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Research article

International industrial symbiosis: Cross-border management of aggregates and construction and demolition waste between Italy and Switzerland

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ABSTRACT

This article describes an international industrial symbiosis located in Canton Ticino, Switzerland, and Lombardy, Italy, involving virgin aggregates and construction and demolition waste. It discusses the potential of the industrial symbiosis to manage transport strategies and its geographic extension, to reduce substantially its transport related externalities, currently equivalent to 11% of the symbiosis value. With recourse to a key informant monitoring methodology, primary and secondary sources, this article estimates the symbiosis' transport environmental impacts, external costs, and returns to distance under various scenarios. We show that intermodal transport strategies have the potential to reduce transport's carbon dioxide equivalent emissions by up to 61% and external costs by up to 81%, and to widen the industrial symbiosis' geographic extension beyond the current 50 km. We also discuss how, despite changes and disagreements in the objectives of different cross-border regional authorities to manage the international industrial symbiosis, the coordination of different mechanisms and incentives is essential for the sustainable management of this international industrial symbiosis. The aim of the article is twofold. Firstly, to highlight the importance of assessing the contribution of transport to the overall industrial symbiosis' environmental impacts, rather than consider transport and its impacts as externally given variables. And secondly, to show policy and decision makers additional methods, and inter-regional authorities coordination experiences, in order to assess impacts and manage an industrial symbiosis in more sustainable ways.

1. Introduction

After the 2007 financial crisis, Italy's construction industry entered a decline in production, whilst Switzerland's construction industry grew substantially. This trend became the antecedent of the interdependency for Aggregates and Construction and Demolition Waste (ACDW) between Canton Ticino, Switzerland, and Lombardy, Italy, to develop what we characterise as an International Industrial Symbiosis (IIS), and which has the potential to become a flagship IIS, should a number of challenges, described ahead, be addressed.

The Industrial Symbiosis (IS) concept regained substantial traction after the European Commission set sustainable development as a goal for the European Union (Cutaia et al., 2015). The reason is the worldwide perception of IS as a core strategy for the promotion of the circular economy (CE) (Genc et al., 2019), a key element of sustainable development goals (Domenech et al., 2019; Iacondini et al., 2015). Yet, the IS concept is in fact rich and not new.

Chertow (2000) described the evolution of the concept, starting in the 1970s with the United Nations' search for non-waste production strategies (Erkman, 1997), changing to consumption of energy and materials in processes producing effluents that serve as raw materials for other processes (Frosch and Gallopoulos, 1989), and incorporating spatial dimensions of environmental and resources systems and location advantages in the 80s and 90s (Kneese and Sweeney, 1985; Krugman, 1991; Piore and Sabel, 1984; Porter, 1998). Integrating various dimensions, Ehrenfeld and Gertler

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(1997, p.69) described the IS as a symbiosis in economic terms, manifesting exchanges of materials and energy between firms in proximity with different logic to that of common market activities.

The IS concept became increasingly complex, with the importance of proximity or colocation losing ground compared to the increased importance given to knowledge exchange in broader regions (Chertow, 2000), as well as excess capacity and resources sharing (Lombardi and Laybourn, 2012), and multiple other dimensions organised in antecedents, consequences, enablers, and limiters, analysed across individual, organisational, network, and institutional levels (Walls and Paquin, 2015).

Although exploring dimensions beyond geographical proximity is correct, dismissing proximity without thoroughly analysing how to manage it, may be premature. According to Chertow and Ehrenfeld (2012), the waste produced by organisations can be the input for production or ancillary services for another organisation; thus, an IS may turn negative environmental externalities into positive ones. Nevertheless, the need to reduce negative transport externalities, and to enhance the geographical extension of an IS with different transportation strategies to reduce the need for proximity, is not always analysed in many symbiotic networks.

Externalities refer to uncompensated or unaccounted costs and benefits derived from interdependencies (Cornes and Sandler, 1996). The analysis in our article addresses usually unaccounted costs and benefits of different transportation strategies evaluated to reduce negative transport externalities and the geographic extension of the IIS network.

The need for geographical proximity (Herczeg et al., 2018; Jensen et al., 2011; Tseng and Bui, 2017) was introduced by Ehrenfeld and Gertler (1997), who stated that it reduces transportation costs and energy degradation in transit, but, also implies a sufficient materials supply from firms within the geographical proximity for the IS to be sustainable. To understand what is geographically proximate, Jensen et al. (2011) and Chen et al. (2012) used the distance of materials exchanged in IS projects in the UK and Japan, respectively. For Boons et al. (2011) proximity should facilitate coordination, knowledge and capacity sharing among firms, regional stakeholders, and society in general. In addition to distance, materials, capacity sharing and coordination in a regional context, Walls and Paquin (2015) considered that stakeholders' interdependence for resources and collective economic and environmental benefits is more likely in proximity. Thus, extending the IS geographical proximity should contribute to reduce transport costs per tonne, reduce negative transport externalities, improve the availability and quality of materials exchanges, improve the capacity sharing and coordination among stakeholders, and improve the overall economic, environmental, and social benefits.

However, there are challenges to further optimise IS networks. Participants in symbiotic networks need previous cooperative experience (Belussi and Caldari, 2008; Jensen, 2016); IS managers need to balance a firm's internal motivations and external incentives to boost the firms' motivations (Liu et al., 2019); complex mathematical optimisations are necessary to ensure the social benefits off-set potentially damaging individualistic behaviours (Bacudio et al., 2016); and IS managers need to coordinate multiple localities and regions' initiatives and incentives (Schwarz and Steininger, 1997).

Furthermore, while wider geographical extensions might require international cross-border operations, there are not enough investigations to inform IS managers about potential strategies or implications. For instance, there are IS comparisons between countries (Lombardi et al., 2012), and assessments of experiences of IS policy transfers between countries, for example from UK to China (Wang et. al., 2015). In addition there are reported differences in qualities and standards of exchanged waste between countries leading to substandard IS network performances (Prosman et al., 2017), and descriptions of how regulatory and incentives differences across countries and at various government levels, i.e. national versus EU, may hamper the long term sustainability of IS networks (Salmi et al., 2012), as well as studies about the importance of public programmes to boost market confidence on end products coming from international waste or recycled materials (Deutz et al., 2019). However, there are as yet no reported studies, to the best of our knowledge, of international industrial symbiosis networks (IIS) with a border and customs operations affecting the IS network's geographic extension.

This article describes the IIS network in the Italian and Swiss regions of Lombardy and Canton Ticino, respectively, with a symbiotic exchange of materials consisting of Switzerland importing virgin aggregates from Italy for its construction industry, and Italy importing from Switzerland construction and demolition waste (CDW) that is necessary for the environmental recovery of its quarries, and to meet the increasing demand for recycled construction material.

The reason for the environmental restoration or recovery of quarries is because if left unattended after exploitation, quarries can generate pressure, erosion, alterations, fragmentation, to landscapes, nature, habitats, and genetic resources (Semeraro et al., 2019).

There are three distinctive features of this IIS. Firstly, it started from the industrial needs on both sides of the border, and grew as a result of firms' internal motivations, with the external support of the Italian and Swiss governments being the only regulatory certainty required for the cross-border management of waste. Secondly, its materials flows are subject to cross-border and customs operations. Thirdly, there is an implicit coordination without central management of the IIS by the Swiss and Italian regional governments to promote the cross-border management of CDW with more sustainable transport strategies, such as better organised road transport, and road combined with rail transport (i.e. intermodal) for the international exchange of materials within the IIS.

These features are highlighted because, they seem to point towards a highly business driven process, rather than a purely ecological or environmental one. This being the case, this article will try to explain why it differs from the findings of Lüdeke-Freund et al., (2018) who describe industrial symbiosis adding more ecological than economic value.

An insight for the reader ahead is the heavily supply chain and logistics-oriented business model of the virgin aggregates and CDW (ACDW) in this IIS. The case in this article sheds light on the potential of implementing intermodal transport management of ACDW, its expected positive environmental effects, and its capacity to widen the IIS geographic extension. The case also takes into consideration the presence of cross-border and customs operations, administrative boundaries, and different regional and national public regulations and incentives.

The aim of the article is twofold. Firstly, to highlight the importance of assessing the contribution of transport to the overall industrial symbiosis' environmental impacts, rather than considering transport and its impacts as externally given variables. And secondly, to show policy and decision makers additional methods, and coordination experiences between different regional authorities, in assessing and managing an industrial symbiosis in more sustainable ways.

To achieve these aims, the rest of the article is structured as follows. The literature review section examines the importance of transport strategies, environmental and other externalities, and the geographic extension of an IS. The methods section presents the reasons for using the case study and key informant monitoring approaches, estimations, and scenarions. The results section describes the case study, the ACDW IIS system, estimations, scenarios, and cross-border regional authorities coordination. The discussion section, discusses the results in light of the previous literature, and is followed by conclusions.

2. Literature review

2.1. The importance of transport in the IS geographic extension

The materials discussed in this article are ACDW. Bain et al. (2010) indicate that the exchange of heavy waste with low market value compared to the transportation costs, tends to be constrained to small distances, and thus an IS of that type of low value material will generally occur in IS with small geographic reach (Bain et al., 2010). The authors of the present article discuss two interrelated dimensions and their environmental implications to the IS network, i.e. the IS geographic extension and the shifting transportation modes. Given that this case study, deals with the presence of an international border, we discuss what the literature has to say about the challenges in coordinating cross-border regulatory policies and incentives for managing IIS.

2.2. Geographic extension and externalities

The implications of an IS geographic extension using different transportation strategies, can be assessed with multiple methodological approaches. The Life Cycle Assessment (LCA) is typical in the IS literature because allows for evaluation of the environmental effects of different scenarios at IS network (Sokka et al., 2011), firm (Martin et al., 2015; Røyne et al., 2015), and meso or inter-systems levels (Mattila et al., 2012). The LCA generally looks at virgin resources, energy and fuel consumption, emissions of CO2, NO2, SO2, etc., comparing alternative materials and energy consumed, transportation modes, and IS distances (Pakarinen et al., 2010). The Materials Flow Analysis (MFA) is another common approach, used to evaluate CO2 emissions savings by recovering, reusing, and recycling materials in IS networks, such as the cases of Kawasaki's IS (Hashimoto et al., 2010), the cement industry's IS in Indonesia (Ulhasanah and Goto, 2012), or the IS with waste recovery of an Indian industrial area (Bain et al., 2010). It is worth noting that LCA and MFA tend to take as given the distance and transportation mode of suppliers of materials in the IS.

IS networks are expected to reduce environmental and transport externalities because they reorganise industries' supply chains to reduce materials flows prioritising suppliers within the IS network (Domenech et al., 2019), and they use waste (generated in proximity), that previously ended in landfills, as inputs of production, reducing the need for raw material, transportation and storage, and pollution in general (Cutaia et al., 2015).

Whilst in general the IS thrives in proximity, when the scale of the materials cycle increases, extending the IS geographic extension might be necessary; but it might come with additional positive and negative externalities. Analysing the growing scale of the Pfaffengrund industrial site, Sterr and Ott (2004) discussed how the IS was unable to meet its growing demand, leading to a search into the broader Rhine–Neckar region and inter-regionally. They identified positive externalities such as more and variegated actors, materials, growing scale, and new exchanges; they also found negative externalities such as higher transport, environmental and coordination costs, institutional mediation, need for mode infrastructure, and capacity building (Sterr and Ott, 2004). Thus, it would be safe to assume that a sustainable IS geographic extension, requires positive externalities offsetting the negative ones.

Furthermore, in the context of ports-IS networks, Schiller et al. (2014) discussed the limits of staying inside geographic boundaries, including land or location scarcity, environmental and infrastructural limits such as protected habitats, heavily utilised roads, or lack of sufficient rail systems. Thus, in line with Schiller et al. (2014), it is surprising how little attention the IS literature had paid to the opportunities offered by different transport infrastructures and modes to redefine boundaries and IS geographic extensions.

2.3. Transportation strategies and externalities

According to Ribeiro et al. (2018), the choice of transportation mode has an effect on the consolidation capacity of an IS. The authors studied the Industrial Park of Salaise-Sablons, and found that intermodal infrastructure (road, rail, harbour, and pipeline) was a good way to diversify access to materials, geographies, economies of scale, flexibility, and so on (Ribeiro et al., 2018). Thus, provided that changes in a network's economies of speed align dynamically with the network's supply and demand planning and scheduling (Fields, 2006; Kurbel, 2013), it is safe to assume that IS managers may prefer transportation systems that extend the reach and scope of the IS with lower negative externalities. Negative transport externalities consist of air pollution (i.e. Greenhouse Gas - GHG- emissions), water and soil pollution, congestion, noise, accidents, reduced public space, visual annoyance, etc. (Janic, 2007; Verhoef, 1994).

Transport also enables positive externalities when transportation and storage services deal with more and variegated materials for reuse and recycling into production and reach more sites (e.g. ceased quarry sites) in need of environmental recovery, as was shown in the flagship case of Kalundborg (Jacobsen, 2006). Other studies such as Martin, (2020) suggest similar findings, avoiding land-filling and disposal in old quarries.

Marcinkowski (2019) highlights the trade-offs between the benefits of covering wider areas to gain diversity in the materials exchange for IS participants, and the negative externalities associated with the longer transportation distance. In fact, it has been reported that maximum distances for materials exchanges in the UK's National Industrial Symbiosis Program (UK-NISP) vary substantially based on the material, such as soils with 139 km and paper & cardboard with 433 km (Jensen et al., 2011), and a recent study reported that, in general, exchanges may not exceed 108 km (van Ewijk et al., 2018). Another challenge is the access to high quality waste, which if sourced from long distances, may not offer the required standards, because waste produced in proximity is more likely to meet the local standards than waste produced in different markets, operational realities, and political administrative boundaries (Prosman et al., 2017).

The 'Protocollo CO.M.E.T.A' (ARPA Lombardia, 2016), an agreement between Canton Ticino and Lombardy to operationalise the cross-border movement of CDW, sets two types of standard for waste to meet; one regarding the presence of contaminants, and another regarding the suitability for operational proposes. The former standard sets limits on the dangerous contaminants present in waste. If the limits are exceeded the cargo is not allowed into Lombardy, either for environmental recovery or for CDW recycling for further use in the construction industry. The latter standard sets conditions to be respected for environmental restoration or recovery sites, or for recycling of the construction material. If the waste does not meet the characteristics in terms of resistance and granulometry for its use in the construction industry, it may only be authorised for environmental restoration (ARPA Lombardia, 2016).

According to Gentile et al. (2017), it is always good to have alternative waste management and sourcing options at hand; hence, assessment of negative transport externalities of either option should be performed. A typical measure of atmospheric emissions of freight is the CO_2 equivalent (CO_2e), an indicator of the relative warning potentials of carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) all together, associated with the provision and use of fuel (Quiros et al., 2017). This measure is commonly used to evaluate the sustainability of transport strategies by road, rail, air, or water. Eisted et al. (2009) showed that diesel trucks have the highest $kgCO_2e$ per tonnes of waste per kilometre, followed by ships, barges, and lastly by trains. Also The UK Government GHG Conversion Factors for Company Reporting in 2019, also showed similar trends (UK-BEIS, 2019).

Another typical measure used by transport economists is the application of monetary conversion factors to the negative transport externalities: External Costs of Transport (ECT). This method for instance was used to estimate the break-even point (distance at which rail transport is as competitive as road transport) of total direct and external costs of road versus intermodal freight in Belgium (Macharis et al., 2010). The main source of monetary costs estimates of transport externalities in Europe is the handbook of external costs of transport, 2019 version, which includes environmental and social costs, i.e. accidents, air pollution, climate change pollution (CO2e), noise, congestion, well-to-tank-emissions, and cost of habitat (van Essen et al., 2019).

Merchan et al. (2019) analysed when to use LCA or ECT to assess transport externalities, and they found that it depends on the outcome of the assessments. LCA is a suitable method to understand which are the most environmentally robust options, whilst, for evaluation and assessment of additional externalities such as accidents, road damage, congestion, noise, and habitat damage, ECT is more suitable (Merchan et al., 2019).

2.4. Challenges beyond the international boundaries

There are also governance issues for the sustainability of an IS. The Gulf Bothnia case is special, as it is the only international IS reported in the literature (Neves et al., 2019). Located in Sweden and Finland, this IS exchanges materials and energy, but in terms of recovery of waste materials in the IS, it reveals the hindrance of regulatory differences between nations and EU interpretations of waste regulations, rendering the long term sustainability of this IIS unpredictable (Salmi et al., 2012).

IS initiatives are likely to be sustainable and achieve resources efficiencies in the long term provided close working agreements are set up between normally unrelated industries or organisations across localities or regions (Jensen, 2016). Unfortunately, it has been found that such agreements are more likely to occur in pre-existing cooperative industrial districts (Belussi and Caldari, 2008).

Costa et al. (2010), stated that waste management requires multiple IS enabling instruments, including institutional, economic, regulatory and voluntary instruments. Institutional instruments are waste regulations and policies; economic instruments are taxes; regulatory instruments are bans and by-products specifications; and voluntary instruments are coordination programmes for resource efficiency (Costa et al., 2010).

For Velenturf et al. (2018), regulatory instruments at the regional level that are more likely to be an incentive to resource efficiencies, include: 1) taxes and tax breaks to mitigate waste production; 2) waste and environmental reporting for accurate dimensioning of the waste production and flows; 3) waste producer responsibility mechanisms to improve quality and quantity of waste production; 4) creation of blacklists, whitelists, and their externalities in economic value; 5) mandatory recycling regimes to improve quality and quantities of used recycled materials; and 6) laws and regulations to reduce the total waste production and promote reuse and recycling.

Velenturf et al. (2018) also recognise the differences across authorities in their preferences between incentives and regulations, or between the ‘carrot’ or the ‘stick’, or some combinations of both. In fact, Schwarz and Steininger (1997) have already pointed out that authorities in general prefer to incentivise waste reduction behaviour. However, their budgets often do not allow for that, leaving them with no choice but to regulate waste through disposal charges.

3. Methods

3.1. Case study research

This article presents the analysis of exploratory research in operational and managerial dimensions, like the complex social environments in case studies discussed in Yin (2018). The data and information were gathered from actors in the ACDW supply and demand networks. It followed a research process recommended for supply chain and operations management studies: case selection, data collection, data analysis, and validation (Stuart et al., 2002). As an exemplary case study investigation, the main guidelines and experiences were acquired from the operational data of Lombardy and Canton Ticino. The information gathered may be informative to all other regions with similar materials flows. In all cases, the data-gathering instrument was in-depth, face-to-face interviews with concept-indicator links to guide the interviews, as suggested in Phellas et al. (2011).

To triangulate information and converge towards a validation of the research findings, as in Turner et al. (2015), primary data were also obtained from public authorities at four governmental levels, i.e. communal, provincial, regional and national. Secondary data from public sources providing operational information regarding the specific industry activities reinforced the analytical process.

The research team included various regional and provincial territorial authorities, and industry stakeholders. For this, the research aligned to Price and Pokharel’s (2005) Key Informant Monitoring (KIM) approach. According to this approach authority representatives and industry stakeholders are Key Informant Researchers (KIRs), and information and data processors are Research Analysts (RAs). The KIM approach is a purist peer ethnographic method that registers narratives without filtering data through analytical frameworks, and ensures confidentiality of the KIRs’ identities (Hawkins and Price, 2002).

The KIM approach requires KIRs to provide or source information and data, to be handed to the RAs. The latter, analyse and elaborate reports and guidelines, submitted to the KIRs. They in turn, evaluate the results for potential implementations for their own duties (Price and Pokharel, 2005).

Our investigation, modifies the KIM approach to include various topics, such as the current and potential management of the transportation systems around the exchange of ACDW, the potential negative externalities effects, the feasibility from a business perspective, and the potential alignment of incentives or mechanisms across regions to support the sustainable and green development of this IIS. Without these topics, the RAs would find it difficult or too time - and resources - intensive to perform analyses and develop guidelines for KIRs.

RAs and KIRs are partners within the framework of the GeTRI research project. KIRs include border regional authorities of Switzerland and Italy: ‘Repubblica e Cantone Ticino’, and ‘Regione Lombardia’, respectively. These regional authorities are responsible for 1) granting export and import permits of CDW from and to their respective regions, 2) authorising the establishment of export platforms and recycling sites for CDW, and 3) implementing random controls and inspections of the CDW, of the export platforms in Canton Ticino, and of the environmental recovery or recycling sites in Italy. KIRs also include provincial authorities of Varese and Como, Italy, who are responsible for setting up 10-year quarry extraction and environmental restoration plans and permits in their respective provinces. KIRs also include rail transport industry partners, in charge of validating the business aspects that RAs' analyses produce.

In summary, all KIRs are responsible for regulating the full cross-border CDW management from Canton Ticino to Lombardy. This facilitated the data generation and analysis required for the understanding of the policy objectives, internal negotiations taking place, political, operational and budgetary constraints, etc, necessary for the description of the results section 4.6 related to the mechanisms and incentives for promoting the intermodal management of the ACDW IIS. In the next section we describe the case study.

3.2. Estimations and scenarios

3.2.1. External cost of transport and scenarios

In line with Merchan et al. (2019), one of the analyses RAs used was the ECT. This was due to the interest in local and regional sustainability impacts and policies by the KIRs. Using the handbook of external costs of transport 2019 version, RAs estimate the costs of accidents, air pollution, climate change pollution (CO_2e), noise, congestion, well-to-tank-emissions, and cost of habitat, which are estimated per heavy goods vehicle per km (van Essen et al., 2019). For robustness check, the analysis presents the GHG emissions (CO_2e) of rigid heavy goods vehicles ($>$ 17 tonnes), based on the UK Government GHG Conversion Factors for Company Reporting 2019 version (UK-BEIS, 2019).

In addition, three scenarios were evaluated, in the search for transport optimisation strategies for the IIS (based on full or empty return trips). This, according to Merchan et al. (2019), is compatible with the use of ECT. The first scenario, unbalanced, represents Business as Usual, where after material delivery either in Lombardy or Canton Ticino, the vehicle returns empty to its region of origin. The second scenario, semi-balanced, simulates a situation where 50% of the vehicles are reloaded after delivery of materials and before returning to the region of origin. The third scenario, balanced, simulates reloading of all vehicles before returning to their region of origin (see Table 2).

The latter scenario considers the fact that 16% of the trips (15,908 out of 99,317) are empty, because the trade flows of virgin aggregates from Lombardy to Canton Ticino are larger than the CDW trade flows from Canton Ticino to Lombardy. The same analysis was performed assuming materials exchanged by rail and is reported in the results section.

3.2.2. IIS Geographic extension and decreasing transport returns

Based on Gentile et al.'s (2017) advice to have alternative waste management and sourcing options at hand, and the likeliness of a potential closure of locations of materials exchanges within the IIS geographic boundaries, as explained in the results Section 4.4, RAs performed an estimation of the returns to road transport distance, assuming the necessity for an IIS geographic extension. Operational data were collected from KIRs and include cross-border logistics operations and the direct costs of transporting virgin aggregates from Lombardy to Canton Ticino. The analysis shows estimates of transported material, cost of transport, and transport plus material costs. These estimates are presented daily and are further split per tonne and per trip.

There are four geographic extension scenarios, ranging from 50 km to 150 km. The first being the current status. The returns to distance equation (Eq. 1) shows the change in daily total transportation volumes normalised by the daily total transportation costs from a based scenario. It reflects the extent to which an increase in the IIS geographic extension disproportionally lowers the capacity of the network to move daily material in relation to the reduction in the daily transport and materials cost due to lesser aggregates exchanged. It indicates the IIS reach of each scenario compared to the base scenario 50km (see Table 3).

$$\left(\frac{TonnesTransport_{x_{km}}}{TonnesTransport_{50_{km}}}\right) \Big/ \left(\frac{Transport{+}Aggregate\ €_{daily\ x_{km}}}{Transport{+}Aggregate\ €_{daily\ 50_{km}}}\right) \quad (1)$$

Where, $TonnesTransport_{xkm}$ represents the daily tonnes transported in scenarios 75km, 100km, and 150km, respectively; $TonnesTransport_{50km}$ represents the daily tonnes transported in the base scenario, 50km; $Transport + Aggregate_{€daily\ xkm}$ represents the daily cost of transport and materials in scenarios 75km, 100km, and 150km, respectively; and $Transport + Aggregate_{€daily\ 50km}$ represents the daily cost of transport and materials in the base scenario, 50km.

4. Results

4.1. The region of the Canton Ticino and Lombardy's ACDW IIS

The Canton Ticino and Lombardy are part of the Insubria Region cooperation community set up in 2015 (See Fig. 1). This community has a 'cross-border CDW management' Working Group, which oversees the coordination of mechanisms and incentives to reduce waste and improve its cross-border management at the same time. It also has a 'shift freight from road to rail' (i.e. Intermodality) Working Group, which oversees the coordination of mechanisms and incentives to reduce negative transport externalities along the border. These two groups declared their intention to set up cross-border waste management, shifting to rail incentives and agreeing to follow the guidelines established by the project 'Gestione transfrontaliera del trasporto di rifiuti inerti e degli inerti vergini in-

Fig. 1. Regio Insubrica. Source: https://www.regioinsubrica.org.

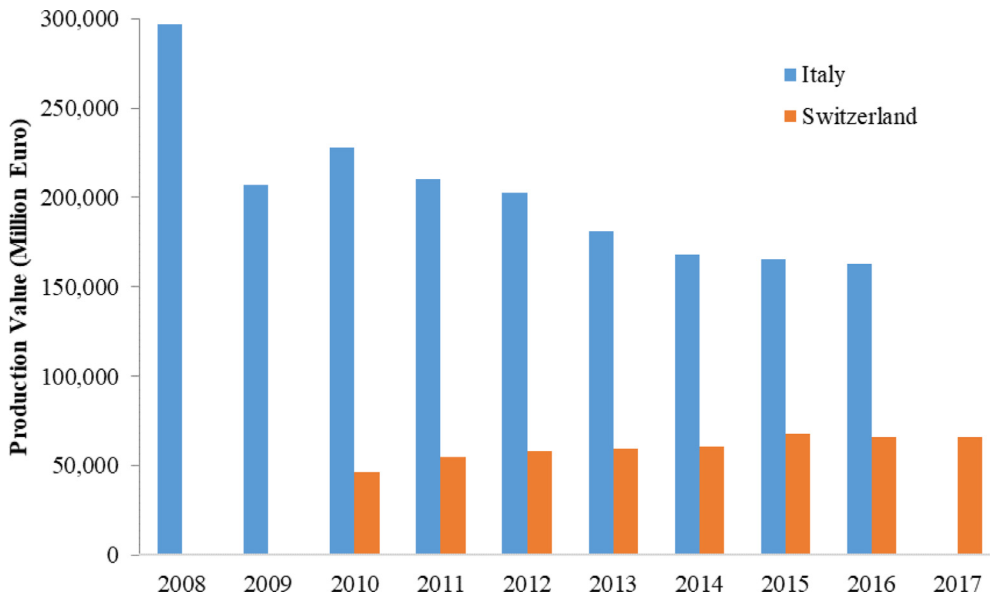

Fig. 2. Evolution of the production value of Italy and Switzerland's construction industry; 2008 – 2017, Million Euro. Source: Own elaboration based on Eurostat, 2019.

termodale – GeTRI', or Cross-border intermodal transport management of ACDW (Interreg V-A Italia-Svizzera, 2018).

4.2. The system of the ACDW IIS

The trade of ACDW between Lombardy and Canton Ticino is interrelated. Data shows that Italy's construction industry entered a decline in production after the financial crisis in 2007. Fig. 2 shows the total decline in production value was 54% from 2008 to 2016. On the other hand, Switzerland grew 42% from 2010 to 2017; and while in 2010 it was only equivalent to one fifth of the Italian construction industry, by 2017 it was equivalent to approximately half of the Italian construction industry (Fig. 2).

The trend described above, became the antecedent of the interdependency and development of the Canton Ticino – Lombardy ACDW IIS. Switzerland's growing CDW industry increased its demand for virgin aggregates and land-fill locations. Italy's declining CDW increased the need for environmental recovery of their quarries and an export market for their underutilised quarries, i.e. excess availability of virgin aggregate. It was in this context that the company 'Industria Ticinese Laterizia SA' located in Balerna, Canton Ticino, which was importing aggregates from Italy to supply the growing construction industry, started exporting CDW to Lombardy in 2010.

The exchange between Canton Ticino, Switzerland, and Lombardy, Italy, grew based on the increased scale and number of actors joining the exchange of material. Data obtained from the Swiss Customs, shows that in 2016 the exchange was 1.3 million tonnes, and in 2018 it reached 1.8 million tonnes, representing more than 35% growth (see Table 1).

This IIS can be described in four phases: a) the CDW industry in Canton Ticino produces waste; b) it ships to an export platform in Canton Ticino; c) the export platform takes full responsibility for the waste, and requests authorisation for special non-dangerous waste export from the Swiss Customs, and authorisation for special non-dangerous waste import from the Italian Customs, and authorisation for deposit in an environmental recovery or recycling site from the Lombardy region; d) upon authorisations and controls, the transport provider collects the CDW, performs cross-border operations, and delivers to the recycling or environmental restoration site. The logistics for the export of aggregates from Lombardy to Canton Ticino is very similar, and also carried out exclusively by road (Fig. 3).

4.3. Negative transport externalities and transport strategies of the ACDW IIS

The current transportation consists of single trips fully loaded from one side of the border to the other side for unloading and returning empty. In the current situation where 1.8 million tonnes of material is exchanged in this IIS, the estimated impact in terms of externalities is close to 8 thousand tonnes of CO_2e, with estimated external costs close to 4.2 million Euro (Table 2). Assuming an approximate market value of 15 euro per tonne of virgin aggregates, and 35 euro per tonne of CDW, the ACDW IS annual market value can be estimated at 39 million euro. This indicates that if the annual ECT is 4.2 million Euro, then ECT is equivalent to 11% of the ACDW market value.

Given that the KIRs look for solutions to reduce externalities, there are two additional optimization scenarios where impacts were estimated. The balanced scenario consists of all Swiss trucks transporting CDW to Lombardy's environmental restoration or recycling sites being later loaded with virgin aggregates in Lombardy to be transported to Canton Ticino for the construction industry. In this scenario, there are 33,900 trucks loaded with CDW, and 15,900 trucks returning empty from Canton Ticino to Lombardy. This scenario implies emissions of 5.3 thousand tonnes of CO_2e, with an estimated monetary externality cost of 2.5 million Euro; which represents a reduction of 33% in GHG emissions and a 40% reduction compared to the unbalanced scenario. A semi-balanced scenario was assessed with 50% of the CDW loaded onto the Italian trucks, which is equivalent to 24,900 trucks, with emissions totalling 6 thousand tonnes of CO_2e, and externality costs for almost 3 million euro (Table 2).

4.4. Negative effects of the geographic extension of the ACDW IIS

It was found that the mean distance of cross-border material exchange within the Canton Ticino & Lombardy IIS region is 50 km, with a maximum of 70 km. Beyond this distance, transport

Table 1
Canton Ticino cross-border shipments of aggregates and CDW with Italy; 2016 – 2018; tonnes (Own elaboration based on data provided by Swiss Customs).

Cantone Ticino cross-border trade with Italy (Mainly Lombardy)	2016	2017	2018
Canton Ticino Imports from Italy			
CN 25.17.1000 (Pebbles, gravel, broken or crushed stone, of a kind commonly used for concrete aggregates, for road metalling or for railway or other ballast, shingle and flint, whether or not heat-treated)	618,865	656,303	752,406
CN 25.05.9000 (Natural sands of all kinds, excluding Silica sands and quartz sands)	464,097	520,162	491,301
CN 25.05.1000 (Silica sands and quartz sands)	1,604	2,271	757
CN 25.30.9090 (Mineral substances not elsewhere specified or included, i.e. Demolition, sand, rocks)	1,189	992	674
CN 27.15.0000 (Bituminous mixtures based on natural asphalt, on natural bitumen, on petroleum bitumen, on mineral tar or on mineral tar pitch, for example, bituminous mastics, cut-backs)	120	175	67
CN 27.14.1000 (Bituminous or oil-shale and tar sands)		35	
Total import	**1,085,878**	**1,179,940**	**1,245,207**
Canton Ticino Exports to Italy			
CN 25.30.9090 (Mineral substances not elsewhere specified or included, i.e. Demolition, sand, rocks)	259,704	552,043	480,554
CN 38.25.1000 (Municipal Waste, i.e. Mixed waste)		6,685	95,037
CN 25.17.1000 (Pebbles, gravel, broken or crushed stone, of a kind commonly used for concrete aggregates, for road metalling or for railway or other ballast, shingle and flint, whether or not heat-treated)	77	57	676
CN 25.05.9000 (Natural sands of all kinds, excluding Silica sands and quartz sands)		6	24
CN 25.05.1000 (Silica sands and quartz sands)	1	11	15
Total export	**259,784**	**558,804**	**576,307**

Source: own elaboration based on Swiss Customs
[1]The C&DW classification were identified with the Combined Nomenclature for extraction of data from the Swiss Customs.

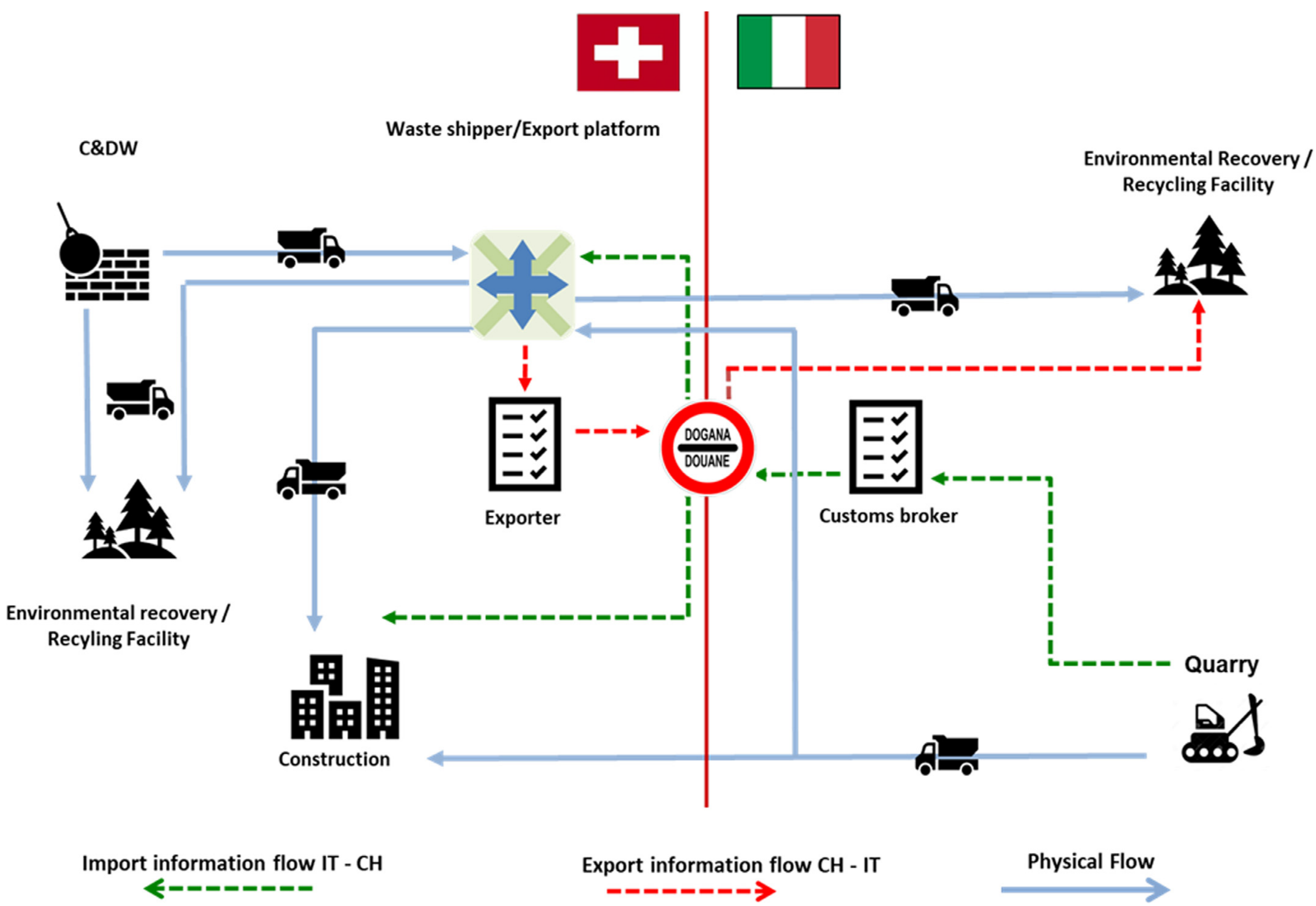

Fig. 3. Canton Ticino & Lombardy ACDW IIS. Source: Own elaboration based on KIRs data.

becomes unfeasible, both in terms of cost and operationality. For instance, at 75 km distance, the cost of transportation would be equal to the cost of virgin aggregate, 15 euro per tonne; and beyond that distance, the cost of transport is higher than the cost of materials (see Table 3).

Operationally, transportation services are usually hired daily, and the transport provider is expected to perform at least two to four trips daily to meet the demand of the construction industry and to allow trucks to drive through narrow streets in Canton Ticino. Extending the transportation range reduces the likelihood of

Table 2
External cost of transport and optimization scenarios in the Canton Ticino & Lombardy IIS.

Operational data	**Scenario 1 (Unbalanced)** Full delivery & Empty Return	**Scenario 2 (semi-balanced)** Trip IT-CH 100% full; Return CH-IT 50% full & 50% empty with CDW	**Scenario 3 (Balanced)** Trip IT-CH full; Return CH-IT full
Aggregates IT - CH (tonnes)	1,245,207	1,245,207	1,245,207
Tonnes loaded of aggregates per truck	25	25	25
CDW CH - IT (tonnes)	576,307		
50% return CH - IT with CDW (tonnes)		423,370	
Rest of trips CH - IT with CDW (tonnes)		152,937	
100% return CH - IT with CDW (tonnes)			576,307
Tonnes loaded of CDW per truck	17	17	17
km per trip	51	51	51
Unit ECT (€ per vehicle per km EU28 average)			
Accidents	0.155	0.155	0.155
Air pollutions (NH_3, NMVOC, SO_2, NO_X, $PM_{2.5}$, PM_{10})	0.094	0.094	0.094
Climate change pollutions ($CO_2e=CO_2+CH_4+N_2O$)	0.065	0.065	0.065
Noise	0.065	0.065	0.065
Congestion (Delays + deadweight)	0.069	0.069	0.069
Well-to-tank-emissions	0.025	0.025	0.025
Cost of habitat	0.024	0.024	0.024
Total ECT (€ per vehicle per km EU28 average)	0.497	0.497	0.497
Unit GHG emissions			
Tonnes CO_2e emissions per vehicle per km (Empty)	.000766	.000766	.000766
Tonnes CO_2e emissions per vehicle per km (100% loaded)	.001096	.001096	.001096
	Scenario 1		
Trips IT-CH full loaded with aggregates	49,808		
Empty return trips CH-IT	49,808		
Trips IT-CH empty for loading with CDW	33,900		
Full loaded trips CH-IT with CDW	33,900		
Total number of trips	**167,417**		
km full load trips IT-CH	2,540,222		
km empty return trips CH-IT	2,540,222		
km empty trips IT-CH	1,728,921		
km full return trips CH-IT	1,728,921		
Total km of transport	**8,538,287**		
		Scenario 2	
Trips IT-CH full loaded with aggregates		49,808	
50% return trips CH-IT fully loaded with CDW		24,904	
50% empty return trips CH-IT		24,904	
Trips IT-CH empty for loading with CDW		8,996	
Full loaded trips CH-IT with rest of CDW		8,996	
Total number of trips		**117,609**	
km full load trips IT-CH		2,540,222	
50% km return trips CH-IT fully loaded with CDW		1,270,111	
50% km return trips CH-IT empty		1,270,111	
km empty trips IT-CH for loading with CDW		458,810	
km trips CH-IT loaded with rest of CDW		458,810	
Total km of transport		**5,998,064**	
			Scenario 3
Trips IT-CH full loaded with aggregates			49,808
100% Full loaded trips CH-IT with CDW			33,900
Empty trips due to imbalanced exchange of ACDW			15,908
Total number of trips			**99,617**
km trips IT-CH fully loaded with aggregates			2,540,222
km 100% return trips CH-IT fully loaded with CDW			1,728,921
km empty trips due to imbalanced exchange of ACDW			811,301
Total km of transport			**5,080,445**
Accidents	1,323,434	929,700	787,469
Air pollutions (NH_3, NMVOC, SO_2, NO_X, $PM_{2.5}$, PM_{10})	800,891	562,618	476,546
Climate change pollutions ($CO_2e=CO_2+CH_4+N_2O$)	554,989	389,874	330,229
Noise	554,989	389,874	330,229
Congestion (Delays + deadweight)	588,288	413,267	350,043
Well-to-tank-emissions	213,457	149,952	127,011
Cost of habitat	204,919	143,954	121,931
Total ECT (€)	***4,240,967***	***2,979,239***	***2,523,457***
ECT expected avoidance relative to scenario 1 (%)		***30%***	***40%***
	7,950	***6,004***	***5,301***
GHG emissions (Tonnes CO_2e)		***24%***	***33%***
GHG expected avoidance relative to scenario 1 (%)			

Source: Own elaboration. Unit ECT based on van Essen et al. (2019). Unit GHG emissions based on (UK-BEIS, 2019).

Table 3
Decreasing road transport returns to distance in the ACDW IIS.

Transport operational assumptions		Transport cost assumptions	
Daily hr	8	Daily transport cost (€)	750
Unloading/loading time (hr)	0.5	Aggregate cost (€/tonne)	15
Border crossing (hr)	0.25	Tonnes per trip	25
Commercial transport speed (km/hr)	50		

Number of road transport deliveries by current and simulated average geographic extensions of the ACDW IIS								
Operations	50 km (current)		75 km		100 km		150 km	
	Hrs	Cum.Hrs	Hrs	Cum.Hrs	Hrs	Cum.Hrs	Hrs	Cum.Hrs
Load - IT	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Trip to CH	1.00	1.25	1.50	1.75	2.00	2.25	3.00	3.25
Cross-Border	0.25	1.50	0.25	2.00	0.25	2.50	0.25	3.50
Unload – CH (First daily delivery)	0.25	1.75	0.25	2.25	0.25	2.75	0.25	3.75
Return trip	1.00	2.75	1.50	3.75	2.00	4.75	3.00	6.75
Load – IT	0.25	3.00	0.25	4.00	0.25	5.00	0.25	7.00
Trip to CH	1.00	4.00	1.50	5.50	2.00	7.00	3.00	10.00
Cross-Border	0.25	4.25	0.25	5.75	0.25	7.25		
Unload - CH (Second daily delivery)	0.25	4.50	0.25	6.00	0.25	7.50		
Return trip	1.00	5.50	1.50	7.50	2.00	9.50		
Load – IT	0.25	5.75	0.25	7.75				
Trip to CH	1.00	6.75	1.50	9.25				
Cross-Border	0.25	7.00						
Unload - CH (Third daily delivery)	0.25	7.25						
Return trip	1.00	8.25						
Daily trips	3		2		2		1	

Road transport returns to distance (average geographic extension)				
Current and simulated geographic extension	50 km (current)	75 km	100 km	150 km
Cost per trip (daily transport cost/daily trips)	250	375	375	750
Total tonnes transported (tonnes per trip*daily trips)	75	50	50	25
Transport cost per tonne (daily transport cost/total tonnes transported)	10	15	15	30
Transport cost + Aggregate cost (€/tonne)	25	30	30	45
Transport cost + Aggregate cost (€/trip)	625	750	750	1125
Transport cost + Aggregate cost (€/day)	1875	1500	1500	1125
Returns to road transport distance	1.0	0.83	0.83	0.56

Source: Own elaboration. Road transport returns to distance estimated based on Eq. 1

performing two or three round trips a day, cutting it down to just one trip daily (see Table 3). To meet the Canton Ticino construction industry's daily demand, the longer distances travelled would imply the need for larger trucks to move more volume per trip; however, the geomorphological characteristics do not allow for this.

The Swiss customs administration data indicates that the municipality importing more aggregate in Canton Ticino is Balerna, near the Chiasso Switzerland border crossing. Following business and operational logics, i.e. maximum transport distance of 70 km, the Lombardy provinces able to supply Balerna are Varese, Como, Lecco, and Monza-Brianza. On the other hand, the second municipality importing in Canton Ticino is Manno. Following the same logics, the only Lombardy provinces able to supply Manno are Varese and Como.

There are several challenges with the latter situation according to reports from the KIRs. Firstly, the Varese and Como provinces, have their 10-year quarry exploitation plans expiring in the year 2020, which means that companies in the IIS would not be authorised to extract materials from quarries in these provinces nor to deposit waste in their environmental recovery sites. Companies in the IIS expect provincial authorities to grant extraordinary extensions to extract and deposit materials until new plans are approved. However, according to interviews with territorial administrations, the political processes and community involvement does not allow for certainty concerning the continuity of quarry and environmental recovery.

Alternatives include quarries located in other provinces in Lombardy that have the capacity and diversity of materials and sites for environmental recovery to sustain the IIS with Canton Ticino, those being Milan, Pavia, Bergamo, Brescia, Mantua, and Cremona. The challenge is how to make business and operational sense of this due to the distance thresholds involved. In fact, the most distant regions between Canton Ticino and Lombardy in terms of high volume and the capacity to produce aggregates and CDW are Cadenazzo, Switzerland and Mantua, Italy, which are 260 km apart.

As stated earlier, a key element for the exchange in the IIS is the limit posed by the transportation system. A solution for the diminishing road transport returns to distance (geographic extension of the ACDW IIS), as exemplified in Table 3, is the shift to intermodal transportation, which means road transport in the collection and delivery section to and from intermodal platforms, and rail transport between Canton Ticino and Lombardy.

4.5. Intermodal cross-border IIS geographic extension

Earlier it was discussed that it was safe to assume an IS with the lowest externalities would be preferred. A comparison of the estimated impact of materials exchange by road (Table 2), and rail, shows the following estimations. The exchanges of material under unbalanced and balanced scenarios, show estimates of CO_2e emissions of 7.9 and 5.3 thousand tonnes, respectively. The transport by rail for the same scenarios, unbalanced and balanced, show estimates of CO_2e emissions of 3.099 and 3.097 thousand tonnes, respectively. Thus, the change from unbalanced by road scenario to the balanced by rail scenario represents reductions of CO_2e emissions by 61%, and of ECT by 81%. In short, shifting material exchanges from road to rail potentially contributes to IIS geographic extensions with substantially fewer negative externalities. This is thanks to a reduction from 8.5 million km driven in the unbalanced road scenario, to 127 thousand km in the balanced rail scenario. However, the challenge is to set up the mechanisms to control the exchanges of ACDW and the shift to a more sustainable mode of transport.

4.6. Mechanisms and incentives for Intermodal Management of ACDW IIS

As discussed above, any IS with national or regional borders will need to coordinate the multiple regional authorities' mechanisms and incentives to promote sustainable behaviour in companies in the IIS, in accordance with their own practices and budgetary capabilities (Costa et al., 2010). The regional authorities of the Canton Ticino & Lombardy ACDW IIS have, in fact, different approaches, but they are now aligning with each other, even as this paper is being written. An assessment of sustainable solutions for the cross-border management of ACDW based on pilots, goes in line with previous experiences to improve economies of reach, scale and scope, such as in The Netherlands. The Netherlands did not need integrated strategies; several experimentations and pilots took place, all backed by a paradigm shift from all stakeholders towards sustainability. Furthermore, the key to improving their economies of reach has been designing rail systems with substantially increased capacity and with as many nodes as possible in and outside the country (Frantzeskaki and Loorbach, 2010).

In the case of the ACDW IIS, one of the KIRs, a regional authority from one side of the border, prioritises the use of regulatory mechanisms to manage the development and growth of the ACDW IIS by stressing the need for monitoring and traceability systems for the provision of information on origin, destination, and transportation routes of materials. This region's KIRs expect coordination across regions to strengthen the prevention of transportation and disposal of contaminated material, and CDW recycling. For the latter, they hope to encourage recycled aggregates by enforcing their use in higher shares in construction projects. Thus, there is a need for access to real-time monitoring and reliable information to enforce administrative penalties in case of non-compliance.

The other KIR, regional authority, expects to incentivise the ACDW IIS by means of investment in the intermodal exchange of materials across regions. The CDW producers and shippers themselves have, on several occasions, investigated the intermodal exchange of materials. One of the reasons for doing so is to reduce transport externalities and to extend the reach to variegated type and quality standards of the virgin aggregates sourced in Italy and the reach to variegated and quality standards of CDW sourced in Canton Ticino. Another reason is the need to have alternatives in the event of local community interventions to close quarries, recycling sites, export platforms, stockpiling sites, etc., locations which have always been highly contested both in Canton Ticino and Lombardy. The KIRs need a pilot to prove the techno-economic feasibility of intermodal management of ACDW.

Within the framework of the GeTRI project, which will inform the Regio Insubria's working groups on CDW and Intermodality, budgets and time to showcase solutions are limited. Therefore, normal tensions would exist between regions that need to promote appealing solutions to their constituencies. The alignment process involves KIRs and RAs finding a way to reallocate budgets in such a way that the expectations of CDW monitoring and traceability are assured while a pilot is set up to showcase the potential of intermodal management of ACDW. Thus, rather than only monitoring and tracing the full road transportation, it will monitor the last and first miles of the transport, which are carried out by road, and it will monitor the long-haul transport, which is carried out by rail. The monitoring of the latter transportation section is inexpensive, given that communication capabilities are widespread for rail operations. The reduction of costs in monitoring and traceability will fund the development of the intermodal pilot.

An additional mechanism to promote the intermodal management of ACDW in the IIS is the harmonisation and facilitation procedures for cross-border operations. It has been estimated that each truck spends 15 minutes at the border in queuing or customs operations. In one year there were approximately 167,417 trucks crossing the border (see scenario 1 in Table 2). Assuming a 15 minutes average waiting time for queuing or customs operations per crossing, there is a striking 4 years and 9 months of estimated waiting time. This is the social time that KIRs on both sides of the border are looking to eliminate with cross-border trade facilitation mechanisms based on rail transportation with pre-clearing or inspections at destinations.

5. Discussion

There are several results of our study worth discussing considering previous literature. Bain et al. (2010) state that heavy waste material with low market value in relation to the cost of transport, will tend to be exchanged in proximity. Similarly, Genc et al. (2019) discussed the fact that transportation costs makes long distances economically unfeasible for exchanges of low value wastes; hence colocation tends to be the solutions for many IS networks (Herczeg et al., 2018; Jensen et al., 2011; Tseng and Bui, 2017). Our study in principle agrees with these assessments; yet, we see geographic proximity not as an externally defined constraint, but rather as an endogenous variable in function of alternative transport strategies. We still consider the limits posed by each transport strategy, or by the availability and operational limitations of the transport infrastructures.

In fact, to increase the connectivity of an IS, Ribeiro et al. (2018) and Schiller et al. (2014) advise locating or developing near extensive and variegated infrastructure stocks. This reduces the need for colocation of non-industrial sites such as the ACDW, which in some cases may be unfeasible, as geological sites are unmovable. With variegated transport infrastructure, IS managers would be in a position to promote multiple transport strategies, depending on the value, sourcing place, weight, volume and frequency of the materials to be exchanged.

The investigation by Liu et al. (2019) in China, stressed the importance of balancing firms' internal and external motivations for the long term sustainability of IS networks. Our investigation shows the origin of the IIS was firms' identifying a business opportunity and exploiting it. However, the IIS growth currently seems to depend on firms' external motivations, as they expect intervention of their regional authorities for regulatory certainty, incentives in the form of either publicly managed or subsidised intermodal platforms for the cross-border exchange of materials, or transfers of tax incentives per tonnes of cross-border ACDW material transfer from road to rail, or trade facilitation mechanisms for preclearing of cross-border ACDW between Switzerland and Italy, or a combination of all those interventions.

The previous discussion of firms' motivations leads also to the characterisation of our IIS. Lüdeke-Freund et al. (2018) suggest that main sustainable business model of an Industrial Symbiosis is built upon ecological value adding, whilst our investigation suggest the opposite. The IIS is a private sector funded initiative with perhaps more economic value generation than ecological or environmental, judging by the ECT equivalent to 11% of the value of the IIS, not accounted for in any local environmental policy.

Our investigation showed how for KIRs, the cross-border management of ACDW needs to be based on accurate and reliable information on the regional and provincial generation of waste, by-products, and the availability and development of environmental recovery sites. Such results are in line with a study by Hou et al. (2019), who analysed resource production and allocation problems across firms in metallurgic industrial parks, and discovered the need for accurate and reliable information across regions. In our investigation, identifying inputs and outputs of production and recycling in the neighbouring regions are increasingly important and interdependent with the need to identify alternative transportation strategies for the IIS extension.

An additional point is the obstacle that transportation faces with the movement of special wastes, which, although they may be non-dangerous, can be subject to numerous administrative procedures and inspections before clearing, for example the transportation of iron, paper mill, and petrochemical cases described by Li et al. (2015). Similarly, the ACDW IIS case discussed in the results, shows that customs procedures and border operations can lead to high social costs, i.e. waiting time. According to the results presented regarding the international challenges of the IIS, the KIRs' requirements for promoting cross-border intermodal transport include: reduction of externalities, more reliable and accurate information and monitoring system for the traceability of ACDW in the IIS, and harmonization and simplification of customs procedures and border operations (i.e. cross-border trade facilitation).

A very relevant discussion is that of Schwarz and Steininger (1997) regarding the preferred instruments that public authorities may have to promote sustainable behaviour, and for which Velenturf et al. (2018) recognise differences in the preferences across authorities, some using incentives, others regulations, and others some combinations of both. Our investigation seems to suggest the combination of incentives and regulations to be the preferred instrument, or better still, the coordination of incentives and regulations between the different cross-border regions' authorities.

At the beginning of the collaboration, each KIR regional authority had their choice of instrument and, over the course of the project, their policy objectives evolved, finding themselves having to find common ground, combining incentives and regulations and coordinating their allocation of resources accordingly. In fact, it can be said that collaboration between the KIRs enabled the identification of coordinated policy instruments. This result relates to previous findings suggesting that IS require close working agreements between industries (Jensen, 2016), or industrial districts (Belussi and Caldari, 2008). As we can now say, it also requires collaboration and coordination between authorities at local and regional level, national or cross-border.

Finally, Merchan et al.'s (2019) advice to use alternative methods to assess externalities can be said to be a robust methodological guideline. We used the ECT (van Essen et al., 2019) and the UK Government GHG Conversion Factors for Company Reporting (UK-BEIS, 2019). But, more importantly, the results confirm that for local and regional environmental policies, the use of the ECT is method that has also strong communication power, it can easily convey a message about the extent of environmental implications of the IIS, and thus, identify and discuss in consequence the potential regulations or incentives required to address the problem at local or regional level, which is where negative transport externalities of the IS are felt.

6. Conclusions

The scenarios show potential strategies to address the limitations posed by the cross-border road transportation of ACDW. One possibility for cross-border management strategy is that of coordinating the logistics operations for balancing trade with reutilization of trucks for both import and export, which could potentially reduce CO_2e emissions substantially. Another potential strategy would be that of cross-border transportation by train, which may reduce emissions even more compared to the unbalanced scenario. It is expected that road balanced scenario 3, and the use of intermodal management of ACDW, may be applicable to other cross-border regions exchanging materials in IS fashion, provided the rail infrastructure is available and intermodal platforms for the management of aggregates and CDW are also available. It is important to know that externalities savings derived from any solution should be used to incentivise more sustainable ACDW, for instance, by funding the development of infrastructure, or by direct transfer to an operator deciding to follow the most sustainable IIS solutions.

The methodology used to identify the externality costs of the IIS, i.e. ECT, could be used to set up an internalisation of external cost mechanism to a degree that compensates investments in sustainable needs in other areas, allowing for a zero sum impact. Whatever scenario, it has substantial associated implications in terms of supply chain sustainable business models, which may shift the economic, environmental and social value added in the IIS.

To sum up, this article showed that the IIS geographic proximity is a manageable endogenous variable; that transport strategy can play an important role in the sustainability profile of an IIS, in other words, it may add substantial negative externalities to the IIS, or reduce them if the transport strategy is the correct one; and that when an international border gets in the way of the growth of an IS, it will be through collaboration and coordination between regional authorities, in addition to the cooperation of the industry that the IS might thrive.

This research used an innovative, adapted version of the KIM methodology, or peer ethnography method, by incorporating a framework to produce rich and clearly defined themes, which to the best of our knowledge has not been implemented before.

There are limitations to our work, such as the type of data we provided regarding estimates of emissions and externalities from intermodal platform to intermodal platform, rather than for the end to end supply chain, in other words, from the producer of waste in Switzerland to the landfill in Italy, and from the quarry site in Italy to the construction site in Switzerland. In addition, future steps should include estimations of the first and last mile distribution/transportation, i.e. from quarries to intermodal platforms in Italy, and from CDW sites production to intermodal platforms in Switzerland. The road transport sector is a very tight community and to gain access to the sector for reliable and first-hand data requires a long process of networking.

As is normal in case studies, we are not able to draw generalizable conclusions from this study, but we can offer a starting point for discussion that other collaborating regions may want to keep in mind if they are exploring the possibility of setting up an IIS. Nevertheless, the findings of this article are mostly aligned with previous literature, which indicates that although ours is a special case in the first IIS reported, it represents similar challenges to those of traditional IS networks.

Future research will include an ex-ante and ex-post assessment of the monitored and traced intermodal pilot management of the Canton Ticino & Lombardy's ACDW IIS, including direct, and external costs and benefits; and will include the LCA and the ECT methodologies. More importantly, it is the authors' hope that the IS research community will assess in future studies, and reassess previous investigations, regarding the share of transport in the overall IS environmental impacts, rather than consider it as a variable given. And, finally, the authors hope policy and decision makers are moved to further explore the additional methods and experiences of inter-regional authorities coordination, to assess impacts and manage industrial symbioses in more sustainable ways.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.spc.2020.09.004.

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