REFLECTIONS ON THE ADAPTATION OF THE COBB-DOUGLAS FUNCTION TO WORK IN CIRCULAR ECONOMY STARTING WITH THE IMPLEMENTATION OF A BIODIGESTER IN SÃO JOSÉ DOS PINHAIS[1]

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Linear Economy, the dominant model in the world, does not contribute to environmental, economic, and social sustainability. Global actions have not been enough to achieve sustainable development. The current Cobb-Douglas economic model operates in a linear economy that does not take into account the principles of sustainability; thus, given the need to operate in a Circular Economy (CE), the Cobb-Douglas function must be adapted. We observed the need for including natural resources and energy as inputs, and the waste generated by production as outputs in the Cobb-Douglas model. It was also observed that public policies should contemplate more sustainable models that favor the promotion of the CE. In this work, we mapped the municipality of São José dos Pinhais (SJP) according to the production of organic waste for the implementation of a biodigester, and analyzed the general equation of production factors (Schumpeter and Cobb-Douglas); further, we analyzed the municipality's Multi-Year Plan (2018–2021) of actions linked to the environment, and the feasibility of the implementation of a biogas thermal power plant. Lastly, we showed the importance of public policies for sustainable development actions in cities and the need for transparency in municipal budgets to ensure the population's access to information. Finally, it is only possible to meet the principles of Sustainable Development Goals (SDG) and Environmental Social Governance (ESG) with the inclusion of new production factors (rejects for recycling, composting, and energy) in the Cobb-Douglas function operating in a CE.

Keywords: ESG; circular economy; Cobb-Douglas model; organic waste; biodigesters.

REFLEXÕES SOBRE A ADAPTAÇÃO DA FUNÇÃO COBB-DOUGLAS PARA TRABALHAR EM ECONOMIA CIRCULAR COMEÇANDO COM A IMPLEMENTAÇÃO DE UM BIODIGESTOR EM SÃO JOSÉ DOS PINHAIS

A economia linear, o modelo dominante no mundo, não contribui para a sustentabilidade ambiental, econômica e social. As ações globais não têm sido suficientes para alcançar o desenvolvimento sustentável. O atual modelo econômico Cobb-Douglas opera em uma economia linear que não leva em conta os princípios da sustentabilidade; assim, dada a necessidade de operar em uma economia circular (EC), a função Cobb-Douglas deve ser adaptada. Observamos a

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necessidade de incluir os recursos naturais e a energia como insumos, e os resíduos gerados pela produção como saídas, no modelo Cobb-Douglas. Observou-se também que as políticas públicas devem contemplar modelos mais sustentáveis que favoreçam a promoção da EC. Neste trabalho, mapeamos o município de São José dos Pinhais (SJP), de acordo com a produção de resíduos orgânicos para a implantação de um biodigestor, e analisamos a equação geral dos fatores de produção (Schumpeter e Cobb-Douglas). Além disso, analisamos as ações ligadas ao meio ambiente constantes no Plano Plurianual (PPA) do município para o período 2018-2021, bem como a viabilidade da implantação de uma usina termelétrica de biogás. Finalmente, mostramos a importância das políticas públicas para ações de desenvolvimento sustentável nas cidades e a necessidade de transparência nos orçamentos municipais para garantir o acesso da população à informação. Concluímos que só é possível cumprir os princípios das Metas de Desenvolvimento Sustentável (SDG) e da Governança Social Ambiental (ESG) com a inclusão de novos fatores de produção (reciclagem de resíduos, compostagem e energia) na função Cobb-Douglas operando em uma EC.

Palavras-chave: ESG; economia circular; modelo Cobb-Douglas; resíduos orgânicos; biodigestores.

REFLEXIONES SOBRE LA ADAPTACIÓN DE LA FUNCIÓN COBB-DOUGLAS PARA TRABAJAR EN ECONOMÍA CIRCULAR A PARTIR DE LA IMPLANTACIÓN DE UN BIODIGESTOR EN SÃO JOSÉ DOS PINHAIS

La economía lineal, el modelo dominante en el mundo, no contribuye a la sostenibilidad ambiental, económica y social. Las acciones globales no han sido suficientes para lograr el desarrollo sostenible. El actual modelo económico Cobb-Douglas opera en una economía lineal que no tiene en cuenta los principios de la sostenibilidad; por lo tanto, dada la necesidad de operar en una Economía Circular (EC), la función Cobb-Douglas debe ser adaptada. Se observó la necesidad de incluir los recursos naturales y la energía como insumos, y los residuos generados por la producción como productos en el modelo Cobb-Douglas. También se observó que las políticas públicas deben contemplar modelos más sostenibles que favorezcan la promoción de la EC. En este trabajo, mapeamos el municipio de São José dos Pinhais (SJP) en función de la producción de residuos orgánicos para la implementación de un biodigestor, y analizamos la ecuación general de factores de producción (Schumpeter y Cobb-Douglas); además, analizamos el Plan Plurianual (2018-2021) de acciones vinculadas al medio ambiente del municipio, y la viabilidad de la implementación de una central térmica de biogás. Por último, mostramos la importancia de las políticas públicas para las acciones de desarrollo sostenible en las ciudades y la necesidad de transparencia en los presupuestos municipales para garantizar el acceso de la población a la información. Para finalizar, sólo es posible cumplir con los principios de los Objetivos de Desarrollo Sostenible (ODS) y de la Gobernanza Social Ambiental (GSA) con la inclusión de nuevos factores de producción (residuos de reciclaje, compostaje y energía) en la función Cobb-Douglas que opera en un EC.

Palabras clave: ESG; economía circular; modelo Cobb-Douglas; residuos orgánicos; biodigestores.

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1 INTRODUCTION

The Sustainable Development Goals (SDGs) represent a global action plan to eliminate extreme poverty and hunger, provide quality education for all, protect the planet, and promote peaceful and inclusive societies by 2030. In action number 12.3, the SDGs also aim to halve food loss and food waste. In support of this essential goal, the first report of the United Nations Environment Programme (UNEP) estimated that food waste in households, retail establishments, and the food service industry in 52 countries totals 931 million tons each year. The report also revealed that the global average of 74 kg per capita of food wasted each year is essentially similar in lower-middle-income countries and in high-income countries, which suggests that most countries, regardless of their income, lack actions to reduce waste-caused impacts (UNFCCC, 2018).

Considering that the emission of 8 to 10% of global greenhouse gas (GHG) is associated with uneaten food, it is essential that public policies guide citizens, entrepreneurs, and government agents to reduce such waste (UNFCC, 2018), and to utilize it in intelligent ways. It is possible, for instance, to generate electricity fueling biodigesters in biogas power plants with organic waste, especially food waste or animal carcasses (Salgado et al., 2010; Cassiolato and Szapiro, 2003; Borsatto, Bazani and Amui, 2020; Costa, 2010; Aldana-Gonzáles et al., 2022; Ángel-Hernández et al., 2021; J. Dorazco-Delgado et al., 2021).

The current widespread crisis scenario highlights the need for discussions and analyses of economic, social, and environmental indicators, aiming to plan strategic actions for the promotion of sustainable public policies throughout society (Porter, 1998; Apak and Atay, 2015; Lastres and Cassiolato, 2005; Rodrigues and Malo, 2006; García-Valladares et al., 2022).

Traditional economic theories do not efficiently meet the regional needs for cities' further economic development, since this would require an adaptation of these theories to local needs. The lack of environmental, economic, and social sustainability is a worrisome scenario and, simultaneously, an opportunity, under a macroeconomic and social perspective, to implement innovations to the current economic models. With society's grasp, appropriation, and active participation regarding the destination of cities' resources, it is possible to elaborate a strategic planning to better meet the population's needs (Méndez, 1998; Maillat, 2002; Sanchez, 2008; Vale, 2009).

The circular economy (CE) had its origin in the 1990s and has Industrial Ecology as its structuring basis. While the Linear Economy works from the make-use-discard point of view, the circular economy works from an approach where there is greater harmony between the economy and the environment, in which waste can be reused and recycled (Haber, 2008; UNFCCC, 2018). Circular economy (henceforth CE) associates economic development with the best use of natural resources, by means of new business models, manufacturing process optimization, less dependence on raw materials, and the prioritization of more durable, recyclable, and renewable inputs (Salgado et al., 2010; Cassiolato and Szapiro, 2003; Borsatto, Bazani and Amui, 2020; Costa, 2010). Linear Economy, the current predominant model, on the other hand, foresees a capitalist structure that leads to extensive use of natural, physical, and human resources, and to environmental degradation.

The Cobb-Douglas model, widely used to study production factors, was developed to serve a Linear Economy. In this paper, we questioned this model for not contemplating the efficient use of natural and economic resources within the principles of a CE consistent with the SDGs. In the definition of a municipal budget, for example, it is necessary to understand a city's internal composition, as well as to look for possibilities within the current economic model to update, modernize, and work with the production factors following sustainable principles in a CE.

In Brazil, there are public instruments for elaborating projects with resources raised by the municipal, state, and federal governments. One of the most important instruments to forecast the application of each Brazilian city's budget is the Multi-Year Plan, which takes place every four years. Although the Multi-Year Plan is available on governmental websites, the access is restricted and unintuitive. Public policies must be designed with a long-term future in mind, regardless of the political regime in place. Thus, considering the importance of knowing a city's budget, this work analyzed the case of São José dos Pinhais (Paraná, Brazil) in relation to the sources of funding destined for environmental actions. In addition, we discussed how public policies can contribute to the development of projects that promote economic, environmental, and social sustainability.

We also suggested the implementation of a biogas thermal power plant in São José dos Pinhais, as an alternative for renewable energy production, and reduction of the environmental impact caused by waste, considering such materials as inputs to the CE model. Within this study, one of the objectives was to analyze the plant's possible location, mapping a strategic area for its implementation. This initiative can be replicated in many cities since food waste generated around the world constitutes the main raw material for the generation of clean energy. The choice for the city of São José dos Pinhais is justified by the fact that the city has 98% of the Atlantic Forest preserved and has been chosen to participate in the "Sustainable Cities Ranking" program developed by the Secretariat for Sustainable Economic Development and Tourism (SEDEST) of the government of State of Paraná. Also, according to the municipality's multi-annual plan (2018-2021), SJP presents a millionaire waste management budget of R$ 26 million (São José dos Pinhais, 2018).

The general objective of this research is to present the Cobb-Douglas economic model, to understand that it is necessary to adapt the Cobb-Douglas production function to act within the sustainability principles contemplated by the EC. As a specific objective, a case study was carried out to analyze public policies to promote economic, environmental and social sustainability with the implementation of a biogas thermoelectric plant, fed by the organic biodigester, for the treatment of organic waste and generation of clean energy in São José dos Pinhais.

2 LITERATURE REVIEW

2.1 History of global climate actions

Economic and environmental sustainability includes energy efficiency and reduction of pollutant emissions by means of production processes that operate with clean technologies and adopt good environmental and economic practices. Figure A.1 (appendix) shows the history of agreements in climate change discussions held by the member countries of the United Nations (UN).

It can be seen in figure A.1 that the first International Agreement on Climate Change was signed in 1994. In 1998, in the city of Kyoto, the Kyoto Protocol was signed with the goal of reducing GHG emissions. This protocol was ratified by the signatory countries in 2005 and remained in force until 2012. Afterwards, the Paris Agreement was signed in 2015 at COP21, which was effective from November 2016 until now (UNDP, 2020; CEBS, 2019). In 2021, COP26 was held in Glasgow, foreseeing a global GHG reduction target of 2.5% by 2030, which was not agreed upon by the signatory countries. Brazil's participation in COP26 was heavily criticized since representatives of the Brazilian government denied the data presented by reports from the National Institute for Space Research (Inpe) and the National Aeronautics and Space Administration (NASA), which showed the great degradation and devastation of the Brazilian biomes in the last 3 years (Inpe, 2021).

2.2 Economic models and production factors

Based on the principles of the linear economy, the production function proposed by Schumpeter (1933) depends on 4 production factors. They are: capital employed (K), labor (L), territorial space required for production (t), and technology (T).

When Schumpeterian theory was developed, the CE's efficient use of production factors was not applied. The general equation 1, proposed by Schumpeter (Pindyck and Rubinfeld, 2010; Varian, 2015), shows the amount of produced goods, products, or services (*Q*) according to its production factors (*K*, *L*, *t*, *T*) applied in a traditional linear economy.

The model proposed by Schumpeter is limiting, since it does not predict yields of scale in production. Thus, in 1976, Cobb-Douglas developed a mathematical-economic model containing such yields in the production and output levels. The Cobb-Douglas function is widely used in economics to represent the relationship between two production factors and the product. Based on the production function, Cobb-Douglas developed his general formula, given by the following equation.

Where *Y* = product; *L* = amount of labor; *K* = amount of capital; and A, α and β are constants determined by technology.

The α and β exponents in equation 2 define the growth scales for production. In other words, through the exponents we can tell whether an economy or production level grows in an increasing, constant, or decreasing scale. If $\alpha + \beta = 1$, the production function has constant growths at scale. If $\alpha + \beta < 1$, returns to scale are decreasing, and if $\alpha + \beta > 1$, growths to scale are increasing. Contrary to Schumpeter's theory, Cobb-Douglas considered the existence of competition as essential in his mathematical-macroeconomic model (Varian, 2015). However, both Schumpeter's production function and Cobb-Douglas's mathematical-macroeconomic model do not contemplate the efficient use of resources necessary to the production of goods, services, and products, nor do they fit into the concept of CE. Even in the face of protocol requirements and international agreements, what we observe is the financialization of nature (Belluzzo, 2020). In other words, traditional linear economics has the Cobb-Douglas function as its macroeconomic model, which does not contemplate environmental and economic sustainability; conversely, it predicts gains in scale through profit maximization and cost minimization, where environmental compensation is not applied. According to Salgado et al. (2010), the traditional linear economy is unsustainable, because its motto is "extract, produce, and dispose". In the work, "Implications of the Material Balance", by the author Welsch (2007), a mathematical derivative was presented in relation to emissions and, the balance of materials and emissions was shown as a way of adapting the Cobb-Douglas production function.

One of the contributions of this article is to reflection on the need to adapt the Cobb-Douglas model, embedded in a CE. When we consider a CE that seeks to insert in the productive cycle what would be discarded and polluting the environment in the Linear Economy, it is necessary to combine the technology function with labor and capital. Thus, these variables of the production function need to be open, so that human, physical, and natural capital are also considered in the production cycle.

2.3 Macroeconomic aspects of São José dos Pinhais

According to the Brazilian Business Council for Sustainable Development (CEBDS, 2019), the drivers of global change through 2030 are population and economic growth, and income per capita. Thus, intensified demand for food and energy, change in production patterns, aging population, increased urbanization, and geopolitical tensions are expected. The increased demand for food directly implies increases in agriculture investment, agribusiness inputs, water demand and consumption, and production volumes and consumption of processed foods.

São José dos Pinhais (SJP), considered the green belt of Curitiba's Metropolitan Area (Paraná, 2018; Comec, 2019), has suffered from climate change caused by environmental damage. In addition, the municipality joined the Ranking of City for Climate program (SEEG, 2021), which foresees the monitoring and follow-up of the GHG Emissions and its Removals Estimation System. The installation of organic biodigesters in strategic locations and the proper disposal of organic waste (which is currently sent to the neighboring municipality of Fazenda Rio Grande) can effectively contribute to the reduction of GHG emissions. The disposal of food in landfills produces highly pollutant methane gas emissions, which generally remain unused. Considering this issue, the implementation of a biodigester not only maximizes the production of methane, but also takes advantage of the gas to produce energy. For the efficient implementation of the thermal power plant in the municipality, it is necessary to map the region considering the availability of organic matter, the logistics of collection, and the economic opportunity.

The city of São José dos Pinhais had a budget of R$ 1.1 billion foreseen for 2021, which was enough resources to finance economic and environmental sustainability. The municipality's Multi-Year Plan (2018-2021) did not foresee resources linked to projects and actions aimed at environmental preservation. The resource bond provides a rubric to the grant, thus, the grant cannot be spent on any activity other than the one it was intended for. On the other hand, free resources can be spent in ways that meet political demands. Although the resource bond increases bureaucracy, it prevents possible corruption and forces public managers to elaborate projects in all areas related to public administration. It is not enough for city budgets to be transparently available to the population if the destination of the resources is not linked to pre-approved projects that actually benefit the population.

Through an analysis of São José dos Pinhais' Multi-Year Plan (2018-2021), we carried out a survey of the amounts spent on waste management, in addition to the analysis of the resources passed on to the competent departments for Environmental Education, waste management, and selective collection.

2.4 Outputs insertion in the Circular Economy

CE seeks a sustainable production process in a closed industrial production circuit. This circuit can become a hybrid model through the co-production of energy, i.e., through the use of outputs generated in the productive system, such as boiler steam, solar, wind, tidal, hydroelectric energy etc. Rejects should also be reused or recycled to save finite natural resources and energy during the production cycle of metals, plastics, and glass, and to avoid the disposal of waste in landfills as much as possible (Leitão, 2015; Sereda and Flores-Sahagun, 2021; Abramovay, 2014).

Thus, it is possible to optimize resource use, opening the possibility of new cycles of energy reconversion, and minimizing the effects of entropy in the production system (Salgado et al., 2010; Loreto-Munoz et al., 2021; Ramírez-Revilla, 2021; Palmay-Paredes et al., 2021).

To consider the urgent and immediate needs of developing countries, rethinking production models and their impacts, such as their effects on climate change, is a challenge that goes from the local to the global sphere, concerning the protection of people, livelihoods, and ecosystems (UNFCCC, 2018). Transformations, not only in the energy matrix, but in the design, production, and use of goods and services are essential for global changes in business models (Abramovay, 2014). In this sense, CE represents an opportunity for this important change in companies and industries, as it forces society to think beyond its ecological footprints and energy efficiency (Leitão, 2015). By proposing an adaptation of the Cobb-Douglas model, introducing input and output variables to the current factor of production model, we also propose a transition to a system in which the value of products, materials, and resources is maintained in the economy for the longest possible time. With the reuse of waste, new forms of innovation and local development are possible, such as the use of biodigesters.

Food waste and animal carcasses disposed of in landfills generate methane gas that can be used as an energy source, but with much lower efficiency than if directed to feed a biodigester, where the controlled environment maximizes the generation of gas and, consequently, the production of electricity, preventing the pollution of the environment (Borsatto, Bazani and Amui, 2020).

Biodigesters are hermetic and impermeable equipment inside of which organic material is placed for anaerobic fermentation, resulting in the formation of gaseous products – mainly methane and carbon dioxide (Maillat and Perrín, 1992; Maillat, 1996; 2002). The biogas is retained in the free part of the biodigester, and can then be channeled for various applications, such as heating or cooling processes, and generating electricity. According to Araújo and Vieira (2017), the fermentation of biomass in anaerobic reactors presents itself as an excellent alternative when considering environmental sustainability, since it reduces the pollution and contamination rate of the production cycle, promotes the generation of biogas, allows the use of the final residue as biofertilizer, and meets the principles of CE (Araújo and Vieira, 2017). Methane gas is highly polluting and has a warming potential of 21, while CO_2 has a warming potential of 1. However, when methane gas and CO_2 are no longer released into the atmosphere, they generate carbon credits and incomes (Velis, 2015; UNFCCC, 2018).

The environmental gains which stem from the implementation of a biogas power plant fueled by the outputs, i.e. food discarded by restaurants and/or the population, are unquestionable. To avoid the misappropriation of public funds, however, the contracts between cities' representatives, the company responsible for power transmission lines, and the power plant operator must be transparent, making the actions' benefits and counterparts clear. This way, the population that separates recyclable waste from organic waste, and the restaurants that discard food can receive benefits, such as reduction of public taxes, besides enjoying the environmental gains generated by the use of this waste. Public policies should also be used to make the population aware of the need to reduce food waste, which is still very high around the world (INPE, 2021).

3 METHODOLOGY

This work was performed according to the following steps.

1) Analysis of the general equations of production factors considering economies of scale of production and analysis of inputs and outputs (Schumpeter and Cobb-Douglas). The Cobb-Douglas model does not foresee the factor "energy" of production, nor the finiteness of natural resources. Production, according to Georgescu-Rogen (1970 apud Varian, 2015), among other factors, involves energy. Thus, to modernize the Cobb-Douglas economic model and insert it into a CE, it is necessary to introduce the factors of energy and natural resources. To this end, we added the input variables of a CE (such as the inputs and products), and the outputs (the waste to be reused with the objective of reducing the entropy of the productive economic system).

2) Evaluation of São José dos Pinhais' Multi-Year Plan (2018-2021), considering the presentation of actions linked to the environment and the resources allocated for environmental education and waste collection in the municipality. Considering its high revenue, strategic

location, and agricultural and industrial potential, it is essential that the Multi-Year Plan's investments and budget forecast are in line with economic, social, and environmental sustainability. Thus, we carried out an evaluation of the Multi-Year Plan to verify the total amount received, the department responsible for the resource (linked or free), and the destination of the resource. The Multi-Year Plan is available on the Transparency Portal on the São José dos Pinhais City Hall website, under the legislation tab.[4]

3) Mapping of São José dos Pinhais' municipality, according to the generation of organic residues (its amount and quality, logistics of transportation and collection), and survey of strategic locations for the implementation of a Thermal Power Plant fed by an organic biodigester.

Regarding food waste generation, we conducted a survey of the number of food establishments in SJP, and an estimate of the total amount of food discarded annually. An active search was performed by direct mailing to 1860 establishments in SJP, of which 97 restaurants answered the questionnaire regarding the amount of food waste generated per month.

In addition, we identified areas with the potential to strategically serve the collection and selection of organic waste and the logistics of its transportation. The choice of this area should meet the minimum size for the implementation of a biogas power plant, which requires at least 15,000 m^2 for its implementation.

Even though it has a simple construction, the biodigester model proposed for *São José dos Pinhais* is similar to the Canadian model in some aspects, presenting a more modern technology: it has a digestion chamber dug into the ground, an inflatable gasometer made of plastic or similar material, and it is the horizontal type, with a masonry inlet box. As biogas is produced, it can be collected in an inflatable plastic dome. Otherwise, it can be sent to a separate gasometer to achieve greater operational control (Junqueira, 2014; Oliveira, 2006).

Since the biodigester will produce electrical energy, the availability of an electrical grid for its distribution was also considered in the analysis. We carried out a 20-day survey of available land belonging to São José dos Pinhais through a scan of the city's real estate records on WebGeo, looking for areas with adequate dimensions for the implementation of a thermal power plant. The selected area should be located in the city's Industrial and Service Zone 1 (ZIS1, acronym in Portuguese), according to the Complementary Zoning and Land Use Law, No. 107 of August 17, 2016.

4. Available at: <http://www.sjp.pr.gov.br/ppa-2018-2021/>. Accessed on: Nov. 22, 2022.

4 RESULTS

4.1 Analysis of Schumpeter's and Cobb-Douglas' general equation for the production factors

According to Georgescu-Rogen (1970 apud Varian, 2015), the economic system is just a subsystem of a larger one, called *environment*. Therefore, the global economy must meet the legitimate needs and desires of people, although its growth must also adapt to the planet's ecological limits (Geração..., 2021).

In an economic system, the degradation of natural resources and environmental pollution are elements that constitute levels of entropic disorder, since entropy is a parameter that measures the degree of disorder in a system. The greater the entropy variation of a system, the greater its disorder and, thus, less energy available to be used, since the loss of energy occurs in any production process, even though it can be minimized. The economic system lives in constant disorder, therefore, an equilibrium point is sought to reduce the economic entropy. If we relate economic resources to the second law of thermodynamics (entropy), we will realize that the current model of economic growth transforms energy and resources (low entropy compounds) into products and other elements, such as its waste and pollution (high entropy compounds), in an extensive way.

Figures A.2A and A.2B (appendix) present the economic system from the perspective of entropy inserted in the circular and in the linear economies. Instead of the Linear Economy's model, where the inputs are the resources and the outputs are the products, the inputs of a CE are the resources, while the products and the outputs are the residues. These outputs must be reused and reinserted into the production system in order to reduce the entropy of the economic system.

From the perspective of the entropy generated in a linear economy (figure A.2A), inputs (resources) and outputs (products) result in a high entropy in the Economic System. In addition, the wastes in this system result in the degradation of natural resources, environmental pollution, and the increase in GHG emissions. According to the second law of thermodynamics, in any physical system, the natural tendency is the increase of disorder, and to restore order, energy must be applied. However, the energy that is spent and not reused generates waste, which increases entropy and powers the Linear Economy (Smith et al., 2015). As proposed by the linear economy, the environmental crisis caused by the extensive use of produced capital (*Kp*) tends to raise entropy and the economic, environmental, and social chaos. In a CE, as shown in figure A.2B, the inputs will be the resources and products, while the outputs will be the waste. Thus, it is possible to reduce the entropy of the system through the use of renewable energy and the reuse of materials when its disposal and separation are done correctly, optimizing the system's outputs, and promoting greater circularity of production factors.

It is necessary to adapt the Cobb-Douglas model, so that CE is implemented in cities and around the world. What we propose in this study is the introduction of new variables to the inputs and outputs of the economic model. In the Cobb-Douglas model, the equation must include inputs and outputs in order to be considered a CE model, which is currently not the case. When inputs are entered, the production factors t (land) and T (technology) are expanded to Renewable Energy, Carbon Foot-Print, Natural Capital, Renewable Resources, and Efficient Resource Incomes in order to operate in a sustainable and profitable production model. The outputs would be the wastes, i.e. the final residues of the products, which can be reused in the system, as is the case of solid residues (recyclable materials such as glass, plastics, and metals) and organic residues capable of generating methane gas in a biodigester. After such changes, the current production factors predicted in the Cobb-Douglas model would be expanded, and input and output variables could be further introduced, contributing to the CE's incoming production scales.

The insertion of such inputs and outputs in the CE's system is only possible if cities carry out long, medium, and short-term strategic planning along with public policies that promote sustainability. Therefore, the reuse of the production resources would be possible with the implementation of efficient public policies towards waste management.

4.2 Analysis of actions linked to the environment in the Multi-Year Plan (2018-2021) of São José dos Pinhais

Of the R$ 1.1 billion of São José dos Pinhais' revenue planned for 2021, 0.4% was allocated to contingency reserves, while the remainder was distributed among 22 Municipal Departments, according to the Multi-Year Plan from 2018 to 2021. Table A.1 (appendix) presents the amount of funds allocated to the Municipal Environment and Health Departments, as well as the sources of funds applied directly or indirectly to environmental actions (São José dos Pinhais, 2018).

As shown in table A.1, only R$ 4,000.00 were allocated to Environmental Education in a city that does not have selective waste collection. São José dos Pinhais does not have a sanitary landfill and, therefore, it allocates by truck at a very high cost the collected waste to Fazenda Rio Grande, which is 28 km away from the SJP city center. Table A.1 shows the high amounts paid by the city for Intermunicipal Allocation of Solid Waste (R$ 5,025,000.00) and Solid Waste Collection (R$ 21,270, 9360.91).

The amount indicated in SJP's Multi-Year Plan for its Environment Department was R$ 52,342,362.01. However, R$ 26,295,936.91 were entirely spent to cover the cost of waste management, i.e., 50.23% of the total amount.

In addition, as SJP does not have a sanitary landfill nor a selective waste collection, there is a large increase in the proliferation of disease vectors (such as *Aedes aegypti*), and an increase of venomous animals (such as brown spiders, scorpions, and snakes). It can also be verified that the city's Health Department had R$ 249,554,967.92, but only R$ 100.00 were allocated to fight dengue fever, R$ 100,00 to zoonoses actions, R$ 10,00 to *VIGISUS* (Health Surveillance actions), and the amount destined to *VIGIAGUA*, which assesses the quality and potability of water, was not informed.

When comparing the cities of Curitiba (the State of *Paraná*'s capital) and São José dos Pinhais, the former has a complete coverage of garbage collection and selective waste collection, which separates materials such as plastics, glass, and metals (Sereda and Flores-Sahagun, 2021). Unlike other countries, when the selective waste collection occurs in Brazil, the population assembles plastic, glass, and metals and puts all these materials in the same plastic bag separated from organic waste, which is accommodated in another plastic bag. To maximize the benefits of recycling these materials, the population must separate glass, plastics, and metals from one another (Leitão, 2015).

In the urban area of São José dos Pinhais there is no selective waste collection. However, unregulated garbage collectors do collect recyclable materials usually mixed with organic waste. In the rural area, garbage collection is even more precarious and, when and where it occurs, it is only once a week. Table A.2 (appendix) shows the values of taxes charged for garbage collection in Curitiba and in São José dos Pinhais.

Table A.2 shows a summary of the amounts charged for garbage collection and the frequency of its collection. In São José dos Pinhais, the tax values for daily garbage collection are higher than the ones charged in *Curitiba*. In addition, there are places in the urban region of SJP where the recyclable and organic garbage are mixed together and collected three, two, or only one time per week. Furthermore, in SJP, there is no public awareness of the importance of separating recyclables from organic waste.

In a survey considering food establishments in SJP, the total amount of food discarded annually was quantified. Of the 1,860 establishments consulted, 97 restaurants answered the questionnaire that was sent to them, verifying that the estimated amount of food wasted by these establishments was 239.51 tonnes per year. A biogas power plant can run efficiently with 239.51 tonnes per year. Even though the total amount of wasted food has not been estimated, the obtained values show that more than one biodigester can be implemented in the city.

The company Ponta Grossa Ambiental S/A (PGA) was created in 2004 to fulfill a contract for Urban Cleaning and Solid Waste Management services in the city of Ponta Grossa, also in the State of Paraná. In 2008, PGA won the public bidding process for the concession of Urban Cleaning and Solid Waste Management services in Ponta Grossa, establishing from then on a wholly-owned subsidiary called Ponta Grossa Ambiental Concessionária de Serviço Público S/A (PGACSP). As a Special Purpose Society, the company provides services to the Municipality of Ponta Grossa. Among the services, there are:

- collection of solid household waste in the urban area and in isolated urban areas, and its transportation to landfills (its final destination);
- mechanized collection with 47 wheeled containers of household waste, and transportation to its final destination in a sanitary landfill;
- Environmental Surveillance and Monitoring of the Botuquara controlled landfill;
- selective collection of recyclable solid household waste, including the provision of 150 collection points of different capacities (from 2.5m^3 to 24m^3);
- manual and mechanized selective collection of organic solid recyclable waste;
- collection, transportation, treatment, and final destination of health services' waste- RSS;
- manual sweeping of streets and public spaces;
- operation and maintenance of a recycling plant for organic waste with the generation of electric energy for the city;
- 5 Standard Mowing Teams for urban cleaning services in squares, streets, and valley floors, including manual and mechanized mowing (trimmers and ride-on mowers), curb painting, among other activities;
- 2 Standard Landscaping Teams for cutting and pruning trees and shrubs (chainsaws, pole saws, and hedge trimmers), planting flowers and tree seedlings (soil drill), and gardening, among other activities;
- 2 Standard Mechanized Mowing Teams (tractor and ride-on mower);
- supply of *Brooks* 7 m^3 dump trailer;
- supply of roll-on roll-off dump trailers (20m^3 to 40m^3) for urban solid waste collection and transportation;
- supply of trash cans and underground garbage bins; and
- 1 "SARS – CoV 2" disinfection team in critical environments of the city.

Since 2021, Ponta Grossa has been benefiting from the use of food waste (with only 10 tonnes per year) to generate electricity in a biogas plant that operates with the collaboration of the local electric company (COPEL), the City Hall, and a private company. Tanks were installed in its facility enabling the reuse of biodigester residues, which are then transformed into biofertilizers after its sedimentation. After decantation, the biodigester effluent becomes non-polluting. In addition, if the garbage bags used to collect the discarded food by restaurants are washed, the polluted water with a high chemical oxygen demand can be used in the biodigester. Thus, these plastic bags, which otherwise would not be used in secondary plastic recycling, can be recycled (Abiplast, 2020; Karaski et al., 2016). The food waste is collected by the city's electric trucks, fueled with energy generated at the biogas plant itself.

Although its goal is to increase the food waste processing in the biodigester to 30 tonnes per year, the business is economically viable with its current production. Thus, considering the amount of waste used in *Ponta Grossa's* biogas plant, and the estimated value of organic waste in SJP, it can be verified that one or more biodigesters can be installed in this city, as the amount of discarded food from the consulted restaurants is already sufficient to generate energy efficiently.

4.3 Survey of a strategic location for the implementation of a Thermal Power Plant in SJP

The chosen area for the study is located in São José dos Pinhais, in the State of Paraná. The city is part of *Curitiba's* Metropolitan Area, along with 28 other cities, and part of Curitiba's Central Urban Core.

São José dos Pinhais's territorial extension is approximately 946 km^2 and, according to Ipardes (2021), its estimated population is 334,620 people. The urban perimeter of the city was defined by the Complementary Law No. 103, December 29th, 2015 (São José dos Pinhais, 2015), which established an urban area of approximately 195 km^2.

The study of the strategic location for the implementation of the Thermal Power Plant fed by the organic biodigester was executed starting from the identification of potential areas that could strategically meet the demands for the collection and selection of organic waste. The logistics of its transportation was also considered while analyzing – with WebGeo – the data provided by the Municipal Urbanism Department. In addition, the zoning for the installation of a Thermal Power Plant should meet the land use and occupation parameters of the city. Such a zone also presents great economic interest because of its proximity to highways, which facilitates the reception of products and the outflow of industrial production. After this complex analysis, the area for the plant's implementation was defined, as shown in figure A.3 (appendix).

Figure A.3 shows the shaded space delimited by the red arrows with a total area of 200,000 m^2, located in the Arujá neighborhood of SJP. Approximately 22,000 m^2 are necessary for the construction of the biodigestor, which represents around 11% of the total area available for the construction of the plant. The centroid of the shaded area in figure A.3 is in the 682682.318 E, 7170265.345 N UTM coordinates of the SIRGAS 2000 geodetic reference system. For the construction of the Thermal Power Plant containing two bioreactors, a transformer, and two sedimentation tanks of residues discarded by the biodigester, over 15,000 m^2 of land are required. It is possible to optimize the project even more if a plastics recycling plant is attached to the same land, in order to process plastic bags used in the food packaging in restaurants, as well as other plastic materials. Considering that washing plastics containing food residues makes the recycling process more expensive and generates polluting effluents, its use in the biodigester is doubly advantageous. The washed plastic bag can be recycled at the plant without additional costs, as the biodigester needs water that can still be contaminated with food.

5 FINAL CONSIDERATIONS

The Cobb-Douglas economic model that currently operates in a Linear Economy can be adapted to operate in a CE, through an econometric tool and a combination of two or more production factors. Even though the purpose of this paper is not to predict an econometric model, it is necessary to develop the mathematical model. Thus, it is possible to expand the variables of the current model of two production factors into a hybrid or open model, inserting inputs and outputs of the CE, and allowing the combinatorial analysis of the production factors. The combination of more than two production factors in an economy of scale returns allows resources to be used more efficiently and sustainably. Taking into account the entropy inserted in a CE that uses the adapted Cobb-Douglas model, the economic system needs the insertion of inputs, such as resources and production processes. In addition, the outputs (waste) produced by the production process must be reinserted into the production system in order to reduce the system's entropy and, consequently, the environmental pollution.

Without the adaptation of the Cobb-Douglas to operate in a CE, the principles of SDG and ESG are not met. According to the latest COP 26, the UN 2030 Agenda – addressing combined climate and economic goals – will not be met.

Currently, the main gap in the world climate efforts is related to industrial public policy guidelines, as the countries with progressing projects to become more sustainable have only developed waste management actions. The contribution of public policies in the elaboration of strategic cities' planning must be considered an important input to reduce the entropy of the economic system, since the energy reuse, the generation of clean and renewable energy, and recycling materials (glass, plastics,and metals) make the system more sustainable and active in the principles of the CE.

Based on the city's annual revenue, which in 2021 was R$1.1 billion, São José dos Pinhais' Multi-Year Plan approved for 2022-2026 did not present differences in resources planning and targeting. Thus, there is a high probability that environmental projects with resources linked to the City Hall will not be contemplated again in this new quadrennium, which highlights the importance of the participation of municipal councils, residents' associations, and community leaders in public hearings.

It is the State Court of Auditors' (TCE, acronym in Portuguese) role to supervise municipal budgets. With the maintenance of 2017–2021 budget distributions for the next quadrennium, we raise the following question: is each State Court of Auditors truly monitoring and verifying the application of previously planned?

The city's budgets must be transparent, so that the population has access to the Multi-Year Plan, the projects that will be supported by it, and the actions that will benefit them, in order to avoid embezzlement of public funds and disorganization while creating sustainable projects. Budgets that include projects which clearly define their inputs and outputs that contribute to the city's sustainability are important tools for achieving a CE, as well as better social, economic, and environmental indicators.

A well-designed and integrative Multi-Year Plan must be apolitical and long-term – unlike what we see today, where public policies in Brazil go through electoral periods and become instruments for politicians' elections.

Further, we concluded from the study that it may be possible to promote actions and implement smarter economic models that reduce the entropy of the economic system. In addition, there is a need for greater citizen participation in monitoring the city's budgets and project plannings of actions that are compatible with environmental, economic, and social sustainability.

The implementation of a thermal power plant in SJP in the ZIS1 zone is feasible, as there is enough raw material (food waste from restaurants and other establishments) to generate electricity in more than one biodigester, reducing environmental pollution. The city could benefit from new public and private investments, attracting investors interested in implementing new business models, reducing costs (currently R$ 26 million) to dispose of the waste in Fazenda Rio Grande.

This biodigester implementation is a good alternative for the disposal of food waste. It is essential, however, that there is transparency in the contracts between the municipalities, the plant's operating company, and the company responsible for capturing the energy generated by the biogas plant, so that the counterparts are known by the population, and the economic and environmental gains are shared among all. The operation of Biogas Power Plants along with strategically located Recycling Plants maximizes gains from the reuse of urban solid waste.

Considering the SDGs and the global history of climate actions, cities must adopt the modernized Cobb-Douglas model by meeting the principles of the CE in order to reduce the entropy of the economic system. New socioeconomic models demand new practices at all levels. Therefore, it is extremely important that there is also a political commitment while elaborating responsible public policies, guaranteeing the population's awareness and better distribution of the municipal budget, thus avoiding the repetition of a history of unsuccessful actions. Furthermore, considering the 2030 Agenda, the adaptation of the Cobb-Douglas model is essential to protect the planet from degradation, especially through more sustainable means of consumption and production. The planet and the current industrial production model urgently need a sustainable management of its resources.

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APPENDIX

TABLE A.1
Summary table of the Multi-Year Plan (2018-2021): enviromental actions

Total amount received (R$)	Municipal Department	Funds and destinations (R$)/2021
52,342,362.01	Environment	Environmental Education ⟶ 4,000.00 Coordination of Intermunicipal Allocation of Solid Waste ⟶ 5,025,000.00 Solid Waste Collection ⟶ 21,270,9360.91
249,554,967.92	Health	Operational Activities of the Technical Department of Health Surveillance ⟶ 3,187,000.00 Campaign against Dengue ⟶ 100.00 Reinforce of Zoonoses Surveillance Actions ⟶ 100.00 VIGIAGUA Program ⟶ Not informed Coordination and maintenance of Health Surveillance Activities (VIGISUS) ⟶ 10.00

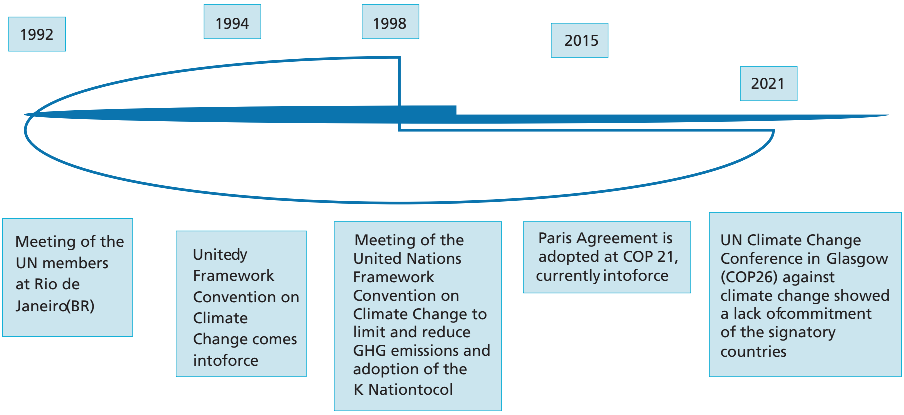
Source: Municipal Finance Department of SJP (Multi-Year Plan 2018-2021). Retrieved Aug. 2021 from: <http://www.sjp.pr.gov.br/ppa-2018-2021/>.

TABLE A.2
Amount charged for garbage collection

	Curitiba	São José do Pinhais	Frequency
Value (R$)	275.40	326.00	Daily
		163.13	3 times per week
		108.75	2 times per week
		54.38	1 time per week
Selective Waste Collection	3x per week included	Not Informed	None

Source: Curitiba City Hall; Municipal Finance Department of São José dos Pinhais, 2021.

FIGURE A.1
Reflections on the adaptation of the Cobb-Douglas function to work in circular economy starting with the implementation of a biodigester in São José dos Pinhais (1992-2021)



General Equation 1: Function proposed by Schumpeter (1933 apud Pindyck and Rubinfeld, 2010)

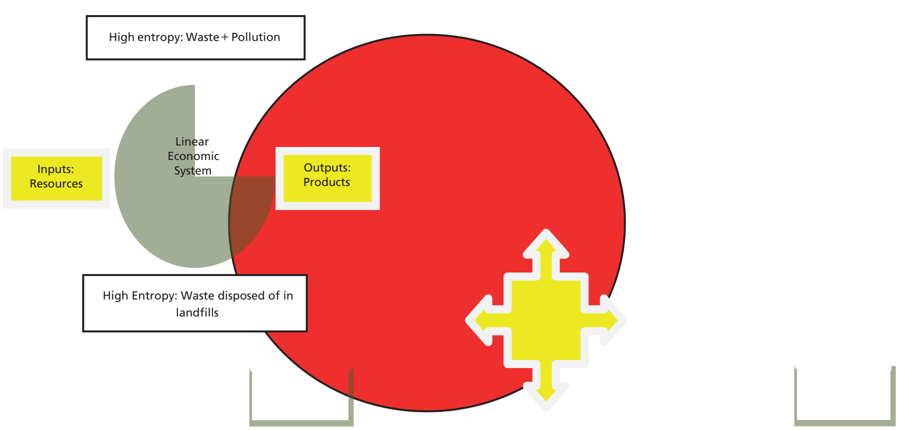
$$Q = F(K, L, t, T) \quad (1)$$

General Equation 2: Function proposed by Cobb-Douglas (1976 apud Pindyck and Rubinfeld, 2010)

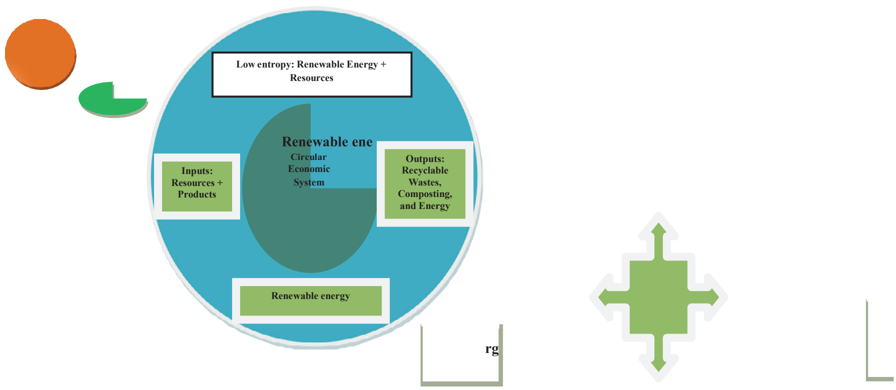
$$Y = AL^{\alpha}K \quad (2)$$

FIGURE A.2
Linear (a) and Circular (b) Economy from an entropy's perspective

A.2A – Linear Economy

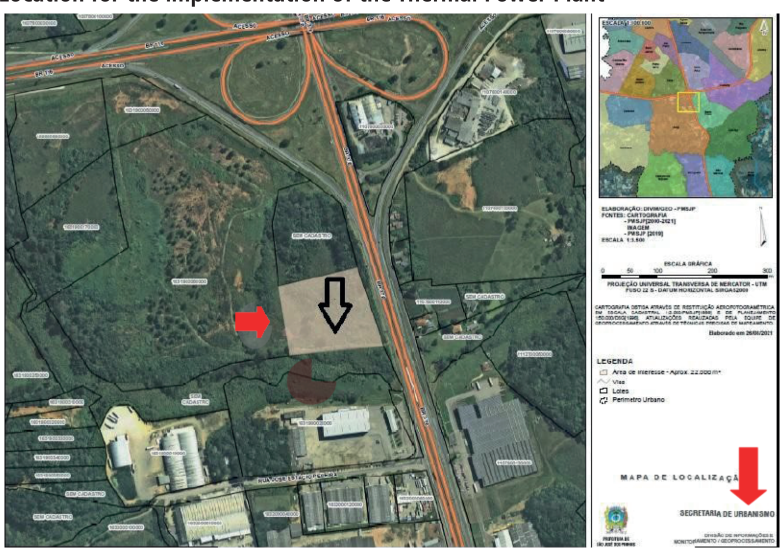


A.2B Circular Economy



Authors' elaboration.

FIGURE A.3
Location for the implementation of the Thermal Power Plant



Source: Webgeo – SJP Urban Planning and Traffic Department (2021). Retrieved Feb. 2021, from: <www.sjp.pr.gov.br/secretarias/secretaria- urbanismo/webgeo-sjp>.