if this leakage is caused by waste management systems. The 67% of the former indicates that only 1/3 of the generated waste reaches the processing systems, the rest falls completely outside their operational boundaries. The WPL (86%), on the other hand, shows that a large part of the plastic waste reaching the process is eventually disposed in a linear manner (e.g. disposal or incineration).

Finally, the results of the CEV analyzis show that the fourth hypotheses (H4) have proved to be real. In other words, international trade in waste is not an appropriate way to close material loops, as the recycling capacities of the importing countries are unsuitable for processing these materials.

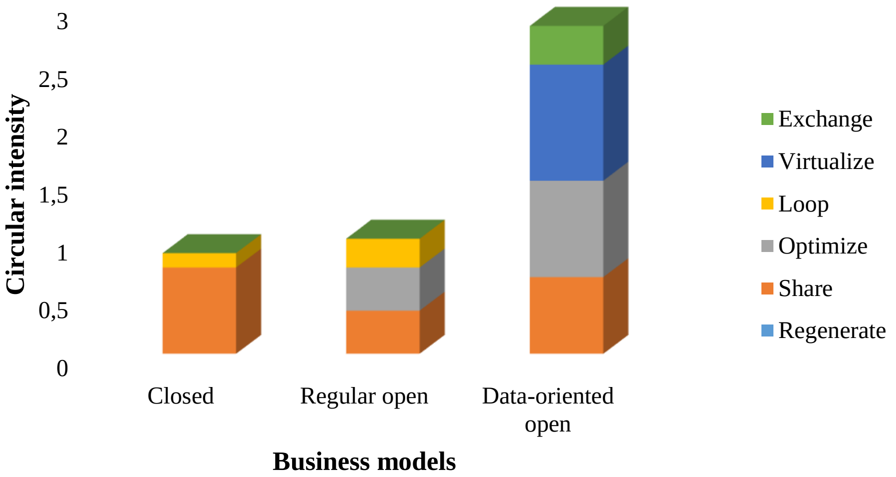
After all, the next chapter present the analyzis of the fifth hypothesis.

3.5. Investigating circular business model innovation trends in biotechnology

In the fifth hypothesis (H5), I sought to find out whether business actors would actually consider circular economy as a newly emerging market challenge, rather than a new sustainability paradigm that would impose environmental and social burdens on them. The analyzis investigated one of the most innovative industries of our time, the pharmaceutical biotechnology, which – according to literary sources – is among the very first industries to respond to changing market conditions. Regarding the business models of the industry, I have been looking at the changes of the last 3 generations, focusing on how emerging structures respond to the principles of circular economy.

The results of the analysis are illustrated in Figure 9 according to the intensity of the ReSOLVE components in each business model generation. The circular building element per a business model was 0.875 for closed structures (1st generation), 1 for regular open (2nd generation) and 2.83 for data-oriented forms (3rd generation). These values are shown in detail in the figure. It can be seen that in the era of closed models there was little need for circular applications. It was the time of economies of scale based on vertical integration. It means that the optimal use of resources was not yet a determining factor and the economic interests dominated the world of business. Small businesses tried to get market relevance by doing R&D. In the absence of sufficient financial resources, it has also happened that some models started to work with products discarded at the end of product development – to save money and time.

Figure 9: Intensity of circular elements in three generations of pharmaceutical business models



Source: Self-made (2019)

The opening of business models was the first sign that the age of mass production production was about to end. The need for resource optimization has emerged which has been followed by the increasing role of SMEs.

However, the real breakthrough was that business models started to use virtual devices not only as a tool but as a central element of their corporate profile. New business structures based on digital innovation and data revolution work more efficiently – in economic and environmental terms as well. And the analyzis showed that these two aspects are strongly related.

Based on the results, it can be stated that the new generation biotechnology business models do not integrate circular elements into their structure only to achieve sustainability. This trend is rather due to market-based considerations to increase their competitiveness. The relevance of the principles of the circular economy can be demonstrated in one of the most important and fastest developing sectors of business. Thus, the concept is not just a new paradigm of sustainability, but a condition of survival in the changing market conditions. This confirms the validity of the fifth hypothesis (H5).

Since the research was able to confirm or disapprove al the hypotheses, the work is considered complete. As a summary of what has been done so far, the following chapter summarizes the new and novel scientific results of the dissertation.

3.6. New and novel scientific results

Following the analyzis of the two strands (practical contradictions, sustainability issues) identified in the dissertation, I covered five different subject areas. Based on the related goals, I formulated hypotheses that prove or reject important professional questions. As the scientific community has not yet reached a unanimous standpoint on these specific topics, my results are considered as new, or at least as a novel scientific approach. For the sake of transparency, I summarize these results briefly in the followings.

1. If the "closing the loop" perspective gains excessive focus in developing sustainable material flows instead of reducing consumption or extending product lifespan, circular developments can lead to significant deadweight losses. To prove this, I have created a new material flow indicator that measures the effectiveness of systems based on their ecological limits. The analysis – carried out with this methodology – has proved that the circular performance of the countries that are in the forefront of recycling is far behind from the ideal level which would offset their ecological deficit. Therefore, if the loop closure (or recycling) becomes the priority of circular transition, it leads to such controversies in material flows, as the rebound effect in energy use.

2. With the results of the cost-benefit analysis based on the monetization of externalities, I have shown that the reduction of GHG emissions in the Hungarian building stock can be achieved effectively if the post-2020 development strategy focuses not on the modernization of old buildings, but on new buildings and new technological solutions. I rejected the assumption that renovation is the most economically and environmentally effective way of modernizing the Hungarian building sector and achieving the EU climate goals for this.

3. My Circular Economic Value (CEV) analyzis showed that local production systems do not only reduce material and energy losses, but can avoid them at. Large systems contain a number of leakage points that appear only to a lesser extent – or not at all – in the local form. Decentralized, community-based renewable energy production offers more favourable economic and environmental conditions than centralized forms, since avoiding externalities in these system processes is more effective.

4. International trends in outsourcing waste recycling to developing countries do not fit the principles of circular economy. In these systems, local capacities collect, manage, and recycle used materials with low efficiency into recycling processes, resulting in a high level of externalities. I have shown that the treatment of recyclable plastic waste in this way leads to a linear process.

5. By examining the tendencies of one of the most innovative industries of our time – the Belgian pharmaceutical biotechnology sector – I proved that the circular transition can be traced in the evolution of business models. The new generation models contain more circular elements than the previous ones. I proved that the transition to a circular economy in business means not only adapting to a new sustainability paradigm, but also meeting market expectations.

After the description of the theses, Table 2 summarizes how the hypotheses of the research can be evaluated based on the results.

Table 2: Evaluation of the hypotheses based on the research results

Number of hypotheses	**Short description of the hypetheses**	**Evaluation of the hypotheses**
1.	The assumption of a rebound effect in improving the efficiency of material use	Valid
2.	The modernization of the Hungarian building stock is more effective by renovating buildings than by replacing them with new ones	Invalid
3.	Decentralized power generation systems are more efficient in terms of circularity than the centralized forms	Valid
4.	Exporting waste to the developing world supports linear processes	Valid
5.	The circular transition can be tracced in the development of business models	Valid

Source: Self-made (2019)

After summarizing the new and novel scientific results of the dissertation, the following section concludes the main findings that can contribute to future research. In many cases, the results reflect pure scientific thinking, but their practical application must take into account social circumstances that may affect their success.

4. Conclusions and Recommendations

The focus of the dissertation was on a comprehensive analysis regarding the circular economy concept, which has been brought to the attention of decision-makers when the European Union made it a strategic priority in December 2015. The goals of the dissertation were based on providing guidance for the practical application of the initiative. Prior to this, I considered it necessary to clarify the scientific background of the concept, since it is still surrounded by many misconceptions. The literature on the subject has shown that the popularly declared "Closing the Loop"activity is not the most important aspect of a circular economy. In the dissertation I conducted a detailed analyzis on the "priorities of circular economy", which showed that materials flows can also be extended and more importantly, they can be narrowed. So, the most effective way to eliminate waste is not necessarily to recycle products but to avoid their consumption.

In the primary objective of the thesis (G1), I focused on this topic because this radical approach is still up to a scientific debate. One of the most important lessons of this research area was that the interpretation of circular transition differs by region or even by country. It was evident that the nations with intense economic activity or scarce bio-capacities (sometimes both at the same time) are already struggling to reduce their consumption levels and recycle waste. Their ecological system does not only conflict sustainable measures in the long run, but already in the present moment. Due to the need, these countries are at the forefront of circular transition today and, as a "lead innovator", communicate their good practices to actors who want to catch up with them. This phenomenon becomes more interesting, since the results show that the ecological conditions in the "lagging countries" are much more favorable than in the case of those who teach them. Thus, in terms of circular transition, it is necessary to consider whether it is worth learning from actors to whom circular economy is not the next level of development, but rather a solution to their self-created problem.

With the second objective (G2), I aimed at clarifying another contradiction regarding the interpretation of circular economy, the trade-off between product life cycle and utility. The relevance of the topic in our country is greater than we think, because the building stock faces an upcoming modernization, and there is a similar decision dilemma. In my study, in addition to the economic aspects, taking into account the environmental factors, I concluded that replacing old buildings with new ones would be a more effective solution in the long run. But putting the results into practice requires further explanation. On the one hand, it should be emphasized that the CBA model did not involve all ecological processes entirely. The demolition of old buildings and the construction of new ones moves significant energy and material flows, which is highly influenced by the recycling potential of construction debris. On the other hand, before the implementation of such a macro-level initiative, the inherent social consequences must be taken into account as well. Comprehensive restructuring of the domestic building stock is only recommended if it is preceded by the economic and political measures supporting it (e.g. providing housing for the affected people, developing a suitable housing loan system).

After this topic, I have intended to stay with the issue of retail energy supply. So, I began to look at alternative solutions like the systemic transformation of the energy production itself. Buildings are partly passive energy users, which means that they are not the producers of the energy they use. It is possible to change this relationship if the population itself takes the matter of its own energy supply. This approach also enables people to decide what source of energy they use. The so-callded “community energy” initiative offers many environmental and social benefits, but most importantly local self-sufficiency which is favoured by circular economy.

My third goal (G3) was therefore to highlight the ecological and financial benefits of this initiative in comparison with the currently applied centralized production systems. The results have shown that decentralized energy supply is more effective in both environmental and economic terms. Future research in this area should focus on expressing the many indirect benefits of self-sufficient energy production to local communities. Such could be the sale of the produced energy, which further improves the cost-efficiency indicators. Furthermore, from a social point of view, it is important that similar initiatives increase people's environmental awareness, as they make people feel involved. The most important aspect of community energy production is to decouple society from central distribution systems, ensuring their self-sufficiency.

This segment of my research dealt with one of the main causes of circular economy, the scarcity of resources. However, the fact that the its practical implementation has become a strategic goal for the EU, has another reason. The amount of waste produced in our consumer societies has become unmanageable. This has also made the EU a net exporter of waste – even in the case of recyclable waste. The importing countries have been mainly part of the third world. And for now, these actors have become more and more resistant to the reception of waste. According to forecasts, the impact of the upcoming regulations be so severe that it will force developed countries to manage their own waste and, in particular, to reduce it. That is why I set my goal (G4) to draw attention to the inadequacy of international waste trade in the circular economy.

The related analyzis focused on Kenya's plastic material flow, which was relevant considering the country's recent regulations. With its rigorous decree, Kenya took up the fight against the use of plastics for the first time. This drastic step has indicated that managing this material is a major burden for the country. The analyzis proved this preliminary assumption. It was evident that local waste management capacities in all fields (e.g. collection, selection, processing, recycling) were operating at very low efficiency. This result also raises two additional questions that may form the basis for future research. One is that why developed countries (e.g. the United Kingdom, France), which have particularly effective recycling capacities, are exporting potential secondary raw materials to areas of the world where there is apparently no adequate capacity to recycle them? The other is that, as developing countries sometimes have to deal with externalities created by others, will it be a trend for them to conduct strict environmental regulations which in other countries come at a higher level of development?

Finally, I came to the discussion of an area that proved the business relevance of circular economy. According to the literature, eco-centered businesses have failed in previous decades because the linear (or “capitalist”, “mainstream”, etc.) economic conception persisted with the principle of profit maximization. This has adversely affected the business structures that had higher costs than the majority due to the representation of social and environmental values. In recent years, however, practical experiences have shown that business models for sustainability have become more efficient than the traditional ones, not only from an ecological perspective, but also from an economic one. So, it seems that nature-based solutions are getting more competitive. The case of plastics was a good example of how the real costs of an ecologically unsustainable operation – which has been exploited in a short-term perspective – has occur in the long run. In business, there were many similar processes in the second half of the 20th century. Therefore, it is expected that sustainable criteria will affect not only some of the companies' activities over time, but complete business models.

Since this criteria system is currently summarized by the circular economy, my fifth objective (C5) was to show the practical appearance of this concept in today's business models. The results of the study showed that the new generation business models in one of the most innovative industries are more in line with circular economy principles than their former counterparts. However, I emphasized that the circular transition is not the main purpose of these companies. The real reason for this phenomenon is that the expectations of market competitiveness are now more and more aligned with the principles of sustainability. During the analysis, I successfully applied a qualitative methodology to evaluate the circular performance of business models. Thus, this circular evaluation criteria is proved to be suitable for assessing business models which can be applied in future research.

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