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Supplementary Material for the Paper: The Facility Location Problem from the Perspective of Triple Bottom Line Accounting of Sustainability

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In this supplementary material, we provide detailed discussion of the 3S validation process, the data values including the references for the data that we used in the case study, and the notation for model and paper characteristics we used in main manuscript.

1. 3S Validation Process

The 3S validation process includes self, scientific and social validation stages that employ the same process. The process is based on a questionnaire including three aspects: the *conceptual coherence* which emphasizes on relations between the indicator and environmental/social quality, the *operational coherence* which assesses the definition of internal operations of the measuring instrument, and the *utility indicator* to nvestigate the applicability of indicator in impact assessment. Figure 1 shows the criteria of each coherence. The validation core is defined as a multi-criteria multi-expert decision problem. Table 1 shows the questionnaire based on three coherences. A value for each question is assigned using the Likert scale showing how much the respondent agrees the indicator's synthesis with the criteria. Likert scale is shown in Table 2.

Table 1.: Questionnaire for the evaluation of indicators.

Conceptual coherence
1.The definition of the indicator and the concepts that comprise it up is suitable.
2.There is a biunivocal correspondence between the indicator and the factor to be quantified.
3.The interpretation and meaning of the indicator are suitable.
Operational coherence
1.The mathematical formulation of the indicator is suitable with regard to the concept which is to be quantified.
2.The data used to establish the indicator and its units are suitable.
3.The proposed measurement procedures to obtain the indicator are suitable, allowing for its reproduction and comparison.
4.The indicator accuracy is suitable to quantify the factor and it is sensitive to changes in the latter.
Utility indicator
1.The indicator reliability is suitable.
2.The reliability of the source of data which the indicator is made up of is suitable.
3.The accessibility to the data and the applicability of the indicator are suitable.
4.The information provided by the indicator may be catalogued as reliable.
5.The cost of the information offered by the indicator can be considered acceptable.

Once all the individual evaluations are collected, their mean for each coherence criteria is considered as a measure of the group evaluation tendency, and the resultant standard deviation is a measure of

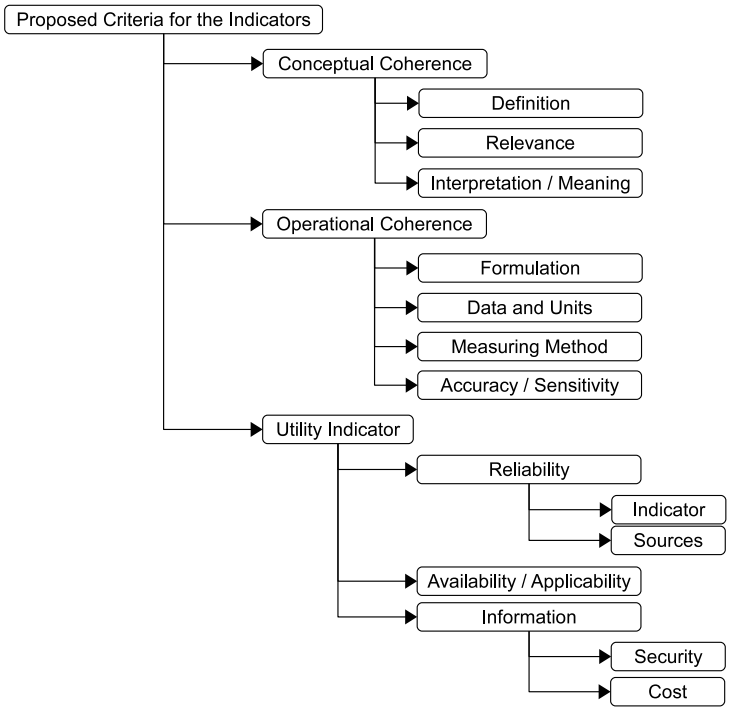

Figure 1.: Validation coherences

Table 2.: Likert scale to assess the criteria

1	Totally disagree
2	Disagree
3	Neither disagree nor agree
4	Agree
5	Totally agree

the group evaluation dispersion according to Noghin (1997). When the mean and variance of each criteria are available, the value of their criteria are integrated using their weigh in order to calculate each coherence value of the indicator. The AHP method (Saaty 1990) based on pairwise comparison is used to determine the suitable weight to criteria and then to each coherence. The pairwise comparison table is shown in Table 3 that is based on the 1-9 scale. Once the values of each coherence is available, they are aggregated to calculate the value of the indicator. The aggregation is done using the weighted sum method.

Table 3.: Binary comparison between criteria of the same hierarchy branch

Binary comparison value	Description $(\forall i, j, k, l)$
1	I consider the $C_{i,j}$ criterion to be equally important to the $C_{k,l}$ criterion
3	I consider the $C_{i,j}$ criterion to be slightly more important than the $C_{k,l}$ criterion
5	I consider the $C_{i,j}$ criterion to be more important than the $C_{k,l}$ criterion
7	I consider the $C_{i,j}$ criterion to be considerably more important than the $C_{k,l}$ criterion
9	I consider the $C_{i,j}$ criterion to be absolutely more important than the $C_{k,l}$ criterion

The indicator is defined as 'validated' if it is higher than the threshold, otherwise they are returned back to redesigned level. The validation results for the social parameters by the scientific-validation is shown in the Table 4. The validation results for the social parameters by the scientific-validation is shown in the Table 5.

Table 4.: The scientific-validation results for the social parameters

		Weight	Job opportunity		Development rate		Land availability		Water availability		Healthcare level		Security level		Education level	
			mean	variance	mean	variance	mean	variance	mean	variance	mean	variance	mean	variance	mean	variance
Conceptual Coherence	Definition	0.33	4.92	0.1	4.9	0.12	4.8	0.15	4.5	0.16	4.55	0.19	4.9	0.2	4.6	0.23
	Relevance	0.31	4.55	0.24	4.8	0.16	4.89	0.1	4.98	0.17	4.58	0.23	4.6	0.17	4.56	0.2
	Interpretation/meaning	0.36	4.89	0.26	4.54	0.18	5	0.16	4.54	0.2	4.7	0.22	4.92	0.25	4.51	0.22
Conceptual coherence total			4.79		4.72		4.89		4.65		4.62		4.81		4.55	
Operation coherence	Formulation	0.25	4.91	0.2	4.41	0.21	4.87	0.23	5	0.19	4.6	0.2	4.8	0.28	4.55	0.16
	Data and units	0.21	4.4	0.11	4.49	0.09	4.5	0.2	4	0.05	4.2	0.06	4.9	0.12	4.9	0.15
	Measuring method	0.27	4.52	0.2	4	0.09	4.7	0.12	4.54	0.1	4.54	0.18	4.63	0.2	4.54	0.21
	Sensitivity accuracy	0.27	4.6	0.21	4.5	0.18	4.73	0.22	4.63	0.25	4.59	0.1	4.8	0.12	4.52	0.17
Operation coherence total			4.6		4.33		4.71		4.57		4.48		4.78		4.62	
Utility	Reliability 1.indicator	0.2	4.79	0.2	4.9	0.32	5	0.34	4.52	0.19	4.2	0.13	4.2	0.1	3.9	0.12
	Reliability 2.sources	0.2	5	0.3	4.53	0.2	4.52	0.21	4.6	0.16	4	0.11	3.9	0.1	3.83	0.05
	Availability/applicability	0.23	5	0.1	4.46	0.12	4	0.08	4.57	0.1	4.57	0.2	4.15	0.12	4.34	0.18
	Information 1.security	0.17	4.97	0.28	4.49	0.21	4.57	0.18	4.75	0.14	4.58	0.3	4	0.1	4.61	0.2
	Information 2.cost	0.2	4.9	0.21	4.7	0.27	4.6	0.3	4.8	0.17	4.9	0.2	4.89	0.3	4.58	0.2
Utility total			4.92		4.6		4.52		4.64		4.45		4.23		4.24	
Conceptual coherence index		0.32	1.53		1.51		1.56		1.49		1.48		1.54		1.46	
Operation coherence index		0.45	2.07		1.95		2.11		2.06		2.02		2.15		2.08	
Utility index		0.23	1.13		1.06		1.03		1.07		1.02		0.97		0.98	
Final evaluation value			4.73		4.52		4.72		4.61		4.52		4.66		4.51	

Table 5.: The social-validation results for the social parameters

		Weight	Job opportunity		Development rate		Land availability		Water availability		Healthcare level		Security level		Education level	
			mean	variance	mean	variance	mean	variance	mean	variance	mean	variance	mean	variance	mean	variance
Conceptual coherence	Definition	0.33	4.89	0.12	4.8	0.11	4.83	0.12	4.43	0.17	4.52	0.13	4.83	0.2	4.51	0.18
	Relevance	0.31	4.61	0.17	4.81	0.15	4.89	0.11	4.95	0.17	4.64	0.13	4.62	0.17	4.58	0.12
	Interpretation/meaning	0.36	4.83	0.23	4.58	0.19	4.95	0.17	4.58	0.15	4.73	0.2	4.9	0.2	4.55	0.19
Conceptual coherence total			4.78		4.72		4.89		4.64		4.63		4.79		4.54	
Operation coherence	Formulation	0.25	4.82	0.13	4.51	0.17	4.82	0.2	4.86	0.13	4.67	0.17	4.83	0.22	4.6	0.17
	Data and units	0.21	4.45	0.1	4.52	0.12	4.58	0.18	4.2	0.07	4.23	0.16	4.8	0.15	4.91	0.14
	Measuring method	0.27	4.42	0.2	4.2	0.08	4.6	0.1	4.5	0.12	4.52	0.16	4.63	0.15	4.57	0.18
	Sensitivity accuracy	0.27	4.63	0.2	4.59	0.12	4.78	0.14	4.68	0.21	4.62	0.11	4.78	0.1	4.55	0.13
Operation coherence total			4.58		4.45		4.69		4.57		4.52		4.75		4.64	
Utility	Reliability 1.indicator	0.2	4.83	0.21	4.92	0.23	4.8	0.24	4.54	0.18	4.1	0.15	4.29	0.11	4.1	0.11
	Reliability 2.sources	0.2	4.8	0.31	4.54	0.12	4.51	0.11	4.62	0.14	4.4	0.1	4.3	0.15	3.89	0.09
	Availability/applicability	0.23	4.7	0.11	4.49	0.1	4.3	0.05	4.59	0.13	4.59	0.12	4.15	0.1	4.24	0.13
	Information 1.security	0.17	4.95	0.24	4.59	0.11	4.58	0.12	4.85	0.11	4.68	0.23	4.6	0.16	4.65	0.12
	Information 2.cost	0.2	4.92	0.22	4.75	0.25	4.7	0.26	4.82	0.15	4.92	0.21	4.92	0.26	4.68	0.12
Utility total			4.83		4.65		4.56		4.67		4.53		4.43		4.29	
Conceptual coherence index		0.32	1.52		1.51		1.56		1.48		1.48		1.53		1.45	
Operation coherence index		0.45	2.061		2.0		2.11		2.05		2.03		2.13		2.08	
Utility index		0.23	1.11		1.07		1.07		1.07		1.04		1.01		0.98	
Final evaluation value			4.69		4.58		4.74		4.61		4.55		4.68		4.52	

2. Data and References for the Case Study

In this section, we provide the values of related parameters used in the case study. Table 6 gives the values of parameters together with their references.

The available transportation links for the example is shown in Table 7. Since road transportation is available among all locations, we show the other available transportation modes only. The sign '–' shows that the corresponding mode of transport is not available in that link.

Table 6.: Real data for the case study

Parameter	**Value**	**Reference**
Priority weight of each social criteria	Based on judgment	Qualitative data
Available water at each location	Depends on location	Arslan-Alaton et al. (2010); tui (2016); orm (2015); wat (2016)
Waste sensitivity at each location	Normalized population density * location geographical dry/aquifer weight	Arslan-Alaton et al. (2010); tui (2016); orm (2015); nuf (2016)
Wage per employee per period in each location	Location dependent, proportional to production capacity of worker/period	Turkish Statistics Institutiontui (2016)
GHG emission	GHG emission (grams) per kg cargo/km of transportation multiplied by average weight of product Air = 3.73, Truck = 0.093, Train = 0.031, Ship = 0.0124	emi (2016); Ten (2015); Blu (2015)
Jobless rate	Depends on location	Turkish Statistics Institution tui (2016)
Development rate	Depends on location	Defined in a research by Iş bank of Turkey IsB (2015)
Security level	Depends on location	CNBCE report 2014 CNB (2015)
Demand	Product demand per person/ period * city population	nuf (2016); Hur (2015); tui (2016)
Default facility construction waste	$6900 gram/m^2$	Moyano, de Arellano Agudo, and Santiago (2011), Jalali (2007)
Product operation waste	$34.5 gr$ (30% of hazard material of labtop),	Haz (2007); Brigden and Laboratories (2006)
Travel distance in km by any mode	Depends on location	Truck distances: Turkey general directorate of highways Gen (2015), Train distances: Turkish state railways Rai (2015), Air distances: Google maps, Sea distances: Turkish ministry of transport, maritime, communications Den (2015)
Transportation cost per product/km	Air = 0.05$, Truck = 0.025$, Train = 0.02$, Sea = 0.015$	Turkish freight companies such as Turkish Airline Cargo, PTT,...
Unit land cost	Direct use	Real estate agencies
Available land at location	Direct use	Zir (2015); orm (2015); oco (2015); kitap Çevre (2009); nuf (2016)
Utility cost per product at each location	Water consumption/product * unit water cost + gas consumption/product * unit gas cost	Gas (2016); suF (2016)
depreciation year	20 : Direct use	Based on average bank credits periods
Population density	Depends on location	tui (2016)
Number of teachers, schools, universities	Depends on location	tui (2016)
Potential population for school, university	Depends on location	tui (2016)
Number of doctors, hospital beds	Depends on location	tui (2016)
Population	Depends on location	tui (2016)
Required land need per equipment	10000 m^2	Based on Arcelik company land structure erc (2016)
Cost per equipment	1000,000$	Based on Arcelik companies reports erc (2016)
Required water per unit product	6.665 (liter) : Direct use	SuL (2016)
The labor hour per product	3 * 8 hours	cne (2016)

Table 7.: Transportation links availability in the example

	Konya			**Sivas**			**Antalya**			**Izmir**			**Van**			**Adana**			**Erzurum**			**Malatya**		
	Air	Train	Sea	Air	Train	Sea	Air	Train	Sea	Air	Train	Sea	Air	Train	Sea	Air	Train	Sea	Air	Train	Sea	Air	Train	Sea
Istanbul	461	-	-	696	-	-	482	-	964	328	-	218	1265	-	-	707	-	-	1048	-	-	851	-	-
Bursa	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Samsun	504	1003	-	182	402	-	690	-	-	848	-	-	680	1126	-	486	900	-	445	946	-	368	651	-
Gaziantep	442	665	-	300	513	-	594	-	-	914	-	-	553	741	-	183	295	-	464	838	-	164	266	-
Ankara	231	675	-	356	610	-	386	-	-	521	-	-	923	1282	-	390	679	-	719	1101	-	501	807	-
Adiyaman	510	-	-	246	-	-	677	-	-	979	-	-	456	-	-	275	-	-	353	-	-	65	-	-
Trabzon	713	-	-	268	-	-	904	-	1808	1114	-	1671	422	-	-	585	-	-	180	-	-	319	-	-

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