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STUDY PROTOCOL

REVISED Integrating regional dimensions into matchmaking frameworks for circular economy

[version 2; peer review: 1 approved, 1 approved with reservations]

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Abstract

Background

The circular economy is implemented at different levels from Urban Industrial Symbiosis to Hubs4Circularity proposing systemic solutions, integrating multiple regional stakeholders, and introducing a variety of operational models to different regional settings and sectoral needs. Previous work has been conducted within Horizon Europe projects, creating matchmaking frameworks that use multicriteria methods, mainly focusing on waste streams and stakeholder compatibility to create efficient collaboration and valorization paths. Most of these frameworks were dedicated to specific resources such as water, technical specialties and technological processes. However, to support Hubs4Circularity concept materialization, there is a need to align symbiosis synergies identification and implementation not only with technical aspects, but also with locality and spatial patterns, considering local strategies, economy, society, and authorities, using regional science methods.

Methods

This study focuses on the integration of regional settings and dimensions, including regional characteristics, spatial patterns, local and national strategies, resources and waste status, infrastructure and capacity, social, environmental, and economic status, and other special needs or local challenges -all these named as “Regional Scenery”- into the matchmaking framework. The collected information

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about the regions is translated into tables that encode them into quantitative parameters, so to prioritize the identified synergies according to their significance, value, and impact to each different area.

Results

The result is a detailed framework to prioritize all the identified symbiosis synergies, and therefore enable decision-making features for local industries, businesses, authorities, and policy makers according to regional needs and priorities. This framework will be validated via the digital platform of IS2H4C Horizon Europe project.

Conclusions

This research sets a baseline and creates a pathway for further specialization and improvements, by expanding this regional context, including more regional aspects and parameters, while maintaining an equilibrium between the quality of granular data and practical issues on availability of data.

Keywords
Urban industrial symbiosis, Circular Economy, Hub4Circularity, Regional, Matchmaking, Framework, Resources

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REVISED **Amendments from Version 1**

This revised version addresses the reviewers' comments by clarifying the study's objectives and methodological steps, strengthening its literature and regional-science foundations, and improving the explanation of the weighting, normalization and validation procedures. A worked example and minor technical corrections have also been included.

Any further responses from the reviewers can be found at the end of the article

Introduction

The circular economy is implemented at different levels through Industrial Symbiosis (IS), and in a broader way via Urban Industrial Symbiosis (UIS), which includes urban areas and their activities in symbiotic value chains, considering methodological, managerial, and other non-technological aspects. The Hubs4Circularity (H4C) concept emerges, proposing systemic solutions beyond environmental engineering, technical or specific, and limited non-technical aspects, by integrating local spatial aspects and multiple regional stakeholders and by introducing a variety of different operational models, owing to the different regional and sector settings and needs.[1] Previous work on identifying and facilitating IS and UIS synergies has been conducted, creating a matchmaking framework using multi-criteria methods, mainly focusing on waste stream types, treatment methods, and stakeholder compatibility, creating valorization matches[2] or other frameworks that are more specialized and dedicated to specific resources such as water and sludge.[3,4] The present framework complements these frameworks or tools already developed, it does not replace relevant technical and economic matching processes; instead, it provides a regional prioritization layer that re-orders technically feasible synergies according to regional resource profiles and environmental, social and economic priorities. Besides, IS and UIS depend not only on technical compatibility but also on institutional and relational conditions. Lack of information sharing, cooperation and trust are recognized as barriers to their implementation.[5] Digital matchmaking can reduce barriers related to information gathering and opportunity identification, but it cannot independently establish trust, contractual arrangements or enabling relevant governance models. To support the H4C concept and these institutional aspects, there is a need to align the UIS synergy identification and implementation with regional development strategies and relevant regional science methods. Thus, this work focuses on the integration of regional settings, including the region's local characteristics, strategies, resources, waste, and special requirements or challenges, called as "Regional Scenery" in this study, into the matchmaking framework. Specifically, this study aims to: (i) translate regional characteristics and strategic priorities into functional scoring parameters; (ii) use these parameters to reprioritize technically feasible synergies; (iii) demonstrate the approach in four regions. The main research question is how regional resources profiles and sustainability priorities can be incorporated into a reproducible digital matchmaking framework, used as a baseline decision-support approach for regions. This framework should be understood as decision support mechanism, rather than predictor of new synergies. The term region in this study is referred to Nomenclature of territorial units for statistics (NUTS) 2[6] level. As shown in Figure 1, the proposed framework comprises three levels: the development of a regional profile followed by two prioritization procedures applied to the identified synergies.

The proposed matchmaking framework is integrated into the IS2H4C project's central digital end-user platform as a separate functionality. All the aforementioned prerequired data of Level 1 regarding entities and their resources -input or output flows- will be collected upon the registration of the users within the platform and thus are considered as given. The regional data will be collected using a digital version of a proposed questionnaire which will be exposed as a mandatory action to the users at a certain point before using the matchmaking functionality. The questions concern a specific region; therefore, it is sufficient to be filled by at least one user that refers to this region, while other users -other organizations within the same region- can update, if necessary, the existing answers.

Level 1 regional scenery

Level 1 includes the collection of all the required data to operate the matchmaking and prioritization features. This includes basic information about the entities/industries such as domain activities (NACE), their input (raw materials) or output (waste, subproducts) flows in terms of quantity, quality seasonality etc., relevant services, or information about entity's maturity on UIS as displayed in previous frameworks.[2,3] This study builds upon previous research and goes

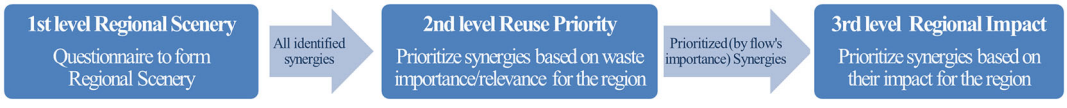

Figure 1. Integration of regional dimension in the matchmaking framework logic.

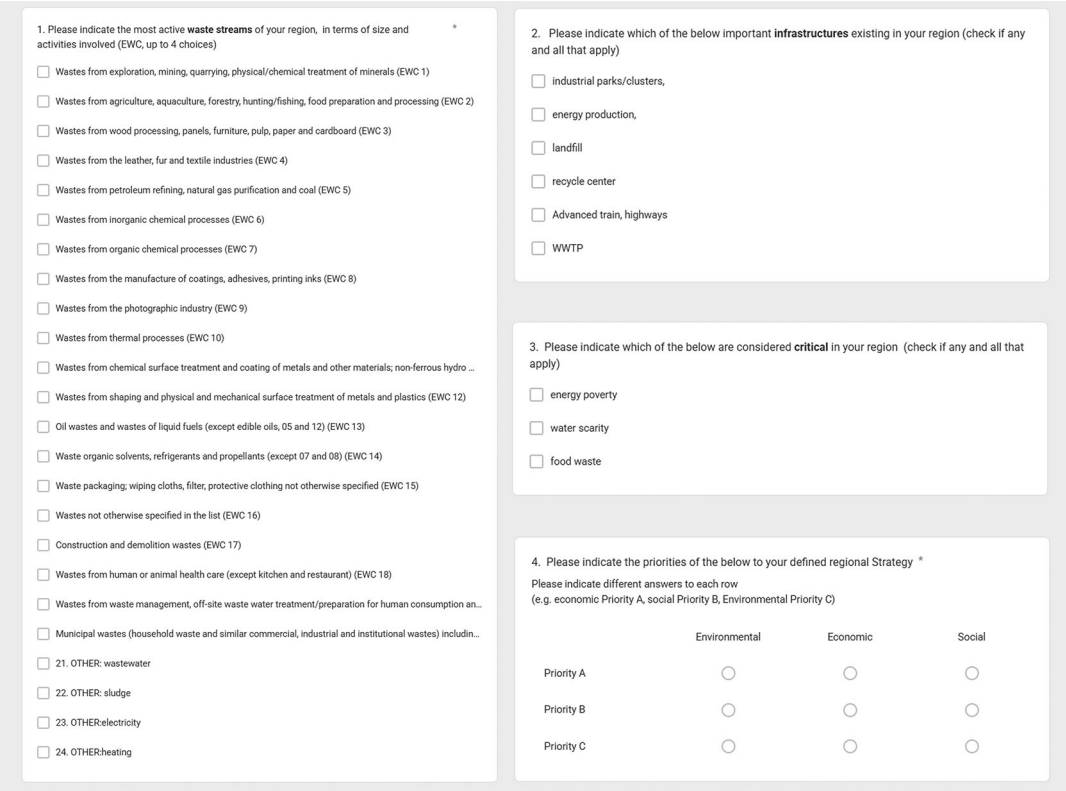

Figure 2. The regional questionnaire.

beyond them by adding the collection of regional data via the dedicated questionnaire (Figure 2) to transform this information into a regional profile, and especially two matrices that depict the regional scenery.

The questionnaire includes information related to:

I. Region type (coastal, non-coastal, island, predominantly rural, intermediate, predominantly urban).[7]

II. Most active waste flows in the region (based on EWC codes[8,9] enhanced with water and energy options).

III. Important infrastructure (e.g., energy production facility, landfill, recycling center, wastewater treatment plant (WWTP)).

IV. Critical resources (e.g. due to energy poverty, water scarcity, food waste).

V. Regional Strategy (Priorities on environmental, economic and social Aspects).

Regarding the three sustainability dimensions, the perceived difficulty of ranking the three dimensions was not formally assessed during this study. A comprehension and usability question can be added to the next validation processes.

The outcomes of Level 1: Based on the information collected through the questionnaire, two matrices are produced (Matrix A and Matrix B) depicting the regional scenery for each region studied, so they can be used in Level 2 and Level 3, respectively, for synergies scoring and relevant prioritization. **Matrix A** provides a quantitative representation of the scale and extent of the waste streams within the region, capturing their relative magnitude and spatial significance. **Matrix B** moves beyond size-based metrics and reflects the various effects generated by the proposed synergies within the region. **Based on the answers, the two matrices are automatically calculated and assigned for each region by the system**. The templates of the two matrices and the calculation rules are explained below.

Transforming questionnaire answers to scores and form Matrix A and Matrix B

Questionnaires' answers were transformed into weights and factors and gathered into two matrices. The purpose is to define and provide a baseline approach that touches the regional dimensions and transforms them into something concrete and exploitable in terms of a matchmaking framework that can potentially be implemented and executed via digital tools; thus, it must be expressed via concrete parameters. The main objective of this transformation is to understand where the focus should be on each region and to create a baseline for the prioritization of the identified potential synergies (matches).

Matrix A calculation rules

Matrix A as per Table 1 includes the exact values that are calculated based on the answers to the questionnaire for all regions to be included in each use case. Regions are identified mainly by NUTS2, and optional can be specialized to even smaller region classifications; thus, NUTS3 (NUTS2 region includes several NUTS3 regions).

Table 1. Template for Matrix A.

REGION'S NAME	-
NUTS2[6]	-
NUTS3 (if applicable)	-
COUNTRY	-
1. EWC1[9]	-
2. EWC2	-
3. EWC3	-
4. EWC4	-
5. EWC5	-
6. EWC6	-
7. EWC7	-
8. EWC8	-
9. EWC9	-
10. EWC10	-
11. EWC11	-
12. EWC12	-
13. EWC13	-
14. EWC14	-
15. EWC15	-
16. EWC16	-
17. EWC17	-
18. EWC18	-
19. EWC19	-
20. EWC20	-
21. WASTEWATER	-
22. SLUDGE	-
23. ELECTRICITY	-
24. HEATING	-

The detailed calculation rules for each of the regions are the below:

- The value 0.5 is set for all columns named 1 to 24 for that region.
- For each selected **Flow** in Question 1, the **value to 1.0**.
- Set **value to 1.0** (if not already) in cells 23,24 if energy poverty was selected question 3.
- Set **value to 1.0** (if not already) in cells 21,22 if water scarcity was selected question 3.
- Add values according to the following answers in question 2 as per Table 2.

For industrial parks/clusters and advanced trains, highway answers to question 2, the answers collected were not used for the current framework, but they will be used in future studies.

Matrix B calculation rules

Matrix B includes the exact values that are calculated based on the answers to the questionnaire for all regions to be included in each use case, as displayed in Table 3. Regions are again identified mainly by NUTS2, and optional can be specialized for NUTS3. The calculation rules for each region are based on the following Table 4, Table 5 and Table 6. It should be noted that factors X1, X2, X3, and X4 are considered environmental factors, whereas X5 is social and X6 is economic.

Based on the strategic priorities of Question 4, the initial values of the magnitudes of the factors are defined as follows: For example, if a region has Economic, Environmental and Social priorities (sorted in this order),

- X6 will be initiated to 1.0 as Economic is Priority A*.
- X1, X2, and X3 are set to 0.5, as environmental is priority B**.
- Finally, X5 is initiated at 0.4, as Social is priority C***.

Table 2. Question 2 extra values for Matrix A.

Answered selected	Value added if selected
Recycle center	+0.2 to cells 2,17,20
Energy production	+0.2 to cells 23,24
WWTP	+0.2 to cells 21,22

Table 3. Template for Matrix B.

REGION'S NAME	-
NUTS2[6]	-
NUTS3 (if applicable)	-
COUNTRY	-
ENERGY CONSUMPTION (X1)	-
RECLAIMED WATER (X2)	-
LANDFILL REDUCTION (X3)	-
GHG EMISSIONS (X4)	-
JOBS CREATED (X5)	-
GDP GROWTH (X6)	-

Table 4. Impact factor initiation according to strategy paths.

	Social	Economic	Environmental
Priority A	X5 =1.0	X6 =1.0 *	X1,2,3 = 0.8, X4 = 1.0
Priority B	X5 =0.7	X6 =0.7	X1,2,3 = 0.5, X4 = 0.7 **
Priority C	X5 =0.4 ***	X6 =0.4	X1,2,3 = 0.2, X4 = 0.4

Table 5. Impact factors type.

Impact Factor	Factor's magnitude	Type
Energy consumption (**X1**)	**F1**	Environmental (Energy)
Reclaimed water (**X2**)	**F2**	Environmental (Water)
Landfill reduction (**X3**)	**F3**	Environmental
GHG emissions (**X4**)	**F4**	Environmental
Jobs created (**X5**)	**F5**	Social
GDP growth (**X6**)	**F6**	Economic

Table 6. Questions 2 and 3 extra values for Matrix B.

Answered selected in question 2 and 3	Value added if selected
Recycle Center	+0.1 to X3
Energy Production	+0.1 to X1
WWTP	+0.1 to X2
Energy Poverty	+0.1 to X1
Water Scarcity	+0.1 to X2

X4, X5, and X6 are not further updated within the current framework; Equivalent and sufficiently reliable questionnaire proxies were not available for GHG emissions, employment and GDP growth at the time of this study. Further adjustments to these factors were therefore avoided to prevent unsupported assumptions and double counting.

This is also why X4, X5, X6 start slightly higher than environmental X1, X2, and X3, which will be further adjusted based on the answers selected in questions 2 and 3 that provide direct regional proxies for these dimensions, as displayed in Table 6.

Again, for industrial parks/clusters and advanced trains, highway answers to question 2, the answers collected were not used for the current framework, but they will be used in future studies.

For both Matrices, the rationale underlying these rules is to ensure that weight and factors' magnitudes values are around 0.5 and 1.0, while allowing individual elements to introduce modest adjustments to specific weights or factors' magnitudes without large deviations. The proposed rules establish baseline values that can be systematically refined through empirical validation. All these values are heuristic baseline parameters rather than empirically calibrated coefficients. Validation within IS2H4C and other projects could combine sensitivity analysis of the baseline values and increments with comparison against independent rankings produced by stakeholders and the results will be used to recalibrate the parameters.

Level 2 reuse priority – Matrix A – 1st prioritization process

The matching process requires the entities -industries, producers, suppliers etc.- input demands, output flows, EWC classifications, quantities, quality and seasonality information, geographical location, and potentially required treatment services. A potential synergy is generated when an output flow is compatible with another entity's input, either directly or through an available treatment or connection technology. The resulting entity–flow–technology combinations constitute the potential -technically compatible- synergies, subsequently prioritized by the regional framework.

In **Level 2** all potential synergies are identified by matching the input/output streams and services. For example, if a waste of an industry can be used as secondary raw material -directly or after a treatment (service)- of another industry, this is indicated as a potential synergy or "match." The exact matching method is beyond the current scope, and it has been analyzed in previous studies.[2,3] To meet the needs of this study, it is assumed that there is already a set of identified synergies (matches) that will be prioritized via levels 2 and 3.

This set of synergies is sorted based on Matrix A results within level 2, so the synergies involving value chains with greater weights will be ranked higher, indicating a higher reuse priority. Prioritization is based only on the calculated weighs indicating the "magnitude," or "capacity" or "importance" of waste streams **generally** in the region. Thus, if water (flow #21, Table 1) has greater weight than municipal waste (flow #20, Table 1) for a particular region, then the synergies related to water will be prioritized and visualized first.

Because of the way it is calculated, Matrix A is already normalized, quantifying the "importance" of the waste type for the region, regardless of the quantity and unit of measurement of each dedicated synergy identified.

Level 3 regional impact – Matrix B – 2nd prioritization process

Level 3 applies a second prioritization to the sorted list produced by Level 2. The total **regional impact factor** = sum (Xi*Fi) was calculated based on Matrix B, and the identified synergies were sorted based on this factor.

Fi (F1-F6) are the impact factors indicating the importance of the corresponding Xi (X1-X6), functioning in fact as weights, calculated automatically by the system from the answers of the questionnaire, and they are stored in Matrix B.

The Fi values, in many cases, can be directly calculated, such as energy consumption (X1), reclaimed water (X2), landfill reduction (X3), or jobs created (X5). In contrast, a complex parameter such as GHG emissions (X4) or GDP growth (X6) can be calculated via standardized and commonly accepted methods such as LCA methods and/or emission factors. Given that they will somehow be estimated, Xi values are normalized to ensure that all of them contribute equivalently (to the extent of their Fi values/weights) to the total regional impact factor, irrespective of their original units and scales.

Min–Max normalization will be used as the default method for each impact indicator across the candidate synergies: $Xi' = (Xi - \min Xi)/(\max Xi - \min Xi)$. When all potential synergies have the same value, the indicator will not differentiate their ranking and its normalized contribution will be set to zero. Z-score normalization will be examined as alternative.

Final double prioritization after level 2 and level 3

The result of this double prioritization in Levels 2 and 3 follows different approaches. A simple sequential prioritization in this case would be useless, as it could only be applied to synergies that have the same score within Level 2. The impact on the region is crucial in our field; therefore, it cannot be applied too narrowly. A scoring weighted total matrix is a better option; therefore, it is the proposed method. The total priority factor which will be the final and only criterion for the final prioritization, is calculated as $A \times w_A + B \times w_B$ (where w_A is the weight that expresses the extent to which A will be considered and w_B respectively the extent to which B will be considered τo the final prioritization) while:

- $w_A + w_B = 1$
- N are the identified synergies
- A = N for 1st synergy, A = N-1 for 2nd synergy, A = N-2 for 3rd synergy …. after prioritization of level 2
- B = N for 1st synergy, B = N-1 for 2nd synergy, B = N-2 for 3rd synergy …. after prioritization of level 3

A simple equally weighted approach ($w_A = 0,5$ and $w_B = 0,5$) can be proposed as an initial assumption, used as the default transparent scenario. However, it can be open and adaptable depending on the user's needs and scenarios. A higher w_A may be selected when resource availability and regional flow magnitude are the main decision criteria, whereas a higher w_B may be selected when strategic regional impacts dominate. The selected weights could be agreed by the relevant stakeholders along with different scenarios e.g. 0.25/0.75, 0.50/0.50, 0.75/0.25.

For example, as displayed in Table 7, if there are e.g. 5 identified synergies.

Table 7. Double prioritization example.

Synergy	Level 1 priority	A	Level 2 priority	B	Calculation	Total	Final priority
Synergy #1	1st	5	3rd	3	0,5 X 5+0,5 X 3	4	2nd
Synergy #2	2nd	4	2nd	5	0,5 X 4+0,5 X 5	4,5	1st
Synergy #3	3rd	3	1st	4	0,5 X 3+0,5 X 4	3,5	3rd
Synergy #4	4th	2	5th	1	0,5 X 2+0,5 X 1	1,5	4-5th
Synergy #5	5th	1	4th	2	0,5 X 1+0,5 X 2	1,5	4-5th

Demonstration of the framework in the four (4) hubs of IS2H4C project

To demonstrate the proposed framework, the questionnaire was shared with relevant partners to fill in the regions hosting the four IS2H4C hubs. For this demonstration, the questionnaire was shared via Google Forms,[10] as the digital platform has not yet been developed, and the answers are displayed in Table 8.

Table 8. IS24HC regions answers to regional questionnaire.

Region and country	1. Most active waste streams[9]	2. Important infrastructures	3. Criticalities	4. Strategic priority A	4. Strategic priority B	4. Strategic priority C
Basque Country	EWC3, EWC5, EWC20	industrial parks/ clusters, WWTP	-	Economic	Environmental	Social
Frankfurt Rhein Main	EWC7, EWC10, EWC19, EWC20	industrial parks/ clusters, energy production, recycle center, advanced trains, highways, WWTP	energy poverty	Economic	Environmental	Social
Izmir	EWC1, EWC5, EWC12, EWC19	industrial parks/ clusters, recycle center, WWTP	energy poverty, water scarcity	Economic	Environmental	Social
Overijssel	EWC2, EWC19, EWC20	industrial parks/ clusters, advanced trains, highways	energy poverty	Social	Environmental	Economic

Based on the formulation rules, the matrices for the regions in IS24HC are formed in Table 9.

Table 9. IS2H4C regions calculated Matrix A.

REGION'S NAME	Basque Country	Frankfurt Rhein Main	Izmir	Overijssel
NUTS2[6]	ES21	DE71	TR31	NL21
NUTS3 (if applicable)	-	DE712	-	-
COUNTRY	SPAIN	GERMANY	TURKEY	NEDERLANDS
1. EWC1[9]	**0,5**	**0,5**	**1,0**	**0,5**
2. EWC2	**0,5**	**0,7**	**0,7**	**1,0**
3. EWC3	**1,0**	**0,5**	**0,5**	**0,5**
4. EWC4	**0,5**	**0,5**	**0,5**	**0,5**
5. EWC5	**1,0**	**0,5**	**1,0**	**0,5**
6. EWC6	**0,5**	**0,5**	**0,5**	**0,5**
7. EWC7	**0,5**	**1,0**	**0,5**	**0,5**

Table 9. *Continued*

REGION'S NAME	Basque Country	Frankfurt Rhein Main	Izmir	Overijssel
8. EWC8	**0,5**	**0,5**	**0,5**	**0,5**
9. EWC9	**0,5**	**0,5**	**0,5**	**0,5**
10. EWC10	**0,5**	**1,0**	**0,5**	**0,5**
11. EWC11	**0,5**	**0,5**	**0,5**	**0,5**
12. EWC12	**0,5**	**0,5**	**1,0**	**0,5**
13. EWC13	**0,5**	**0,5**	**0,5**	**0,5**
14. EWC14	**0,5**	**0,5**	**0,5**	**0,5**
15. EWC15	**0,5**	**0,5**	**0,5**	**0,5**
16. EWC16	**0,5**	**0,5**	**0,5**	**0,5**
17. EWC17	**0,5**	**0,7**	**0,7**	**0,5**
18. EWC18	**0,5**	**0,5**	**0,5**	**0,5**
19. EWC19	**0,5**	**1,0**	**1,0**	**1,0**
20. EWC20	**1,0**	**1,2**	**0,7**	**1,0**
21. WASTEWATER	**0,7**	**0,7**	**1,2**	**0,5**
22. SLUDGE	**0,7**	**0,7**	**1,2**	**0,5**
23. ELECTRICITY	**0,5**	**1,2**	**1,0**	**1,0**
24. HEATING	**0,5**	**1,2**	**1,0**	**1,0**

Given the calculated matrix A of Table 9, the same potential synergies would have different priorities in each of the four regions. Indicatively:

- Municipal waste (20) synergies were of high priority in Frankfurt Rhein Main, but this was not the case for Izmir.
- Wastewater (21) synergies are of high priority in Izmir; however, this is not the case for Overijssel.
- Electricity (23) synergies are of high priority in Frankfurt Rhein Main, but this is not the case in Basque Country.

Correspondingly, different conclusions can be drawn from the calculated Matrix B in Table 10, according to the different impacts of the same synergies in the four regions. Indicatively:

- For Overijssel a synergy that contributes to job creation is of high priority.
- In Izmir, reclaimed water synergies are classified as slightly more important than landfill reduction.

Table 10. IS2H4C regions calculated Matrix B.

REGION'S NAME	Basque Country	Frankfurt Rhein Main	Izmir	Overijssel
NUTS2[6]	ES21	DE71	TR31	NL21
NUTS3 (if applicable)	-	DE712	-	-
COUNTRY	SPAIN	GERMANY	TURKEY	NEDERLANDS
Energy consumption (X1)	**0,5**	**0,7**	**0,6**	**0,6**
Reclaimed water (X2)	**0,6**	**0,6**	**0,7**	**0,5**
Landfill reduction (X3)	**0,5**	**0,6**	**0,6**	**0,5**
GHG emissions (X4)	**0,7**	**0,7**	**0,7**	**0,7**
Jobs created (X5)	**0,4**	**0,4**	**0,4**	**1,0**
GDP growth (X6)	**1,0**	**1,0**	**1,0**	**0,4**

As a worked example: all Basque Country Matrix B weights are first initialized from its priorities: Economic as priority A gives 1.0 to GDP growth, Environmental as priority B gives 0.5 to energy, water and landfill reduction and 0.7 to GHG reduction, while Social as priority C gives 0.4 to employment. The presence of a WWTP then adds 0.1 to reclaimed water, producing the final vector [0.5, 0.6, 0.5, 0.7, 0.4, 1.0] shown in Table 10.

Potential use cases of proposed matchmaking framework

The proposed regional matchmaking framework can be exploited mainly at the two user levels as follows:

Industry/organization perspective use case

User is a company representative e.g. process engineer, R&D manager, etc.

- Step 1: User registers and fills in the questionnaire for the region to which the organization belongs.
- Step 2: User fills in data for its resources/waste.
- Step 3: The user can search for recommendations of potential synergies based on their input(s)/output(s) waste/service(s). A list of all the "technical" feasible matches will be displayed, with a preliminary prioritization performed, based on the "magnitude" of the flows in the specific region (Level 2, Matrix A).
- Step 4: The user can request the calculation of the regional impact factor (Level 3, Matrix B) and have a relevant total prioritization of all available potential synergies resulting from Step 3.

Regional perspective use case

The user is a regional representative, for example, manager, government, and association. This case requires that at least some organizations in the region have already filled in data for their resources/waste/services (use case 1: Industry/Organizational level).

- Step 1: User registers and fills in data for the region user represents.
- Step 2: Users can search for recommendations for potential synergies between **all the companies within the region**, based on specific waste types or other criteria. A list of all the "technical" feasible matches is displayed, with a first prioritization performed, based on the "magnitude" of the flows in the specific region (Level 2, Matrix A).
- Step 3: The user can request the calculation of the regional impact factor (Level 3, Matrix B) and have a relevant total prioritization of all available potential synergies resulting from Step 3.

The difference here is that the user has an overview of all the potential synergies between **all the companies within the region** and makes decisions based on the total strategic regional criteria, not based on the interest of a specific company.

Discussion and conclusion

This study aims to introduce local and regional dimensions that enhance the matchmaking framework developed in previous studies to identify and pre-assess UIS synergies, so that they can be aligned and to support the systemic regional approach of Hubs4Circularity. The same synergies in terms of waste streams and technological aspects may have different priorities, results, and impacts in different regions that have their specific development strategies, regional settings, local characteristics, resources and waste, and special requirements and challenges. From a regional-science perspective, UIS is embedded in spatially specific infrastructure, institutions, markets, networks and socio-cultural conditions. Regional priorities consequently influence both the desirability and the implementability of potential synergies. The Regional Scenery operationalizes part of this territorial embeddedness by translating regional conditions and strategies into parameters used for prioritization, while complementing -but not replacing- technical assessment. To depict these different regional settings, two matrices were proposed, which were calculated for each region based on regional information retrieved by a relevant questionnaire, and they were used by the matchmaking framework to prioritize the recommendations of potential synergies. The proposed framework was demonstrated in four regions of the IS2H4C project.

There are several assumptions made and limitations in the proposed framework concerning the accuracy with which we approach regional factors, flow quantities, priority of uses, and other technical aspects such as the potential correlation and overlap of variables and prioritization between the different levels. Concerning the double prioritization attempted via Level 2 (Matrix A) and Level 3 (Matrix B), there are two main challenges: (1) If the weights have a wide range of different values, the prioritization may downgrade solutions that are much larger in volume/quantity than others; (2) the special case in which a specific resource has a small presence in a region may not necessarily indicate less importance of this flow, but the opposite, a criticality. Furthermore, there is extensive research on regional factors, including economic, environmental, and social aspects, as the three main dimensions of regional development that affect a region's status and development path.[11,12] This discussion, referring mainly to regional science, goes beyond the scope of this study, but at the same time creates great potential for future research to enhance the questionnaire approaching regional dynamics to a deeper and more accurate level. The aim of this study was to create a first simplified form setting a baseline, as an introduction of regional and local aspects to matchmaking frameworks; therefore, only some specific indicative and commonly recognized aspects related to resource and waste management, infrastructure, challenges, and strategy dimensions are taken into consideration.

Future research should clearly prioritize expanding this regional context while maintaining an equilibrium between the quality of granular data and practical issues (e.g., unavailability of data, resistance, challenges in depicting strategy aspects into parameters) to collect valuable information. The overall approach will be improved in terms of which parameters are considered and how the two matrices are calculated by further research and validation within the IS2H4C Horizon Europe project and other projects beyond. Additionally, there are several domains -beyond regional dimensions- that this study can be enhanced in future research, such as: (1) specializing and improving the double prioritization of the potential synergies; (2) considering the volume of the potential synergies as well beyond the prioritization of level 2, including comparison of flows' sizes using mapping between different units (applying normalization using Min–Max or Z-score, or transforming the commonly recognized units, tons for solid waste, m^3 for water, and kWh for energy to common equivalent units such as tons, or in the future based on a common output such as quantity per ton of produced product); (3) integrating the dimension of time (e.g., duration and exchange rate of the waste) and seasonality of resources.

Hub 4 Circularity is expanding IS and UIS beyond environmental engineering, integrating regional and social sciences into studies concerning circular transition. Local and regional dimensions are crucial for successful implementation, sustainability, and maximization of the impact of UIS synergies. The main purpose of this study is to define a baseline approach that touches these regional dimensions, transforms them into something concrete and exploitable in terms of digital tools, and creates a pathway for further specialization and improvements in this domain.

Ethics and consent

The four participants, upon answering the questionnaire, have checked the mandatory box of statement as "I understand and agree to the above" to consent text: "This form does not contain personal and sensitive data. The responses relate to regional data and will be used for research purposes and potential scientific publications related to synergies based on regional needs on I-US, under the project IS2H4C funded by EC. Data will be stored to online sheets. Users can request the data. Data will be available upon publication. Data do not contain sensitive and personal information. Answers are anonymous and refer to regions." No other ethical approval and consent were required.

Data and software availability

All data are under CC-BY 4.0 Creative Commons Attribution Only license (data available within the article as well as in 10.5281/zenodo.18670714[10] and 10.5281/zenodo.18679080[13]).

Extended data

The full questions and answers are already available within the article and especially in Table 8 IS24HC regions answers to regional questionnaire, as well as in 10.5281/zenodo.18670714.[10] The questionnaire is provided on 10.5281/zenodo.18679080.[13]

Annex (EWC and descriptions) is provided on 10.5281/zenodo.18712700[9]

Acknowledgements

This paper builds upon preliminary research previously presented at the 12th International Conference on Sustainable Solid Waste Management Paphos, Cyprus, 25–28 JUNE 2025 and published in conference proceedings.[14] The conference contribution reflected the submission of the initial draft abstract and was delivered as an oral presentation.

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✔ **Olcay Genc**
Bursa Uludag University, Nilufer, Turkey

I thank the authors for their revision of the protocol. Although the author response itself is brief, the changes made in the text address my previous comments point by point, as detailed below.

Rationale and objectives: The introduction now states explicit study aims and clearly formulated research question and clarifies that the framework is intended as a prioritization layer rather than a replacement for technical matching processes. This resolves my earlier concern about the objectives being only implicitly derivable from the narrative.

Study design: The weighting scheme for the final double prioritization (wA, wB) is now accompanied by operational guidance on when a departure from equal weighting would be warranted, including illustrative scenarios (0.25/0.75, 0.50/0.50, 0.75/0.25). This is a useful addition. I note, however, that the baseline values in Matrix A and Matrix B are still explicitly described as heuristic rather than empirically calibrated. The authors now acknowledge this directly and outline a validation approach (sensitivity analysis combined with comparison against independent stakeholder rankings), which is an appropriate way to frame this limitation in a study protocol, though the calibration itself remains future work.

Methodological detail for replication: The description of the matching process in Level 2 now specifies the required inputs (input/output flows, EWC classification, quantity, quality, seasonality, geographic location, and treatment compatibility), which gives readers unfamiliar with the referenced prior studies enough to follow the workflow. The choice of Min-Max normalization as the default method in Level 3 is now stated explicitly, with the treatment of the degenerate case (identical values across synergies) specified, and Z-score normalization is retained as an alternative for future testing. The rationale for leaving X4, X5, and X6 unadjusted, namely the lack of reliable questionnaire-based proxies for GHG emissions, employment, and GDP growth at this stage, is now given directly rather than left implicit. These additions substantially improve the reproducibility of the described procedure.

Data presentation: The addition of a worked example for the Basque Country region, tracing the

calculation from the stated strategic priorities and the WWTP infrastructure answer through to the final Matrix B vector reported in Table 10, addresses my request for a step-by-step demonstration. I checked the arithmetic against Tables 4 and 6 and confirm it is internally consistent with the reported result.
Overall, my previous concerns have been substantively addressed in the revised text.

My one remaining reservation concerns the empirical grounding of the baseline parameter values, which the authors now openly characterize as provisional and subject to future validation; I consider this an acceptable limitation for a study protocol rather than a barrier to approval, provided it continues to be flagged as such in any subsequent publication reporting validation results.

I have no further comments.

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: Circular economy, industrial symbiosis, industrial ecology, sustainability, bio-inspired design, construction management

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard.

Version 1

Reviewer Report 03 July 2026

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?

Johan Berg Pettersen
Industrial Ecology Programme, NTNU, Trondheim, Norway

The paper outlines a simple procedure to identify industrial symbiosis opportunities on local-to-regional level using standard classification of sector activity and waste, supported by stated local priorities concerning economical, environmental and social dimensions. The procedure includes routines to register market or connection technologies for realization of IS. The procedure is survey-based and the paper illustrates possible uses for four concrete locations.

The paper acknowledges that the procedure does not replace mapping of resource, energy or service flows, as steps to identify IS opportunities. Moreover, it states that certain local considerations – such as missing flows rather than presence of waste flows - may not be properly reflected.

The paper mentions some existing examples of sector- or challenge-specific matchmaking tools. It is quite short in introducing the relevant literature on IS generally, and on IS matchmaking, and does not discuss whether lack of such matchmaking tools is likely to offer more IS cases. Surveys like these would allow more IS if they allow actors to overcome barriers for information sharing, as trust and culture for sharing are known barriers for IS, as discussed for instance in the following reference: https://onlinelibrary.wiley.com/doi/abs/10.1111/jiec.12159

There is also work from the same author where it would be useful for context to describe how the procedure in this paper supplements or extends existing approaches: https://www.frontiersin.org/journals/chemical-engineering/articles/10.3389/fceng.2024.1363888/full

The survey-based approach does allow consideration of local and regional priorities as guides to identify and rank IS options. It would be recommended to review the survey and deepen the discussion of criteria that may, or may not, be relevant on local scale, for governance actors and Hubs4Circularity actors. As an example, the current “sustainability” dimensions in Figure 2 include three main pillars without any further details. It would be interesting to hear the answer from the four respondents if they found it difficult to rank the, as the three dimensions likely need some more information and context. E.g., social aspects are difficult to interpret for anyone answering, and probably harder to interpret for the user of the survey outcomes. It would be advised to supplement the question with some guide on possible aspects within each of the three dimensions, for instance “social” could be social entrepreneurship (for construction material reuse, or textile sorting and resale), or social labor aspects of construction (low salary, right to organize, work conditions...).

The paper mentions very briefly that “ there is a need to align the UIS synergy identification and implementation with regional development strategies and relevant regional science methods.” There is a large gap in the IS literature in placing the concept more into social science and considering IS not only as a technical concept but as a generic approach that should be adapted to local ecological, societal/cultural and business-ecosystem setting. Here, "regional science" should have insights to offer for UIS development.

Is the rationale for, and objectives of, the study clearly described?

Yes

Is the study design appropriate for the research question?

Partly

Are sufficient details of the methods provided to allow replication by others?

Yes

Are the datasets clearly presented in a useable and accessible format?

Yes

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: Industrial ecology methods (environmental systems analysis) and concepts.

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard, however I have significant reservations, as outlined above.

Author Response 03 Sep 2026

Charalampos Manousiadis

We sincerely thank the reviewer for the valuable comments. The revised manuscript strengthens the literature review and regional-science contribution and clarifies the role and limitations of digital matchmaking. We also acknowledge that the perceived difficulty of ranking the sustainability dimensions was not formally assessed in this initial demonstration; this limitation is now explicitly stated, and its assessment is included in the planned validation process.

Competing Interests: No competing interests were disclosed.

Reviewer Report 13 June 2026

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?

Olcay Genc
Bursa Uludag University, Nilufer, Turkey

Thank you for the study protocol entitled " **Integrating regional dimensions into matchmaking frameworks for circular economy**". My comments, suggestions, and views on this article are as follows:

Summary: The study protocol proposes a framework for integrating regional dimensions into existing matchmaking frameworks developed for urban industrial symbiosis within the Hubs4Circularity concept. The authors introduce the notion of "Regional Scenery," encompassing regional characteristics, spatial patterns, infrastructure, resource and waste status, and strategic priorities, and translate this information into two quantitative matrices through a dedicated questionnaire. These matrices are subsequently used in a three-level prioritization process that ranks identified symbiosis synergies first by their relevance to regional waste stream magnitudes and then by their broader regional impact across environmental, social, and economic dimensions. The framework is demonstrated across four hub regions of the IS2H4C Horizon Europe project, with the intention of being validated through the project's digital platform upon its completion. The study positions itself as a baseline contribution, acknowledging its current limitations and identifying several directions for future refinement and expansion.

1. **Is the rationale for, and objectives of, the study clearly described?**

-The rationale for the study is generally discernible from the Introduction section, where the authors identify the gap between existing matchmaking frameworks and the need to incorporate regional dimensions into the Hubs4Circularity concept. However, the connection between this gap and the specific objectives of the study is stated in a somewhat implicit manner rather than being formulated as explicit research objectives or research questions. The article would benefit from a clearly delineated objective statement that specifies what the study sets out to achieve, what the proposed framework is intended to accomplish, and under what conditions it is expected to operate.

-The Introduction also conflates background narrative with methodological description in places, which weakens the clarity of the rationale. The reader is introduced to the concept of Regional Scenery and the three-level framework structure before the justification for why such an approach is necessary has been fully established. Restructuring the Introduction so that the gap in knowledge is more thoroughly argued prior to the presentation of the proposed solution would strengthen the overall logical flow and make the rationale more convincing.

2. Is the study design appropriate for the research question?

The study sets out to integrate regional dimensions into an existing matchmaking framework for urban industrial symbiosis, and the overall design, comprising a three-level structure of regional profiling, waste stream prioritization, and regional impact assessment, is broadly appropriate for this purpose. The use of a questionnaire-based data collection instrument combined with matrix-encoded quantitative parameters is a reasonable approach for translating qualitative regional characteristics into operationalizable inputs for a digital matchmaking platform.

- Several design choices are insufficiently justified. The assignment of baseline values in Matrix A and Matrix B, such as the default value of 0.5 for all waste stream columns or the incremental adjustments of 0.1 and 0.2 for specific infrastructure answers, is accompanied by a general rationale aimed at keeping weight and factor magnitude values within a bounded range. However, this rationale remains at a descriptive level and is not grounded in theoretical reasoning or prior empirical evidence from the literature. The authors acknowledge that these rules are intended to establish baseline values to be refined through empirical validation, yet no validation plan is described within this protocol. For a study protocol, it would be expected that the proposed validation procedure, including the criteria for success, the data to be collected through the IS2H4C digital platform, and the analytical approach to be applied, is laid out with sufficient specificity to allow the reader to assess whether the design is capable of testing the framework's effectiveness.

- the double prioritization mechanism combining Level 2 and Level 3 outputs through a weighted total matrix introduces a degree of methodological complexity that warrants more explicit justification. The authors acknowledge that the equal weights assumption (wA = wB = 0.5) serves as an initial approximation and that the scheme is adaptable to user needs and scenarios, as also illustrated in Table 7. However, beyond this general acknowledgment, the protocol does not provide operational guidance on how alternative weighting schemes would be evaluated or selected in practice. for example, under what regional conditions or decision contexts a departure from equal weighting would be warranted, and by what criteria such a choice would be made.

Addressing this gap would considerably strengthen the alignment between the study design and its stated objectives.

3. Are sufficient details of the methods provided to allow replication by others?

The article provides a relatively detailed account of the two matrices and their calculation rules, and the inclusion of the questionnaire template, matrix templates, and demonstration tables for the four IS2H4C hub regions is a meaningful step toward transparency and replicability. The availability of supplementary data via Zenodo is also commendable and consistent with open research principles.However, several methodological aspects remain insufficiently specified for independent replication.

-Normalization procedure applied to the Xi values in Level 3 is described only in general terms, with Min-Max and Z-score normalization mentioned as possible options without a clear indication of which method is to be adopted, under what conditions each would be preferred, or how the choice would affect the final prioritization outcome. Given that normalization directly determines the relative contribution of each impact factor to the total regional impact score, this ambiguity represents a meaningful gap in the methodological description.

-Similarly, the exact matching method used to identify potential synergies in Level 2 is explicitly noted as being beyond the current scope, with the reader referred to prior studies. While this is understandable given the incremental nature of the work, the protocol would benefit from at least a concise operational description of the inputs required for the matching process and the form in which these inputs are expected to be available, so that a reader unfamiliar with the referenced prior studies can follow the full workflow without interruption.

- The calculation rules for Matrix B also merit further clarification. The authors note that X4, X5, and X6 are not further updated within the current framework and explain that this is why their initial values are set slightly higher than those of X1, X2, and X3, which receive additional increments based on questionnaire responses. While this partial explanation is noted, the underlying rationale for why X4, X5, and X6 are treated differently in the first place, that is, why these particular factors are not subject to further adjustment based on regional inputs, is not sufficiently elaborated. A brief justification of this design choice, grounded either in the literature or in practical considerations related to data availability and measurability, would improve the methodological transparency of the protocol.

4. Are the datasets clearly presented in a useable and accessible format?

The article performs reasonably well in this regard. The questionnaire responses for the four IS2H4C hub regions are presented directly within the article body in Table 8, and the calculated outputs of Matrix A and Matrix B are provided in Tables 9 and 10 respectively, making the demonstration data immediately accessible to the reader without requiring retrieval from external sources. The decision to embed this information within the article rather than relegating it entirely to supplementary repositories is appropriate for a study protocol of this nature, as it allows the reader to follow the demonstration without interruption. The Zenodo deposits referenced throughout the article further support accessibility, covering the regional questionnaire, the questionnaire responses, and the EWC annex. The assignment of DOIs to these datasets and the statement that data are available under a CC-BY 4.0 license are consistent with open data

principles and the data policy of Open Research Europe.

-One area warranting attention concerns the presentation of the calculation rules themselves. While the rules for deriving Matrix A and Matrix B values from questionnaire responses are described in the text and supported by Tables 2, 4, 5, and 6, there is no worked example that traces a single region's questionnaire answers through each calculation step to arrive at the final matrix values shown in Tables 9 and 10. Including such a worked example, even for one region, would substantially improve the usability of the framework for readers who may wish to apply or adapt it independently. Without this, the tables presenting the final matrix values function more as demonstration outputs than as fully reproducible results, which somewhat limits the practical accessibility of the data as presented.

Is the rationale for, and objectives of, the study clearly described?
Partly

Is the study design appropriate for the research question?
Partly

Are sufficient details of the methods provided to allow replication by others?
Partly

Are the datasets clearly presented in a useable and accessible format?
Partly

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: Circular economy, industrial symbiosis, industrial ecology, sustainability, bio-inspired design, construction management

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard, however I have significant reservations, as outlined above.

Author Response 03 Sep 2026

Charalampos Manousiadis

We sincerely thank the reviewer for the constructive comments. The manuscript has been revised to clarify its objectives and methodological steps, including the matching process, weighting, normalization and validation procedures. A worked example and relevant technical corrections have also been added.

Competing Interests: No competing interests were disclosed.