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An industrial symbiosis simulation game

Evidence from the circular sustainable business development class

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Abstract

This study presents the industrial symbiosis (IS) business game developed in the "circular sustainable business development" (CSBD) class at the University of Twente. The game was designed by the instructors to allow students to experience the strategic business dynamics of IS. Spreading knowledge regarding IS dynamics is fundamental for fostering circular business development and equipping students, "the managers of tomorrow," with the skills of circular economic thinking. In this paper, the rules of the IS business game are presented along with the game settings. Further, the results of the gameplay are presented and discussed from a dual perspective, that is, through the theoretical lenses provided by the IS literature and the intended learning outcomes. Overall, we aim to spread this experience and the related results to promote teaching activities focused on IS.

KEYWORDS
business game, circular economy, industrial ecology, industrial symbiosis, sustainability, teaching

1 | INTRODUCTION

Industrial symbiosis (IS) is a sub-field of industrial ecology that involves "traditionally separate industries in a collective approach to competitive advantage involving physical exchange of materials, energy, water, and/or by-products" (Chertow, 2000, 313). IS is now recognized as a key strategy that companies can adopt to support the transition toward a circular economy (Domenech et al., 2019; Lüdeke-Freund et al., 2019). Nevertheless, the diffusion of IS among companies, according to Lombardi (2017), is below the expected levels at less than 0.1% of the 26 million active enterprises in Europe. This scenario is due to several barriers including personal barriers associated with how managers perceive IS, company barriers linked to poor provisions of expected economic benefits, and inter-company barriers triggered by operational and business-oriented challenges (e.g., Fichtner et al., 2005; Herczeg et al., 2018; Mortensen & Kørnøv, 2019). Several studies have highlighted that companies are sometimes unaware of the industrial value of their by-products discarded as waste (e.g., Yedla & Park, 2017). Furthermore, companies that know of IS are often unaware of implementation and management of IS relationships (ISRs) from an operational and business perspective (e.g., Mauthoor, 2017; Promentilla et al., 2016). Hence, spreading awareness about its dynamics concerning operational and business issues is fundamental to overcoming such barriers and fostering its development (Fichtner et al., 2005). This aim should involve both company managers and the "managers of tomorrow" that is, the students. An efficient higher education of future managers is critically important to achieve the mindset required for the transition from a linear to a circular economy, wherein IS is a key business model. Accordingly, many universities worldwide have incorporated sustainability into their courses and curricula (Lidgren et al., 2006) and included industrial ecology and circular economy classes into their teaching portfolios (Finlayson et al., 2014).

Since 2017, the University of Twente (UT) has included the "Circular Sustainable Business Development" (CSBD) class in the master's degree program of industrial engineering and management. UT, whose motto is "High-Tech Human-Touch," is a technical university located in Enschede (The Netherlands), which focuses on technology, sustainability, and society. In the CSBD class, that is attended mainly by engineering and business students, the topic of IS is addressed from several perspectives such as technical, economic, environmental, operational, business models, and research methods. At the end of the course students are required to play a business game, aimed at experiencing the main dynamics of IS from the companies' perspective, that are discussed from a theoretical standpoint during lectures. Business games are considered as useful tools for learning purposes in the form of "edutainment," an English neologism that represents the forms of playful communication aimed at teaching (Charsky, 2010). It is widely recognized that instruction with games might yield higher learning gains than conventional methods of instruction, especially if the game is supplemented with other instructional methods such as theoretical lectures (Wouters et al., 2013). To the best of our knowledge, IS business games are not available either on the web or as software, and the instructors of the class have designed their own IS business game.

This paper presents the IS business game designed for the CSBD class. It highlights the learning goals, explains the learning experience of students, and discusses the intended and unintended learning outcomes. Overall, the paper aims to spread this experience and the related results to promote teaching activities focused on IS.

The remainder of this paper is structured as follows. Section 2 presents the theoretical background of the study and introduces the main concepts of IS as well as some information concerning business game theory. Section 3 describes the development of an IS business game. Section 4 presents the results of the game play. Section 5 discusses the achievement of learning outcomes. Finally, Section 6 concludes the paper.

2 | THEORETICAL BACKGROUND

This section is divided into two subsections. Section 2.1 discusses IS and focuses on the operational and business dynamics that are more relevant to this paper's aim.[1] Section 2.2 discusses business games, with a focus on business games for education.[2]

2.1 | Operational and business dynamics of industrial symbiosis

IS practices engage different companies in the physical exchanges of waste. Accordingly, two companies establish an ISR when waste produced by one is utilized by the other to replace production inputs or for new product generation (Albino & Fraccascia, 2015). ISRs can create environmental benefits for the society by reducing the amount of waste discharged, primary inputs (i.e., raw materials, water, energy) used by industrial processes, and greenhouse gas emissions (e.g., Jacobsen, 2006; Kim et al., 2018; Sokka et al., 2011).[3] Moreover, companies can achieve economic benefits in the form of extra revenues as well (Fraccascia et al., 2019). *Ceteris paribus*, these economic benefits are the driving factors for companies to participate in IS as they provide a competitive advantage against other companies that do not implement IS (Esty & Porter, 1998; Yuan & Shi, 2009). Furthermore, trust between the companies involved and their geographic proximity are considered key facilitators for the establishment of ISRs (Hewes & Lyons, 2008; Jensen et al., 2011).

An IS network (ISN) can arise when multiple companies are involved in waste exchange. ISNs can be created according to different dynamics (Boons et al., 2017):

- can be designed top-down as a result of the initiative of a public or industrial actor who that drives and manages the overall process, such as the eco-industrial parks (Lowe, 1997; Afshari et al., 2018);
- can arise from the bottom as a result of a self-organization process undertaken by independent companies, driven by the willingness to benefit from IS (Chertow & Ehrenfeld, 2012; Doménech & Davies, 2011).
- can be the result of a facilitation process driven by a third-party organization, that establishes a market for IS exchanges, such as an online platform (Fraccascia & Yazan, 2018) or engaging companies in a collective learning process toward ISRs (Mirata, 2004; Cutaia et al., 2015).

This paper focuses on the self-organized IS approach, described by Boons et al. (2017) under the "self-organization" dynamic. Accordingly, industrial actors look for suitable partners interested in establishing an ISR. Once a potential partner is found, the companies negotiate the contractual terms of the relationship and post mutual agreement to it, the relationship is established. Several issues can be raised concerning these dynamics

[1] We recognize that IS is a complex topic, characterized by a high level of multidisciplinarity. IS has been studied from several perspectives, such as technical (e.g., Prosman and Wæhrens 2019), economic (e.g., Yuan and Shi 2009), social (e.g., Boons and Spekkink 2012; Hewes and Lyons 2008), strategic (e.g., Yazan et al. 2020), operational (e.g., Herczeg et al. 2018), etc. Hence, Section 2.1 is not intended to be exhaustive on the topic but is aimed at presenting the operational and business dynamics that are more relevant to the aim of this paper.

[2] There is an enormous body of literature concerning games for educational and training purposes. This section is not intended to be exhaustive on the topic but aims at providing the readers with the basic theoretical background and contextualizing this paper with respect to the literature.

[3] A large body of the literature on measuring the environmental benefits of IS is available. Readers are referred to the recent reviews by Neves et al. (2019) and Fraccascia and Giannoccaro (2020).

(e.g., Mortensen & Kørnøv, 2019). First, two companies in an ISR are linked by a strong interdependence: there cannot be a sole beneficiary of IS because the benefits are created through cooperation with the symbiotic partner. From a strategic perspective, both companies involved have a strong dependence on each other: if one decides to defect from the relationship, the other no longer gains any benefit (Aid et al., 2017). Although companies have to cooperate to create benefits, they have to compete when negotiating on its share—accordingly, IS can be considered as a form of "coopetition," that is, something in between pure cooperation and competition (Yazdanpanah & Yazan, 2017; Osarenkhoe, 2010). In particular, companies have to negotiate the quantity of waste to be exchanged, the tenure of the ISR, the waste exchange price, and the sharing of the additional operational costs (e.g., the costs to make wastes viable as inputs and its transportation costs) arising from the ISR (Yazdanpanah et al., 2019). This phase is crucial for the establishment of ISRs: the potential economic benefits from it must motivate companies toward cooperation and, simultaneously, avoid an incentive misalignment between themselves.[4]

One of the toughest issues hampering the establishment of ISRs from an operational perspective is tackling the potential mismatch between the supply and demand of wastes (Bansal & McNight, 2009; Yazan & Fraccascia, 2020). Finding a symbiotic partner able to provide/accept the right amount of the right waste at the right time can be difficult and/or costly (Madsen et al., 2015). Such a mismatch can be exacerbated by the lack of information, since companies could be unaware of which (and how many) wastes are produced/required by other companies (Fraccascia & Yazan, 2018). Nevertheless, companies operate in dynamic business environments, which means that waste production and input requirements can fluctuate over time (Fraccascia, 2019). This phenomenon can further exacerbate the mismatch between the supply and demand of waste. Moreover, the waste disposal cost, input purchasing cost, and IS operational costs can change over time. Accordingly, existing ISRs can become detrimental over time, and therefore, come to an end.[5]

Apart from the above-mentioned technical and economic issues, social issues are important for operating ISRs. Several studies have investigated the role of social relationships among the managers of companies involved in ISRs. The game described in this paper focuses on the business perspective and, as discussed in Section 3.1, social issues are not part of the intended learning outcomes.[6]

2.2 | Business games

Business games are games at the intersection of *simulation games*, *serious games*, and *management games* (Greco et al., 2013). *Simulation games* combine the features of games (i.e., rules, participants, competition, cooperation) with those of simulations (i.e., a working representation of reality, which can be an abstracted, simplified, or accelerated model of a real process) (Ruohomäki, 1995). *Serious games* are "games primarily focused on education rather than entertainment" (Miller et al., 2011, 1425). These games are interactive, based on a set of agreed rules and constraints, directed toward a clear goal that is often set according to a challenge, and constantly provide feedback (e.g., as a score or changes in the game environment) to enable players to monitor their progress toward the goal (Wouters et al., 2013; Connolly et al., 2012). *Management games* are "the simulations used to support managerial[7] learning through an experience that features competition and rules in the socio-economic environment" (Baldissin et al., 2008, 10). According to Greco et al. (2013, 649), "a business game is a game with a business environment that can lead to one or both of the following results: the training of players in business skills (hard and/or soft) or the evaluation of players' performances (quantitatively and/or qualitatively)'.

According to the experience provided, two main categories of business games can be distinguished: (1) games that allow players to experience the company's perspective, tracking both the company's internal dynamics and its interaction with the external environment; (2) games allowing players to simulate a limited set of business functions (e.g., sales management and manufacturing management) or business concepts (e.g., team behavior, budget control, and negotiation) (Hall, 1999).

Business games can be used for several purposes, such as corporate training and development, research, and education[8] (Summers, 2004; Eilon, 1963). The game we developed belongs to the category of "educational business games" that aims to teach topics and train the players in business skills such as soft, conceptual, and hard skills[9] (Greco et al., 2013; Gredler, 1996).

[4] The misalignment incentive problem arises when independent agents have to cooperate to pursue a common goal (e.g., the establishment of an IS relationship) but the benefits stemming from such a cooperation are unevenly shared (Narayanan and Raman 2004). In the case of IS, companies might be tempted to behave opportunistically when negotiating to capture the majority of the economic benefits created by ISRs while leaving a scant part to the partner (Yazan et al. 2020).

[5] A large body of the literature on this topic at both company and ISN level is available. Readers interested to deepen this dynamic are referred to the following papers: (Chopra and Khanna 2014; Zhu and Ruth 2013; Wang et al. 2017b, 2017a; Li and Shi 2015; Ashton et al. 2017; Yang and Zheng 2020).

[6] Readers interested in the social perspective of IS can refer to the following papers: (Jacobsen 2007; Doménech and Davies 2009; Hewes and Lyons 2008; Jensen et al. 2011; Boons and Spekkink 2012; Spekkink 2016). This list is not intended to be exhaustive.

[7] Here managerial is used with the meaning of "related to the management of organizations".

[8] Business games for educational purposes have become very popular nowadays. According to Jerman Blažič and Džonova Jerman Blazic (2015, 305), "the process of the globalization and liberalization of the business world has changed the types and qualities of human capital required by the corporate sector. Therefore, business graduates are not only expected to have a theoretical understanding of business; they are also expected to have communication skills, thinking skills [...], and the ability to apply the multidisciplinary knowledge acquired during their study. The popularity of BGS [business games] in education follows on from these findings, but the interest in using simulation games when teaching business subjects is driven by its effectiveness".

[9] For a detailed discussion of the reasons related to the importance of using business games for teaching purposes, readers are referred to a recent work by Goi (2019).

According to the framework proposed by Charsky (2010), educational business games are characterized by actions, rules, goals, and challenges. During gameplay, players can undertake actions and decisions to achieve victorious conditions, that must be challenging (Malone & Lepper, 1987; Hannafin & Peck, 1988). A set of rules limits the actions that players can take. These games have clear goals that define the conditions of victory and are set to match the learning outcomes. Players can achieve these goals through competition, that makes the learning enjoyable and increases the motivation of players to complete the game activities by keeping themselves engaged in the game (Alessi & Trollip, 2001; Charsky, 2010). This has a positive effect on learning processes (Hamari et al., 2016).

3 | THE INDUSTRIAL SYMBIOSIS BUSINESS GAME

The IS business game is a mandatory activity of the CSBD class, a five ECTS credits[10] course in the master's degree program of Industrial Engineering and Management at UT, which is also open as an elective course to students from different programs. The game aims at enabling students to experience the operational and business dynamics of IS with respect to the establishment and management of ISRs over time.[11]

This section is divided into three subsections. Section 3.1 presents the intended learning outcomes of the game. Section 3.2 describes the game environment—in terms of game players (Section 3.2.1), costs and benefits of ISRs (Section 3.2.2), and information available to players (Section 3.2.3). Section 3.3 describes the game characteristics, which are based on Charsky (2010), that is, competition and goals (Section 3.3.1), rules of the game (Section 3.3.2), game actions (Section 3.3.3), and game challenges (Section 3.3.4).

3.1 | Intended learning outcomes

The game was designed to enable students to achieve the learning outcomes discussed below.

- *Recognizing and experiencing the impact of operational barriers on the establishment and running of ISRs.* The game was designed to allow students to experience two IS barriers, namely, the potential mismatch between waste supply and demand, and access to information. Concerning the former, students are expected to recognize that a supply-demand mismatch might arise because waste is not produced upon demand but emerges as a by-product of manufacturing activities, whose production volume, together with production technologies, drives the amount of waste produced (Yazan & Fraccascia, 2020). Concerning the latter barrier, students are expected to recognize how difficult it is implement IS when companies do not have access to information such as the types and amounts of wastes produced/required by other companies because (1) such data are not publicly available and (2) companies have a low willingness to share such sensitive information (Golev et al., 2015). Overall, students are requested to deal with the above-mentioned barriers when establishing and implementing ISRs.
- *Assessment of influential factors deciding establishment of self-organized ISRs and its long term implementation.* Students should consider multiple aspects both while seeking potential IS partners and when operating ISRs. First, students are expected to recognize the role of geographical distance between partners from an economic perspective as technical feasibility might not derive economic profitability due to excessive transportation costs. Nevertheless, ISRs between distant partners might be more promising owing to different economic values of input replaced/waste saved, different cost-sharing contracts, or a better match between waste supply and demand. Furthermore, students are expected to observe the impact of technical factors, such as main product market demand (which drives the output production), technological efficiency (which affects the amounts of wastes produced/inputs required per unit of output), and waste-input substitution rate (which drives the feasibility of ISRs), on the IS practice, particularly considering the amounts of wastes exchanged and the economic benefits created (Fraccascia, 2019). Overall, students are expected to recognize that multiple potential ISRs might exist, and that geographic proximity is not the only aspect to consider when seeking symbiotic partners for a successful ISR.
- *Dealing with the coopetitive nature of IS from a managerial perspective.* As mentioned in Section 2.1, companies need to cooperate to establish ISRs and compete when sharing ISR costs. In this regard, students are expected to learn to share costs emphatically, establish trust via long-term thinking, and react against contract interruptions. The IS interactions are aimed at teaching the importance of being empathic to the potential IS partner, not being greedy in cost-sharing, not losing potential environmental benefits while trying to maximize economic benefits, and being a trustable business partner (Yazan et al., 2020).

[10] ECTS stands for European Credit Transfer and Accumulation System, a tool of the European Higher Education Area for making studies and courses more transparent (https://ec.europa.eu/education/resources-and-tools/european-credit-transfer-and-accumulation-system-ects_en)

[11] The authors are aware that IS a multidisciplinary concept that involves multiple dynamics. This business game is not intended to provide experience of all the IS dynamics but a simplified (realistic) experience of them.

3.2 | Game environment

3.2.1 | Description of players

The game is played by students, divided into groups, each representing one company. Players are required to perform managerial activities related to the IS. Two types of companies are distinguished: waste producers and receivers. For the sake of simplicity, it is assumed that (1) each company produces one main output for the final market; (2) each waste receiver requires one production input, and each waste producer generates one waste. The amount of produced waste and required inputs depend on the amount of output generated and the production technologies.

Two types of waste producers are distinguished: companies producing waste A, and companies producing waste B. The generic waste producer j generates x_j units of output and produces $w_{jA} = W_{jA} \cdot x_j$ units of waste A ($w_{jB} = W_{jB} \cdot x_j$ units of waste B), where W_{jA} (W_{jB}) is a technical coefficient denoting the number of units of waste A (B) generated by company j per unit of output produced.[12] Without IS, all of the waste produced is discharged. The waste producer j pays waste disposal costs $dc_{jA} = udc_{jA} \cdot w_{jA}$ ($dc_{jB} = udc_{jB} \cdot w_{jB}$), where udc_{jA} (udc_{jB}) is the cost for j to dispose one unit of waste A (B).

All the waste receivers require the same input. The generic waste receiver i generates x_i units of output and requires $r_i = R_i \cdot x_i$ units of input, where R_i is a technical coefficient (primary input coefficient) denoting the number of units of input required by company i per unit of output produced. Without IS, the overall amount of input is purchased from traditional suppliers. Waste receiver i pays input purchase costs $pc_i = upc_i \cdot r_i$, where upc_i is the unitary input purchase cost. Waste receivers can replace their production inputs with wastes A and B. Waste receiver i can use one unit of waste A (B) to replace $s_{A\to i}$ ($s_{B\to i}$) units of inputs.[13]

3.2.2 | Costs and benefits of industrial symbiosis relationships

By implementing ISR, companies can achieve economic benefits by reducing production costs. Let us consider waste producer j (producing waste A) and waste receiver i who exchanges $e_{jA\to i}$ units of waste A. Here, j can reduce the waste disposal costs by $udc_{jA} \cdot e_{jA\to i}$ euros and i can reduce the input purchase costs by $upc_i \cdot s_{A\to i} \cdot e_{jA\to i}$ euros. However, companies are required to deal with three additional costs: waste transportation costs, waste treatment costs, and transaction costs of cooperation (Yazdanpanah et al., 2019). Waste transportation costs depend on the distance between companies and the amount of waste exchanged. The waste treatment costs depend on the amount of waste exchanged. When the ISR is established, both companies have to pay a fixed cost, independent of the amount of waste exchanged, to register the contract ruling the relationship[14] (Albino et al., 2016)—see Section 3.3.2 for IS contracts. While transaction costs arise at the level of a single company, other additional costs arise at the level of ISR, and might be shared between the companies (Yazan et al., 2020). Furthermore, companies can earn extra revenue. In this case, extra revenue for one company corresponds to extra costs for the other company. Overall, the economic benefits that waste producer j gains from the ISR with waste receiver i and *vice versa* can be computed as follows:

$$EB_{jA\to i} = \left[udc_{jA} - \alpha_{jA\to i} \cdot \left(tc \cdot d_{ji}\right) - \beta_{jA\to i} \cdot rc\right] \cdot e_{jA\to i} - ec_{jA\to i} - cc \tag{1}$$

$$EB_{i\leftarrow jA} = \left[upc_i \cdot s_{A\to i} - \left(1 - \alpha_{jA\to i}\right) \cdot \left(tc \cdot d_{ji}\right) - \left(1 - \beta_{jA\to i}\right) \cdot rc\right] \cdot e_{jA\to i} + ec_{jA\to i} - cc \tag{2}$$

where $\alpha_{jA\to i}$ is the percentage of transportation costs paid by j, tc is the cost of transporting one unit of waste per km, d_{ji} is the distance between j and i, $\beta_{jA\to i}$ is the percentage of treatment costs paid by j, rc is the cost of treating one unit of waste, $ec_{jA\to i}$ is the waste exchange price paid by j to i (if i pays j, this term is considered negative),[15] and cc is the cost of signing the IS contract. The parameters $\alpha_{jA\to i}$, $\beta_{jA\to i}$, and $ec_{jA\to i}$, which depend on the negotiation between companies (see Section 3.2.2), rule how the total economic benefit created by the ISR is shared between j and i.

[12] Here, the reader can follow the role of companies producing waste A in the main text and the role of companies producing waste B in parenthesis.

[13] For example, $s_{A\to i} = 0.4$ means that the company i is able to use one unit of waste A to replace 0.4 units of primary input: therefore, if the waste receiver would like to replace one unit of primary input with the waste, it should demand 1/0.4 = 2.5 units of waste A. *Ceteris paribus*, the conversion factor s impacts the demand for wastes: the higher the value of the conversion factor (i.e., the higher the capability of waste to replace the input), the lower the amounts of waste demanded.

[14] The cost to register the contract simulates the transaction costs that companies are required to pay when operating IS. The contract cost simplifies the transaction costs described by Williamson (1981), which are used to model ISNs in Fraccascia and Yazan (2018). We are aware that transaction costs comprise more than just the costs to establish IS contracts. However, such simplification was introduced for learning purposes.

[15] An extra cost for company j results in an extra revenue for company i and *vice versa*.

3.2.3 | Information available to players

Before the game starts, each company is provided with the following information:

- *General information*
  - Name, physical address of the company, and email address.
  - Email address of other companies—to allow communication among companies.
  - Type of waste produced (only for producers).
  - Matrix of distances among companies (km).
- *Technical information*
  - Technical coefficient of production (waste coefficient W or primary input coefficient R).
  - Conversion factor *s* (only for receivers).
- *Economic information*
  - Average market demand for main output.
  - Unit transportation cost *tc* (€ per (ton*km)).[16]
  - Unit treatment cost *rc* (€ per ton).
  - Transaction cost *cc* (€ per contract).
  - Unit discharge/unit traditional purchase cost dc_{jk} / pc_i (€ per ton).

3.3 | Game characteristics

3.3.1 | Competition and goals

The goal of each company is to maximize the environmental and economic benefits created through ISRs with other companies. Two environmental and economic performance indicators are defined for each company. The *environmental performance* is computed as follows: for waste producers, the ratio of the amount of waste exchanged to the amount of waste produced; for waste receivers, the ratio of the amount of traditional input replaced to the amount of input required. The *economic performance* is computed as the ratio of the net cost savings due to symbiotic cooperation to the traditional production costs, that is, the costs the company would have paid without IS. The computations for these indicators are presented in Appendix A1. At the end of the game, companies are ranked according to the numerical values of the two performance indicators, which are computed by considering all the game periods.

3.3.2 | Rules of the game

The game is played continuously for several days. Each day is divided into three game periods: 06:00–14:00, 14:00–22:00, and 22:00–06:00. These periods simulate what happens in the real world over a longer timeframe, for example, weeks or months. The market demand for companies' output is referred to as one game period, that is, every 8 h each company produces a given amount of output and, as a consequence, produces/requires a given amount of waste (according to the equations presented in Section 3.1.2). Every day, companies operate based on the game actions (described in the following subsection) from 09:00 to 18:00.[17]

In each game period, companies can establish and implement as many ISRs as they want. Accordingly, each waste producer can exchange waste with multiple waste receivers simultaneously, and *vice versa*. Each waste receiver can use waste from multiple waste producers simultaneously. Each relationship is ruled by a contract signed by both parties, wherein terms are negotiated by the companies. Each contract defines the following issues.

- Duration of the relationship (in terms of time periods) and the waste exchange rate (i.e., the amount of waste exchanged per period).
- The amount of waste to be exchanged during the relationship.
- The cost-sharing policy, that is, how waste transportation and waste treatment costs are shared between the involved companies.
- The waste exchange price, that is, if the waste producer (user) will pay the waste user (producer) or the waste exchange is operated free of charge.
- The penalty paid by the company that ends the contract prematurely.

[16] The metric ton is considered, referred to as "ton" in the remainder of the paper.
[17] Such constraints were added to avoid students playing outside the traditional working hours (e.g., in the evening or during night) to ensure a good work-life balance.

Generally, companies cannot stock waste.[18] Accordingly, in a given period, companies cannot exchange more waste than those produced/required in that period. Hence, at the end of the game period, all waste that is not exchanged is discharged. Finally, each group has an official email address, such that groups have at least one communication method; however, groups are free to select other ways (e.g., instant messages) to communicate.

3.3.3 | Game actions

Players can undertake the following actions: (1) seek a potential partner, (2) negotiate the contractual terms of ISRs, (3) create ISRs, (4) renegotiate ISRs, and (5) interrupt ISRs (Figure 1). After selecting a potential partner, companies negotiate contractual terms (Section 3.3.2). If the negotiation succeeds, both companies fill a contract module and pay administrative costs. At each period, companies can ask to renegotiate an existing contract by changing one or more ongoing contractual clauses. If the partner accepts the renegotiation and agrees on the new clauses, the companies sign a new contract module, which replaces the previous contract and pay the administrative costs. Alternatively, if the partner is not willing to renegotiate the clauses, the company can decide whether to keep the current contract until its natural ending or to terminate it in advance. In this case, the company terminating the contract pays a penalty (set during the negotiation phase) to the partner. Nevertheless, companies can terminate a symbiotic contract whenever they want, as long as they pay a penalty to their partner.

3.3.4 | Game challenges

The game poses two main challenges: (1) identifying a potential partner, creating ISRs with other companies, and negotiating the contractual terms, and (2) operating these relationships in a turbulent business environment. For the sake of simplicity, two kinds of environmental turbulence are considered: changes in the market demand for outputs produced by companies and changes in policy actions undertaken by the government.[19] Concerning the former, the market demand for each company can unexpectedly increase or decrease over time. This impacts the amount of waste produced and the inputs required. Concerning the latter, it is assumed that the government (role played by the teachers) can make decisions that change costs or that lead to unexpected economic benefits or losses.[20] Players are informed of these changes via email by the teachers.

4 | GAMEPLAY: INITIAL GAME SETTINGS AND DYNAMIC CHANGES

The game was played twice by two different classes: from October 16 to 25, 2019, by the class of 2019 and from October 19 to 27, 2020 by the class of 2020. Students were divided into 16 groups (four producers of waste A, four producers of waste B, and eight waste receivers), each composed of three or four students. The companies were located in the Netherlands (Figure 2). The locations of companies were chosen to comply with the following principles: (1) not all technically feasible ISRs are economically feasible, due to the high waste transportation costs, and (2) cooperation with companies not located nearby can be characterized by a higher supply-demand match, which can result in better economic benefits owing to the lower amount of waste that remains to be discharged or to be purchased (input). For each company, Table 1 depicts the values of output demand, as well as the amounts of waste produced and required, waste disposal costs, input purchase costs, waste transportation costs, waste treatment costs, and administrative costs. From a technical perspective, it is notable that companies have different values of technical coefficients R and W, according to the different production technologies adopted, that are characterized by different technological efficiencies. This issue drives a mismatch between the amount of waste produced and required. From an economic perspective, transportation costs and treatment costs were considered equal for both wastes A and B.[21]

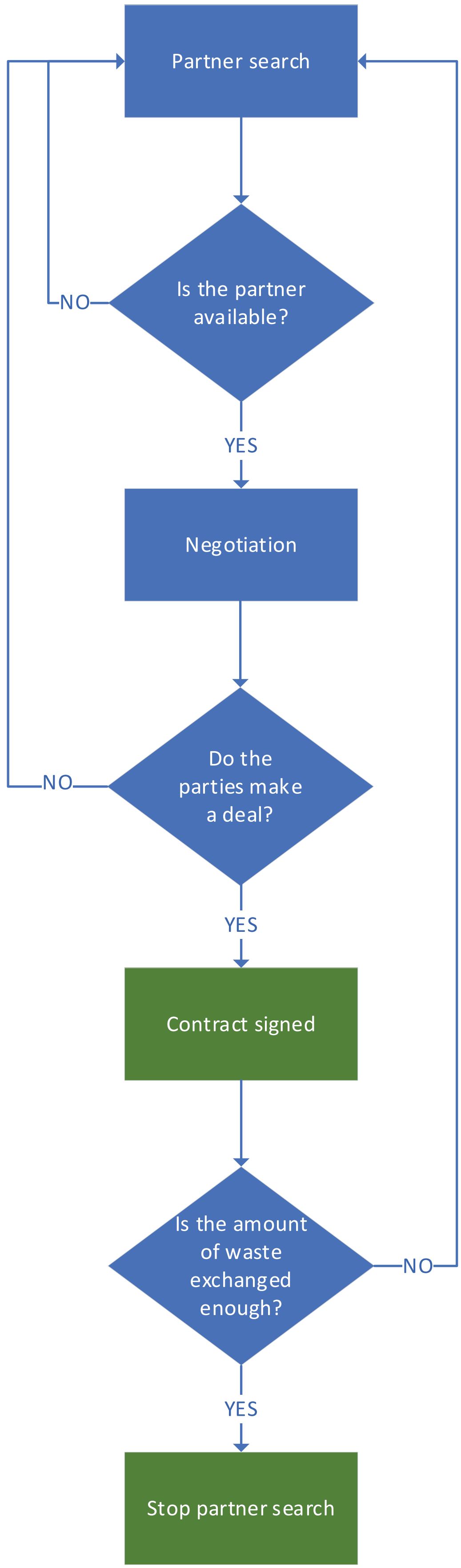
During the game, several changes to these values were made for students to experience the turbulences related to market and regulatory conditions. The following cases were simulated: (1) an increase in the main product demand and (2) changes in waste disposal costs, input purchase costs, and operational costs.

[18] According to the cases described in the literature, the practice of stocking wastes is rarely implemented due to the normative framework, technical reasons (e.g., in the case of perishable wastes), or economic reasons (firms prefer not to stock because they are not willing to pay inventory costs for wastes) (Golev et al. 2015; Herczeg et al. 2018; Lèbre et al. 2017).

[19] Authors are aware that several other turbulences, not considered in this game, might happen—see, for example, Fraccascia (2019). However, these turbulences allow students to experiment the effect of changes in the external environment on the existing and potential ISRs.

[20] Two examples, both resulting in higher economic benefits from IS, are reported as follows: (1) the waste disposal cost is increased by 20% due to a new taxation policy; (2) companies that discharge more than 50% of waste produced are forced to pay additional taxes.

[21] The authors recognize that transportation costs could be different depending on the specific waste (e.g., Yazan and Fraccascia 2020). However, keeping the same transportation cost allows avoiding introducing inequalities between companies producing waste A and companies producing waste B, which would reflect on the results of the game. However, this assumption can be easily relaxed in future game playing.



(a)

FIGURE 1 Flow chart of game actions: (a) seeking for a partner and negotiating the contractual terms; (b) renegotiating a symbiotic contract; (c) interrupting or renewing a symbiotic relationship

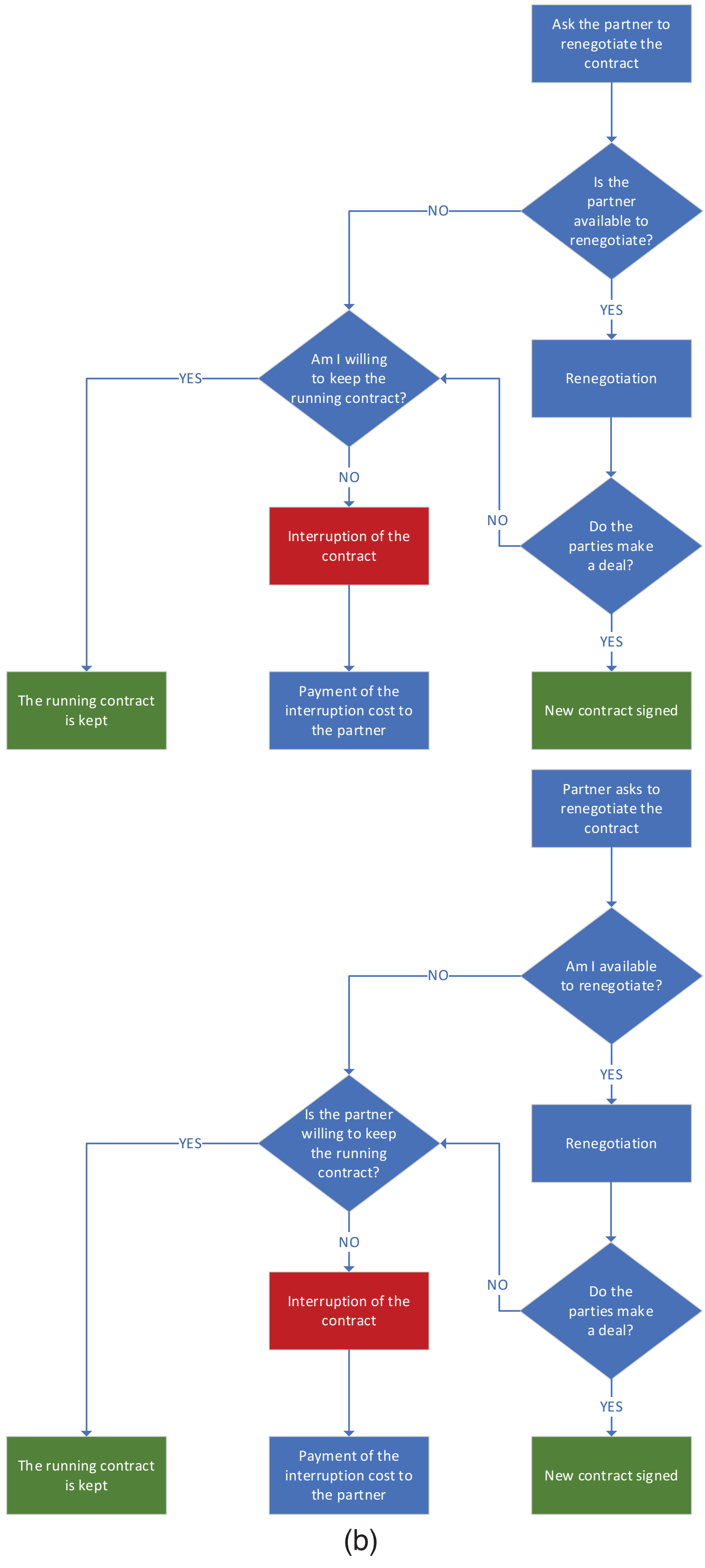
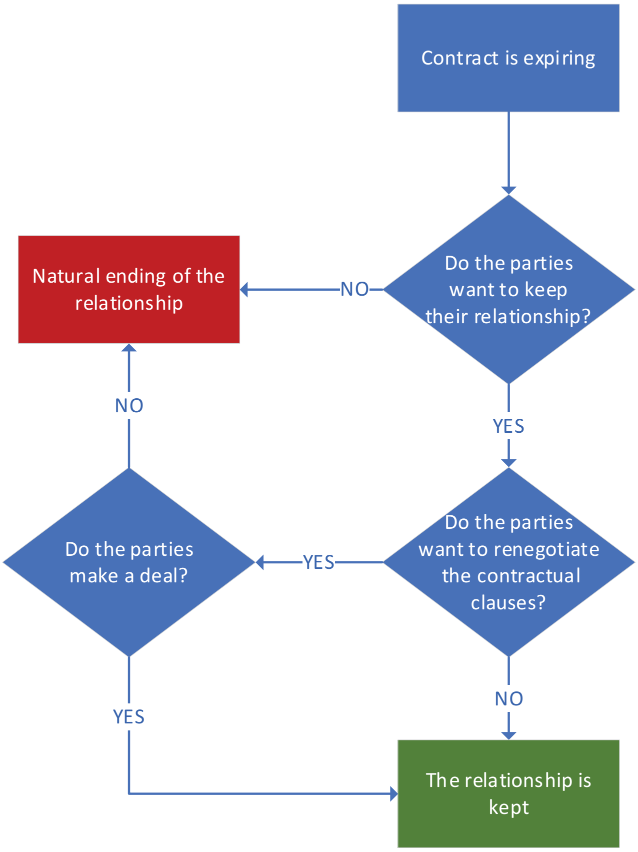


FIGURE 1 Continued



(c)

FIGURE 1 Continued

Students played the game without the physical supervision of lecturers. However, lecturers were available for clarification. Each group was provided with a structured Excel file (shared among the group members and lecturers for remote supervision), wherein students were required to report all periodic data related to the ISRs created or interrupted. Through the Excel file, the performance indicators mentioned in Section 3.3.1 were automatically computed using the data entered by the students. At the end of the game, each group was required to write a report to describe the game experience by using the theoretical perspectives discussed during lectures, and mention all the factors that influenced them in creating and managing ISRs, as well as the barriers encountered.

5 | DISCUSSION

This section is divided into three subsections. Section 5.1 focuses on the intended learning outcomes. Section 5.2 focuses on unintended learning outcomes. Section 5.3 discusses the limitations of this game.

5.1 | Intended learning outcomes

The IS game is arranged such that students are challenged to overcome the IS barriers mentioned in Section 2.1. The students experienced the relevance of a range of factors when implementing, maintaining, or interrupting ISRs to obtain multiple perspectives. The intended learning outcomes are briefly discussed below.

- *Recognizing and experiencing the impact of operational barriers on the establishment and running of ISRs.* Concerning the operational barriers to IS, all groups recognized that operating IS might be difficult because the match between the supply and demand of waste is difficult to achieve.

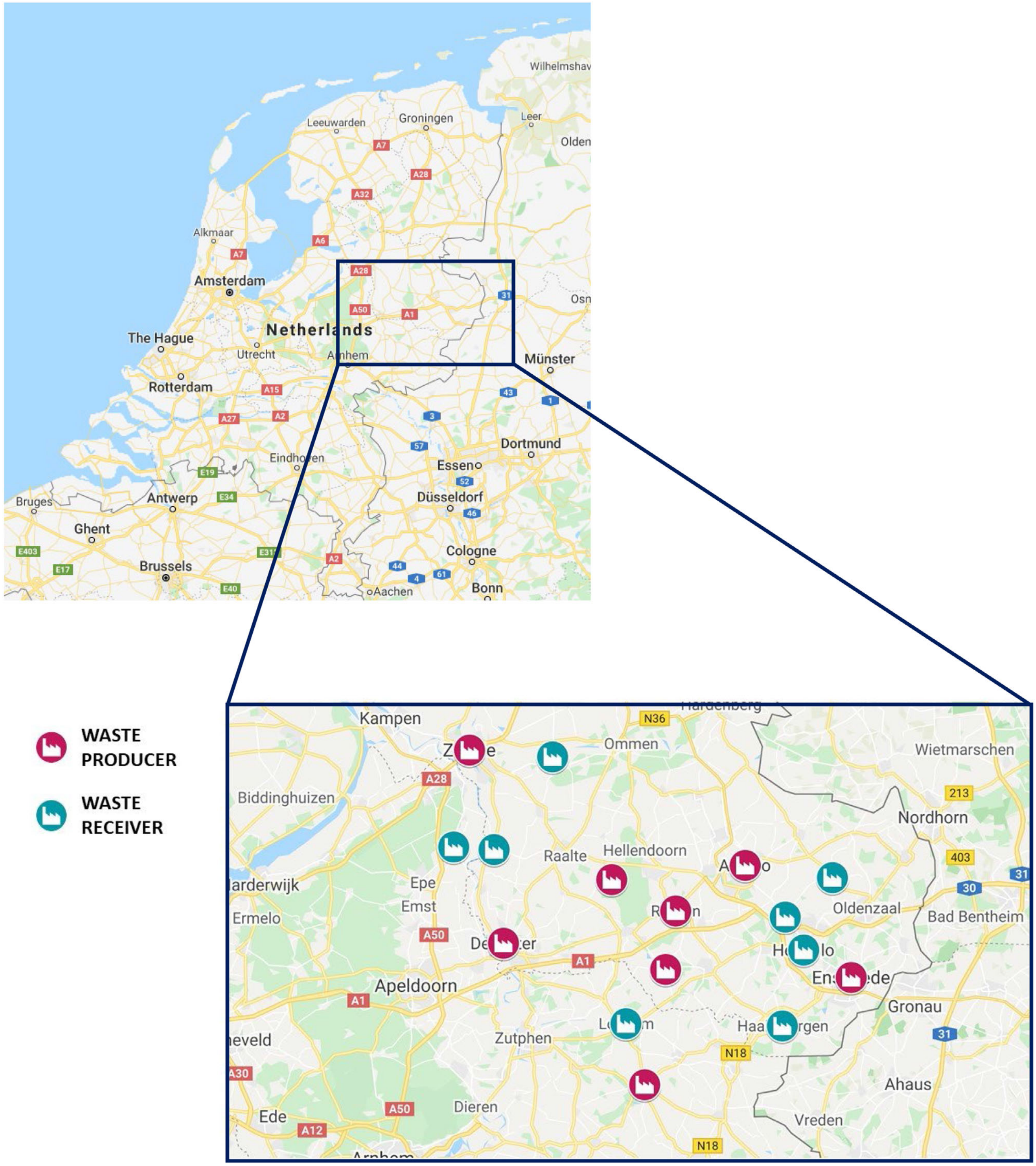


FIGURE 2 Locations of companies in the Netherlands. Waste producers are depicted in red. Waste receivers are depicted in blue

> *Another barrier that we encountered during the industrial symbiosis game was the match between supply and demand. We experienced that it was often difficult to find a partner that could deliver the right type and the right quantity of waste. For example, at the beginning of the game, we required 35 units of a certain type of waste. When we finally thought we found the right partner, we discovered that they could only deliver 34 units of waste. Hence, we need to substitute the remaining units.* **G11-WR_2020**.

Access to information was perceived as a key barrier to IS. On the one hand, such a lack of access was due to difficulties in communication among groups.

> *Another barrier encountered was related to communication. Owing to the use of email and other network messages as communication channels, such as chat and SMS, the response time was particularly long. These are asynchronous communication systems; therefore, they require no immediate response. Another platform for sharing information would probably have been more efficient* (**G16-WP_2019)**.

On the other hand, the low willingness of groups to share private information with others resulted in drawbacks during partner selection and negotiation processes.

> *One of the main barriers is that other players were reluctant to share their information. This was especially challenging in the identification phase of possible partners. [...] In the negotiation phase, the companies contacted were averse to sharing their data, such as the number of their resource requirements and purchasing costs. The information, even if it were sensitive to their business, would have been essential to ensure a fair share of costs by making use of the framework for industrial cooperation* (**G3-WP_2019**).

When playing the game, students of the 2020 class immediately recognized the difficulty of operating IS without proper information and decided, autonomously, to create a WhatsApp group that functioned as an online platform, wherein they shared information about waste supply or demand.

> *During the period of the project, members of our group were participants in a WhatsApp group that functioned as an online marketplace for this game. In this marketplace, waste suppliers and receivers had the opportunity to come into contact with each other, and every group could clarify how many and which kind of supply/waste they needed or produced*—**G11-WR_2020**.

- *Assessment of influential factors deciding establishment of self-organized ISRs and its long term implementation.* The students considered multiple factors in their decision-making processes. First, the geographic distance was highlighted by students as a relevant factor affecting partner selection. In fact, in the early phases of the game, many groups tried to contact a potential IS partner based on proximity to reduce transportation costs, *ceteris paribus*. Thus, the students experienced how the spatial scale of ISRs affects waste transportation costs.

> *Another barrier is the distance to certain potential partners in combination with high transportation costs. Because of these high transportation costs, only the partners that were at most 30 km away from our location were selected as potential symbiotic partners – **G12-WR_2019**.*

> *Our initial focus was minimizing transportation costs, that is, establishing symbiotic relationships with the close-by waste receivers. [...] However, other waste receivers who were in the range of 50 km had already agreed with other waste producers. Since we were producing more waste than the only waste receiver was able to take over, we had some leftover waste. The result was that the economic viability of establishing a symbiotic relationship with other waste receivers was impossible due to the high transportation costs – **G5-WP_2019**.*

When companies gained access to more information by interacting with multiple companies over time, they became aware that more promising opportunities might have existed, as opposed to companies located close by. Analyzing the contractual sheets filled by companies, it was evident that some groups continued to prefer to keep short-distance ISRs because they were already engaged in long-term relationships. Alternatively, other groups decided to exploit more promising relationships with long-distance IS partners during the game.
Apart from the geographic distance, students recognized the importance of technical factors when assessing the economic feasibility of ISRs. These factors influenced students' decisions.

> *We had the idea of basing our initial strategy on the following points: [...] 2) Going for waste type B. For the 24 traditional inputs needed, we would need 40 tons of waste A and 30 tons of waste B. Since the transport costs were the same for both types of wastes, we would save 10 euros per km if we chose waste B. Therefore, based on transport costs, it would be beneficial to choose waste B if the distance between the two companies were similar – **G15-WR_2020**.*

> *Initially, we created a list of features that we sought in the potential partners, ranking them by importance. These priorities were mainly based on geographical distance and the type of waste produced. Accordingly, we had to choose between collaborating with Waste Producer 5 and Waste Producer 8 since both of them were the closest (10 km away from us), followed by Waste Producer 2 (20 km away from us). Regarding the type of waste, Group 5 was a supplier for waste A and group 8 for type B. Since the conversion factor for type A was more significant than the conversion factor of type B (0.9 vs. 0.6), we prioritized waste type A. Therefore, we concluded that waste producer 5 was the best option, followed by waste producer 8 and waste producer 2* – **G9-WR_2020**.

- *Dealing with the coopetitive nature of IS from a managerial perspective.* From the students' reports, it was evident that the costs were fairly shared. No groups tried to capture a majority of the economic benefit from the ISR. This allowed the creation of stable ISRs over a long period of time. Few contracts were interrupted because partners were asked to renegotiate them. This reveals that, on average, students preferred to create long-term ISRs and avoided changing their IS partners frequently.

5.2 | Unintended learning outcomes

In their reports, students highlighted the role played by social relationships in partner selection and the communication process.

> *The second contract we signed was based not only on a "professional" relationship with the waste producer, but also a personal relationship with the people in the other group. Contact between the two groups was first established by the people in the group that already knew each other and were on friendly terms* – **G12-WR_2020**.

Ceteris paribus, having social relationships with members of other groups allowed for clear and quick communication among groups.

> *Lastly, we already knew group members from waste producer 3 through other study projects and, therefore, switched from negotiating via email to having an in-person discussion about our mutual goals. [...] Knowing the people in other groups made the negotiations easier, fair, and less time-consuming* – ***G16-WR_2019***.

> *We think that we had a troublesome start in the game because we did not have many social relationships and we had to mail groups in order to establish a relationship. If we have learned anything from the practice phase, it is that mailing is a frustrating and slow way of communicating. We immediately found that speaking to other people in person or via WhatsApp was quicker and made things clearer. Quick communication is key to discovering what each other's needs are, which is especially important in this game* – **G16-WR_2019**.

Students recognized that implementing long-term ISRs built trust between groups, and that trust was built over time. Even players with good social relationships were hesitant in the first phase of the game, but they became more confident in their partners while carrying out symbiotic synergies. Trust was recognized as a facilitator of the communication process, which encouraged information disclosure between groups.

> *There was a pretty fast transition from email to WhatsApp.* [...] *The advantage of WhatsApp over email is that it is much more informal. Business negotiations changed into friendly conversation with a deal on the site* – **G8-WP_2019**.

> *It was easy and comfortable to negotiate a contract with a contact person we already had a trustful relation with* – ***G13-WR_2020***.

> *We observed that during the start-up phase both parties were very hesitant and carefully trying to explore the potential of a symbiotic relationship with the other party. However, the contact and negotiation became easier as the groups came to know who their opponent was* – **G4-WP_2019**.

Furthermore, the existence of trust between groups enhanced the fair play in negotiating the sharing of additional costs required to operate the ISR, which in turn enforced the long-term relationships, in line with the dynamic described by Yazan et al. (2020).

> *Equally shared costs led to harmonic relationships, that resulted in negotiations for further long-term relationships. Experiencing this, we were able to achieve long-term contracts (over one week), which gave us more freedom, as negotiating and writing contracts proved to be quite time-consuming tasks.* [...] *In the gameplay, we felt that deviating from the 50-50 split in costs was perceived as acting in bad faith* – **G13-WR_2019**.

Alternatively, not having social relationships with members of other groups was perceived as a drawback because it affected the way groups communicated and, in turn, the trust development process. For example, members of Group 2–2019 (waste producer) had no social relationships with members of other groups. Such a lack of relationships might have contributed to creating a distrust climate, that was reflected by the opportunistic behavior of the group. Moreover, members of Group 2–2019 decided to set low penalty costs for interrupting symbiotic contracts to always have the opportunity to easily switch among different partners. Accordingly, the numerical analysis revealed that the group was unable to establish long-term relationships.

TABLE 1 Values of the variables considered

Group	Average main product demand [tons per period]	Average amounts of waste produced [tons per period]	Average amounts of waste A required [tons per period]	Average amounts of waste B required [tons per period]	Waste disposal cost [€/ton]	Input purchase cost [€/ton]	Waste transportation cost [€/(ton*km)]	Waste treatment cost [€/ton]	Administrative cost [€/contract]
G1-WP	40	32	–	–	40	–			
G2-WP	40	28	–	–	60	–			
G3-WP	40	32	–	–	40	–			
G4-WP	40	36	–	–	50	–			
G5-WP	50	60	–	–	20	–			
G6-WP	50	30	–	–	60	–			
G7-WP	50	30	–	–	50	–			
G8-WP	50	55	–	–	30	–	1	2	120
G9-WR	30	–	30	45	–	50			
G10-WR	30	–	36	45	–	30			
G11-WR	30	–	27	35	–	30			
G12-WR	30	–	45	45	–	60			
G13-WR	30	–	48	33	–	60			
G14-WR	30	–	35	27	–	50			
G15-WR	30	–	40	30	–	60			
G16-WR	30	–	39	27	–	50			

Abbreviations: WP, waste producer; WR, waste receiver.

> *Furthermore, the limited means of communication restricted us. We did not know the people we were working with, and initially had no contact information other than their emails. Having representatives in close proximity for face-to-face information exchanges would have made an immense difference.* [...] *The competitive environment engendered a distrusting attitude toward producers and receivers. We did not know what specific individual target quotas of each of the companies were and what information they had. Consequently, we subconsciously perceived the environment as one where everyone was following their economic interests and environmental goals to outperform us.* [...] *We decided to maintain our flexibility by setting meager penalty costs to terminate contracts. In this way, we kept the opportunity to exit any contract once we discovered a better collaboration opportunity in the marketplace* – **G2-WP_2019**.

Thus, the students were able to experience the extent to which social relationships and trust matter in IS.

5.3 | Limitations of the game

IS is a multidisciplinary context that involves complex dynamics. This game simplifies some IS dynamics, for example, the research process for suitable partners,[22] the waste transportation process,[23] the additional investments required to operate IS,[24] the transaction costs among companies, waste production, and input requirements. Thus, this game can be a useful teaching tool to enable students to experience the main IS dynamics, considering that no similar tools are available. The current version of this game was implemented after four years of gameplay experience in the class and using student feedback every year. Further developments and complexity improvements are possible and planned for the following years.

Scientists conducting research and education in different institutions must consider the composition of the study programs offered in their institutions. Therefore, once interdisciplinary topics such as IS or circular economy enter the curricula of an educational institution, the priority of diversified aspects of a topic might differ institutionally. The course of CSBD is open to engineering, business, and (information) technology students at the master level. Hence, the content of the course and the design of the game are associated with business, management, and network design aspects, wherein information technology serves as a business facilitator.

In future versions of the game, the variety of actions available to the players will be increased to enable students to experience more aspects of IS in terms of actions that are not limited to waste exchange.

6 | CONCLUSIONS

Today's educational activities call for more interdisciplinary teaching. When it comes to teaching "circular economy" oriented classes, many disciplines need to be considered. This is observable in the class of CSBD in which students from multiple backgrounds (e.g., industrial, financial, and construction engineering, business administration, business information technologies, sustainable energy technologies, technology, liberal arts, and sciences) are present in the class. While students' engagement is high in learning sustainability and circular economy, it is a challenge to maintain the students' interest in the content and their willingness to cooperate with their fellows because the levels of preknowledge are not identical. In such cases, business gameplay is an optimal way to make the class enjoyable based on a challenge-based learning strategy.

As IS operation is a complex topic, particularly for students not familiar with business courses, a simple communication language is preferred in the class to explain most of the concepts from a cost-benefit perspective. Thus, the students can be encouraged and prepared for the gameplay accordingly. The course contained several theoretical topics, such as sustainability, circular economy, monetary, physical, and information flows in supply chains, and industrial ecology. The most extensive part of the course was dedicated to IS, wherein the concepts of redundancy, market dynamicity, waste supply-demand matching, cost- and benefit-sharing, information-sharing platforms for IS, the role of governmental regulations in IS, the formation of ISNs, and learning fair-play and drawbacks of opportunistic behavior in IS were explained in detail. In terms of methodologies, cooperative and non-cooperative game theory (to assess IS opportunity and understand cost-sharing), agent-based modeling and simulation (to implement IS and form ISNs), and input-output modeling (to monitor IS performance) were addressed.

Apart from the gameplay, a case-based essay (group assignment with different group members) and an individual written exam were part of the course as two complementary assessment methods to ensure that each student achieved the intended learning outcomes of the course. Overall, the IS game contributed to the multi-perspective thinking skills of students, which is necessary to implement innovative and circular business models such as IS. Based on the positive feedback of students over several years, we gradually improved the complexity of the business game.

[22] In this game, companies do not need to find out what types of wastes might replace their inputs, since this information is already available to them, and then identify companies that produce these wastes. This might not happen in real contexts, unless companies use decision-support tools for IS, such as recommender systems (van Capelleveen et al. 2018) or online platforms (Fraccascia & Yazan 2018).

[23] In this game, companies do not need to design the waste transportation process, for instance according to their transportation capabilities (i.e., number of trucks). This aspect can be considered in a future version of the game. Moreover, a third-party company can be introduced to mutualize the collection and treatment of all wastes.

[24] Specific investments might be required by both single companies (e.g., buying new machinery or adapting an existing production plant) and multiple companies (e.g., joint investments for building infrastructures) (e.g., Cao et al. 2017; Wen et al. 2018). These aspects were not considered in this version of the game and they can be considered for future releases.

The version presented in this paper is from the academic year of 2019–2020, while our ongoing cooperation with colleagues from the Laboratory of Behavioral, Management and Social Sciences Faculty (BMS Lab) of UT is to model the business game on an online platform with a completely new interface and updated functionalities. Furthermore, we are developing a circular economy game where not only IS but also other types of 'loop-closing' activities can be addressed in a spatial setup in which companies, households, and public institutions are geographically in the same town/city/metropolitan/region. Student groups, each representing more than one stakeholder, will try to find circular solutions to improve the sustainability indicators of the system under investigation. Recommender models are embedded in the game allowing stakeholders to look for potential cooperators based on available resources. Once identification is complete, the execution of the loop-closing phase takes place, followed by the measurement of individual and collective sustainability indicators. According to our expectations, such a game set-up would roughly cover 3–5 credits depending on the complexity level achieved. More games based on multiple perspectives, such as water- or energy-oriented IS, will be implemented depending on the learning goals of other courses. The entire set of these games will form the infrastructure for **Sym**biosis for **C**ircular **E**conomy **L**aboratory (SymCEL) at UT, an online Lab where students are trained for learning circular economy transition in a challenge-based learning environment. Hence, we hope this study will play a role in inspiring and ameliorating the teaching of circular economy.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

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APPENDIX A1: COMPUTATION OF THE ENVIRONMENTAL AND ECONOMIC PERFORMANCE INDICATORS

The environmental performances of generic waste producer *j* and generic waste user *i* are computed as follows:

$$ENV\_PER\,(j) \;=\; \frac{\sum_t \sum_i e_{jA \to i}\,(t)}{\sum_t w_{jA}\,(t)} \tag{3}$$

$$ENV\_PER\,(i) \;=\; \frac{\sum_t [\sum_j s_{jA \to i} \cdot e_{jA \to i}\,(t) + \sum_k s_{kB \to i} \cdot e_{kB \to i}\,(t)]}{\sum_t r_i\,(t)} \tag{4}$$

The value of the environmental performance indicator, both for waste producers and receivers, can range between zero and one. It is equal to zero when the company does not save any unit of waste/recover any unit of input due to an ISR, while it is equal to one when the company saves all the wastes produced/replaces all the inputs required with waste.

The economic performance of each company depends on the amount of costs saved because of the symbiotic cooperation as compared to the costs the company would have paid without IS. The economic performances of generic waste producer *j* and generic waste user *i* are computed as follows:

$$ECO\_PER\,(j) \;=\; \frac{\sum_t \sum_i EB_{jA \to i}\,(t)}{\sum_t dc_{jA}\,(t)} \tag{5}$$

$$ECO\_PER\,(i) \;=\; \frac{\sum_t [\sum_j EB_{jA \to i}\,(t) + \sum_k EB_{kB \to i}\,(t)]}{\sum_t pc_i\,(t)} \tag{6}$$

The meaning of the economic performance indicator is more complex than that of the environmental performance indicator. In this regard, the value of the environmental performance indicator, both for waste producers and receivers, can theoretically range between -∞ and +∞. In particular, five cases can be highlighted:

- When the value of the economic performance indicator is lower than zero, it means that the company has lost money as compared to the traditional business, that is, in the absence of IS. Here, the costs to manage the ISRs are higher than the costs required to dispose the waste produced/purchase the input required.
- When the value of the economic performance indicator is equal to zero, it means that the company has not gained any economic advantage from the IS practice and, simultaneously, is not losing money as compared to the traditional business, that is, in the absence of IS.
- When the value of the economic performance indicator ranges between zero and one, it means that the company has saved money as compared to the traditional business, that is, in the absence of IS. Here, the company reduces the waste disposal costs/input purchase costs.
- When the value of the economic performance indicator is equal to one, it means that the company has completely reset the waste disposal costs/input purchase costs owing to IS.
- When the value of the economic performance indicator is higher than one, it means that the company, in addition to resetting the waste disposal costs/input purchase costs, has achieved further economic benefits owing to IS.

Data available on request due to privacy/ethical restrictions	The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.