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SUSTAINABILITY INDEX WITH INTEGRATED INDICATOR DEPENDENCIES

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Abstract. Sustainability is a growing concern worldwide. While companies used to focus on financial performance, now the focus has shifted to considering environmental and social performance as well. This trend is not only based on 'image', but recent research has proven that a complex approach regarding sustainability could significantly increase a company's performance.

The selection of sustainability indicators as well as the development of sustainability frameworks has been analysed by researchers already. The authors argue that interdependencies exist between different sustainability indicators and concepts. To address this issue, the fuzzy set method has been used and integrated into assessment methods, making it possible to develop a sustainability index which is able to consider the dependencies of the integrated variables. The proposed method can prove that indicator dependencies have a significant influence on the sustainability performance of a company and therefore on its overall performance.

Keywords: indicator dependencies, dependency assessment, sustainability indicators, sustainability index, fuzzy set theory, driving and dependence power.

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JEL Classification: D20.

1. Introduction

Sustainability is an increasing challenge that can be contemplated in a generic sense and is therefore present in many different domains ranging from agriculture to cities and organisations (Bell, Morse 2008; Zäh, Aull 2006).

However, regardless of the sector, it is crucial to measure and monitor performance in order to achieve sustainability (Bell, Morse 2003). Often the different aspects of sustainability are analysed independently but it is important to look at them jointly and to consider possible dependencies. Therefore, this paper addresses the relevance of sustainability indicator dependencies and introduces a method in which these dependencies are integrated.

2. Sustainability measures and dependencies

'You can't manage what you don't measure'. Therefore, it is important to measure company performance (Ranganathan 1998). However not only financial performance but also environmental and social performance is important (Veleva *et al.* 2001b). In addition, according to Eccles *et al*. the consideration of sustainable factors could increase a company's performance remarkably (2012).

So far considerable research has been conducted regarding the selection of indicators (Azapagic, Perdan 2000; Fan *et al.* 2010; Krajnc, Glavič 2003; Staniškis, Arbačiauskas 2009; Veleva, Ellenbecker 2001). Besides the sustainability indicators, however, holistic sustainability frameworks have been introduced (Olsson *et al.* 2009; Deif 2011) as well as indices (Krajnc, Glavič 2005; Hazel *et al.* 2012; Knoepfel 2001; Veleva *et al.* 2001b) that help to measure progress and therefore to improve sustainability performance. R. K. Singh *et al.* (2009) and R. Grunda (2011) provide an overview of some assessment methods for sustainability.

Nevertheless, sustainability is a highly complex issue and therefore, interdependencies exist between the different criteria of sustainability (Tseng *et al.* 2009). Dependencies are sophisticated as well and have been researched in many other areas besides sustainability, e.g. in the manufacturing environment (Zäh, Aull 2006). Consequently, it can be argued that dependencies play an important role when considering sustainability performance. Nevertheless, these influences are often vague and uncertain and sometimes information is incomplete. To satisfy these issues, fuzzy set theory can be applied (Andriantiatsaholiniaina *et al.* 2004; Alsulami, Mohamed 2012; Tseng 2013) and integrated into assessment methods (Phillis, Andriantiatsaholiniaina 2001; Pislaru, Trandabat 2012).

3. Calculation methodology

The presented method is designed to calculate a company's sustainability index and is based on the method introduced by D. Krajnc and P. Glavič (2005).

However, the major difference to their method is that the presented one addresses the dependencies of indicators to calculate the sustainability index. These dependencies are not always obvious and easy to identify. Therefore, the dependencies are to be determined from experience. Since the necessary information is vague, imprecise and often incomplete, linguistic variables can be used to identify these dependencies (Zadeh 1979) which can be determined in a pair-wise comparison matrix (Saaty 1980).

There are five different steps that need to be taken to calculate the sustainability index (Fig. 1). At first the sustainability indicators need to be selected according to the appropriate selection criteria (Step 1). Then the existing dependencies need to be identified and evaluated in terms of their intensity (Step 2). In a next step, it is important to define boundaries in order to normalise the indicator values (Step 3). Afterwards, the indicators need to be weighted based on their importance towards sustainability (Step 4). In a last step the sustainability index can be calculated (Step 5).

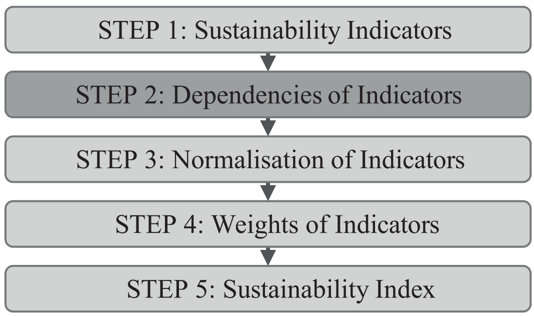

Fig. 1. Sustainability Index Calculation Scheme
(Source: own figure based on Krajnc, Glavič 2005)

3.1. Sustainability indicators

The selection of appropriate indicators is important and should be simple and directionally safe. Simple means that the number of indicators should be limited to avoid uncontrollable complexity and the method of calculation should be transparent. Indicators are directionally sound if they are relevant and significant (Spangenberger, Bonniot 1998: 4). However, the indicators should represent all three dimensions of sustainability; environment, economy and society (Veleva *et al.* 2001b). In addition, they need to be available as well as accessible (Hardi, Zdan 1997). G. B. Guy and C. J. Kibert (1998) have also identified different criteria that should be considered when identifying indicators. Nevertheless, the selection of indicators always depends on the purpose for which the indicators are used.

3.2. Dependencies of indicators

The dependencies can be characterised by the following linguistic variables: very strong (vs), strong (s), medium (m), weak (w) and very weak (vw). This classification has been discussed in great detail with the experts and this graduation has been approved as sufficient.

In addition to the intensity, the direction of dependency needs to be identified which can be expressed by plus (+) or minus (–) signs. However, the sign is no evaluating the dependency in a positive or negative way but provides information on the type of dependency. A 'plus' type dependency implies that the influence acts in the same direction. This means that an increase/decrease of the initial indicator value v_{oi} results in an increased/decreased value of the influenced indicator v_{oj}. A 'minius' type dependency, in contrast, implies that the influence acts in the opposite direction meaning that an increase results in a decrease and conversely.

To determine all the dependencies of the selected indicators, the indicators are to be compared in a pair-wise comparison matrix. For this purpose the following question could be asked: Does indicator I_i have an influence on indicator I_j? If this is the case, the changed indicator value vcj of the influenced indicator I_j can be calculated as follows:

$$v_{cj} = v_{oj} \cdot (1 + d_i \cdot (p - 1)), \quad (1)$$

where, v_{oj} is the initial indicator value of indicator I_j, d_i is the percentage by which indicator I_j is influenced by indicator I_i based on the dependency intensity and p is the percentage by which the influencing indicator I_i is manipulated.

The changed value of the influencing indicator can be calculated by multiplying the original value v_{oi} by the percentage p by which the indicator is to be changed.

3.3. Normalisation of indicators

It is difficult to compare different values with one another, especially if they do have different units and/or reference magnitudes. Therefore, the indicator values need to be normalised. In this proposed method, there are six different fuzzy set types between one can choose to normalize the indicator values (Table 1).

Table 1. Fuzzy set types (Source: created by the authors)

Type	Description
1	The more the better (raising straight line)
2	The less the better (declining straight line)
3	Only one value is good (triangle)
4	Only one value is bad (reversed triangle)
5	Only a range of values is good (trapezium)
6	Only a range of values is bad (reversed trapezium)

For all the fuzzy set types, boundaries need to be defined at which the indicator values are 'good' or 'bad', where 'good' is assigned the numerical value 1 and 'bad' is assigned the numerical value 0. All values between the boundaries may be allocated to a numerical number between 1 and 0.

Fuzzy set types 1, 2 and 5 are most common. The formulas for the fuzzy set types are as follows:

Fuzzy Set Type 1:

$$y_1(v_c) = \begin{cases} 0, \; v_c \leq LB \\ \dfrac{v_c - LB}{UB - LB}, \; LB \leq v_c \leq UB \\ 1, \; UB \leq v_c \end{cases}, \tag{2}$$

where, LB is the lower boundary that defines at which value the indicator is 'bad' and UB is the upper boundary that defines the value at which the indicator is 'good'.

Fuzzy Set Type 2:

$$y_2(v_c) = \begin{cases} 1, \; v_c \leq LB \\ \dfrac{UB - v_c}{UB - LB}, \; LB \leq v_c \leq UB \\ 0, \; UB \leq v_c \end{cases}. \tag{3}$$

In fuzzy set type 2, the upper and lower boundaries have the opposite meaning compared to fuzzy type 1 because fuzzy set type 2 represents the case the less, the better. Therefore, the lower boundary represents the value for which the indicator is 'good'. The upper boundary defines the limit at which the indicator value is 'bad'.

The formulas for the fuzzy set types 3 and 4 are not presented at this point because they have not been selected for any of the defined indicators used in this method. In addition, these fuzzy set types barely reflect reality since there is usually not one single value that determines whether an indicator is 'goog' or 'bad'. This is better described by a value range.

Fuzzy Set Type 5:

$$y_5(v_c) = \begin{cases} 0, \; v_c \leq LB \\ \dfrac{v_c - LB}{MB_1 - LB}, \; LB \leq v_c \leq MB_1 \\ 1, \; MB_1 \leq v_c \leq MB_2 \\ \dfrac{UB - v_c}{UB - MB_2}, \; MB_2 \leq v_c \leq UB \\ 0, \; UB \leq v_c \end{cases}, \tag{4}$$

where, MB_1 is middle boundary 1 and MB_2 is middle boundary 2. These two boundaries define the range in which the indicator value is 'good'. For fuzzy set type 6, in contrary, these boundaries would define the range for which the indicator value is 'bad'.

3.4. Weights of indicators

According to their importance towards sustainability, the indicators need to be weighted. The weighted indicator values v_w can be calculated as follows:

$$v_w = y_t\left(v_c\right) \cdot w \,, \tag{5}$$

where, w is the weighting percentage that is determined by the weighting matrix.

For the weighting matrix, the indicators need to be checked against each other for their importance. According to their relevance, the indicators are evaluated and the weighting percentage w can be calculated.

3.5. Sustainability index

The sustainability index is a cumulated indicator. The indicators from all three sustainability dimensions are summarised to one index which can be calculated as follows:

$$SI = v_{wi} + \sum_{j=1}^{n} v_{wj} \,, \tag{6}$$

where, v_{wi} is the changed, normalised and weighted value of the influencing indicator I_i and v_{wj} is the changed, normalised and weighted value of the influenced indicator I_j.

If more than one indicator is changed, the sustainability index needs to be calculated in series. Only one indicator change can be considered for each sustainability index calculation. The changed indicator values of the prior calculation are always the basis for the next index calculation.

The calculation is based on the cumulated sustainability index proposed by Krajnc and Glavič (2005) but is extended by the existing indicator dependencies. The initial cumulated sustainability index has been developed to compare companies on their sustainability performance. In this case the idea is to compare the modified sustainability index with the original sustainability index to analyse the effects of indicator dependencies in order to derive predictions on their influence.

4. Case study: exemplary application

A case study has been conducted to illustrate the proposed method and to calculate the sustainability index with integrated indicator dependencies.

The indicators listed in Table 2 have been selected prior to this case study. To address the idea of sustainability always four indicators represent one dimension of sustainability; environment, economy and society. Consequently, the indicators I_1 to I_4 are environmental indicators, I_5 to I_8 are economic indicators and I_9 to I_{12} are social indicators.

Table 2. Sustainability indicators (Source: created by the authors)

No	Indicator name	Dimension	Type
I_1	Relative energy consumption	Environment	2
I_2	Relative water consumption	Environment	2
I_3	Relative scrap generation	Environment	2
I_4	Relative material consumption	Environment	2
I_5	Productivity	Economy	1
I_6	Production output	Economy	1
I_7	Cost associated with saftey, health and environment compliance	Economy	2
I_8	Investments in environmental protection	Economy	5
I_9	Lost workday incident rate	Society	2
I_{10}	Employee turnover	Society	5
I_{11}	Rate of employees' safety, health and environment suggestions	Society	5
I_{12}	Time of average employee education	Society	5

In order to normalise the indicator values, each indicator has been allocated to one of the six different fuzzy set types. In this case, only fuzzy set types 1, 2 and 5 have been used because they most likely represent reality.

For indicator I_{10}, for example, it is assumed, that the indicator belongs to fuzzy set type 5. High staff fluctuation can be evaluated as negative because new employees need to be trained and do not know the company and its processes. However, no fluctuation rate again is an undesirable situation as well. Employees who have been in a company for many years may become professionally blinkered but new views and ideas could improve processes and therefore business.

The indicator weightings and dependencies have been determined by an expert of the company. Therefore, two pair-wise comparison matrices have been filled out. For the weightings only have of the matrix needs to be filled out because the weightings are interchangeable. Indicator I_6 is the indicator with the highest weighting of 12% and is therefore most important to the company. The indicators I_8 and I_{11} have the lowest weighting of 6% and can be considered as least relevant to the company (Table 3).

Table 3. Sustainability indicator weighting (Source: created by the authors)

	I_1	I_2	I_3	I_4	I_5	I_6	I_7	I_8	I_9	I_{10}	I_{11}	I_{12}	%
I_1	–	9	5	8	5	3	7	7	7	5	7	7	11
I_2	1	–	3	3	3	3	6	6	6	5	7	7	8
I_3	5	7	–	7	2	4	7	7	7	7	7	7	10
I_4	2	7	3	–	5	4	7	7	7	7	7	7	10
I_5	5	7	8	5	–	3	6	7	5	5	7	6	10
I_6	7	7	6	6	7	–	8	8	7	6	8	7	12
I_7	3	4	3	3	4	2	–	5	6	6	6	6	7
I_8	3	4	3	3	3	2	5	–	4	4	4	5	6
I_9	4	4	3	3	5	3	4	6	–	5	7	5	7
I_{10}	3	5	3	3	5	4	4	6	5	–	5	5	7
I_{11}	3	3	3	3	3	2	4	6	3	5	–	5	6
I_{12}	4	3	3	3	4	3	4	5	5	5	5	–	7

These weightings represent the company's attitude towards sustainability and imply which factors are important for the company. Therefore, the weighting is closely linked to the company's strategy and philosophy which is an important aspect of sustainability.

For the dependencies, in contrast, the complete matrix needs to be filled out because the indicator dependencies are not interchangeable (Table 4). This is due to the fact that for example indicator I_i (row indicator) may influence another indicator I_j (column indicator) but this indicator I_j does not necessarily need to influence the first indicator I_i.

Table 4. Sustainability indicator dependencies (Source: created by the authors)

	I_1	I_2	I_3	I_4	I_5	I_6	I_7	I_8	I_9	I_{10}	I_{11}	I_{12}
I_1	–	no	no	no	–vs	no	m	no	no	no	no	no
I_2	s	–	m	m	–s	no	m	no	no	no	no	no
I_3	m	no	–	m	–s	no	no	no	no	no	no	no
I_4	m	no	m	–	–m	no	no	no	no	no	no	no
I_5	–m	no	–m	–m	–	no	no	no	no	no	no	no
I_6	–w	–w	w	w	w	–	no	no	m	vw	no	–w
I_7	vw	vw	vw	vw	m	m	–	m	m	–m	s	–w
I_8	–w	–w	–w	–w	no	no	–vw	–	no	–vw	–vw	no
I_9	no	no	vw	vw	–m	–vw	s	vw	–	m	no	–m
I_{10}	vw	vw	m	m	–m	–m	m	vw	m	–	m	m
I_{11}	–vw	–vw	–vw	–vw	vw	vw	m	vw	–w	–w	–	no
I_{12}	–vw	–vw	–m	–m	s	–vw	–m	no	–m	–m	m	–

5. Indicator clustering

According to their dependencies, indicators can be clustered into groups based on their driving and dependence power (Bossel 2004; Tseng *et al.* 2009).

In Fig. 2 the indicators have been clustered in a matrix according to their dependencies but without considering their weighting. In this case, every dependency regardless of its intensity has been evaluated with the numerical value 1 and no dependency with 0. The sum of each row represents the driving power which is plotted on the y-axis. The sum of each column represents the dependence power which is plotted on the x-axis. Indicator I_{10} for example influences all the other indicators and therefore has a driving power of 11. The dependence power of this indicator is 6 since I_{10} is influenced by six other indicators.

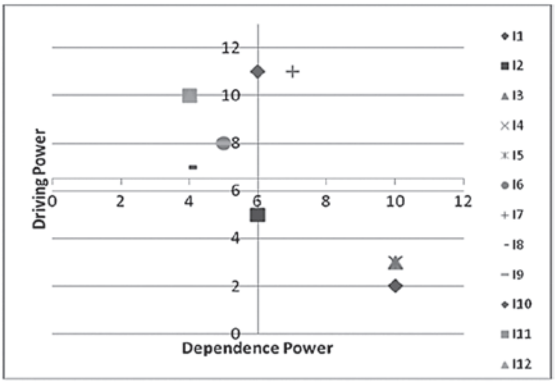

Fig. 2. Indicator clustering without weighting (Source: created by the authors)

According to Fig. 2 the indicators I_7 and I_{10} have the highest driving power. The indicators I_1, I_3 and I_4 have the highest dependence power.

When considering the intensity of the dependencies, however, indicator I_{10} has the highest driving power followed by I_{12} and I_7. Regarding the dependence power, only indicator I_5 remains high power (Fig. 3).

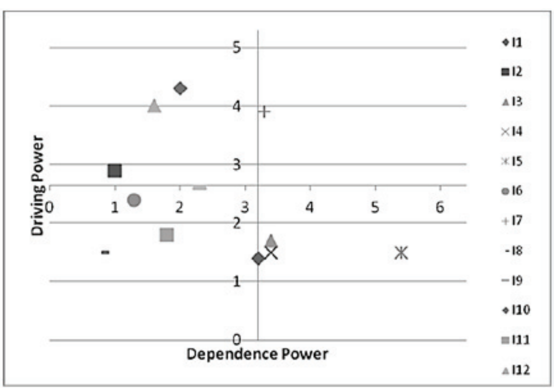

Fig. 3. Indicator clustering with weighting (Source: created by the authors)

Consequently, some indicators have lost a siginficant amount of their driving or dependence powers such as the indicators I_1, I_2, I_3, I_4 and I_{11}. This means that these indicators may have numerous dependencies but they are assumed to be relatively weak.

6. Sustainability index

The sustainability index provides information on the sustainability performance of a company. To maximise this performance, the sustainability should be maximised. Therefore, the critical indicators need to be identified that have the greatest influence on the sustainability index.

For the presented company, improving the three indicators I_2, I_5 and I_{10} have a maximum affect on the sustainability index when considering the dependencies of sustainability indicators. Therefore, these indicators are most critical (see Table 5).

Table 5. Maximum sustainability index with dependencies (Source: created by the authors)

Sustainability index	Indicator combination	Percentage
93.94%	I_2, I_5, I_{10}	80%; 120%; 80%
	I_2, I_{10}, I_5	80%; 80%; 120%
	I_5, I_2, I_{10}	120%; 80%; 80%
	I_5, I_{10}, I_2	120%; 80%; 80%
	I_{10}, I_2, I_5	80%; 80%; 120%
	I_{10}, I_5, I_2	80%; 120%; 80%

For the given boundaries and the maximum changing ranges of ±20%, the company could reach a maximum sustainability index of 93.94% when improving the three indicators in any order by the maximum range of 20%. In addition, according to the indicator clustering, I_2 has the highest driving power and I_{10} has the highest dependence power, which supports the findings above that these indicators have the highest impact on the sustainability index.

Without considering the dependencies of sustainability indicators, the sustainability index would reach for the same combinations only a percentage of 67.48%. This is a discrepancy of more than 25%. Consequently, it can be argued that the dependencies have a significant effect on the overall index result.

However, the maximum sustainability index without dependencies is 80.88% (see Table 6) and the significant indicators are I_1, I_4 and I_6. This index without dependencies is inferior to the index with dependencies for the same combinations which is 85.65%.

Table 6. Maximum sustainability index without dependencies (Source: created by the authors)

Sustainability index	Indicator combination	Percentage
80.88%	I_1, I_4, I_6	80%; 90%; 110%
	I_1, I_6, I_4	80%; 110%; 90%
	I_4, I_1, I_6	90%; 80%; 110%
	I_4, I_6, I_1	90%; 110%; 80%
	I_6, I_1, I_4	110%; 80%; 90%
	I_6, I_4, I_1	110%; 90%; 80%

In this case, the maximum sustainability index can be achieved by increasing the indicator I_6 to only 110% and reduce the indicator I_4 by only 10% to 90%. Further increase of indicator I_6 to 120% or decrease of indicator I_4 to 80% respectively, does not improve the sustainability index any further but requires more resources to achieve. This is due to the fact that these indicators are already at a maximum according to the boundaries. Therefore, the normalised value is maximal with a value of 1. Since this method does not consider dependencies, further improvements of these indicators have no influence on any other indicator and their normalised values. Consequently, the sustainability index does not change.

For this reason, it can be argued that the dependencies between the indicators have a significant effect on the sustainability index and the the identification of critical indicators.

It is also striking that the critical indicators with dependencies each belong to a different sustainability dimension. For the critical indicators without dependencies, however, only the environmental and the economic categories are represented but not the social one.

In addition, this phenomenon is also confirmed by the fact that the indicators I_2, I_5 and I_{10} have the highest frequency distribution rate when analysing the indicator combinatations with dependencies that result in the best 100 and 500 sustainability indices (SI) respectively (see Fig. 4). In contrast, the other indicators except for I_1 and I_3 have little to no frequency distribution proportions.

Consequently, the indicator ‘Employee turnover’ plays a significant role in this company, followed by the indicators I_1, I_3 and I_5. Therefore, these indicators and in particular indicator I_{10} need to be incorporate when defining specific actions to improve the company’s sustainability performance.

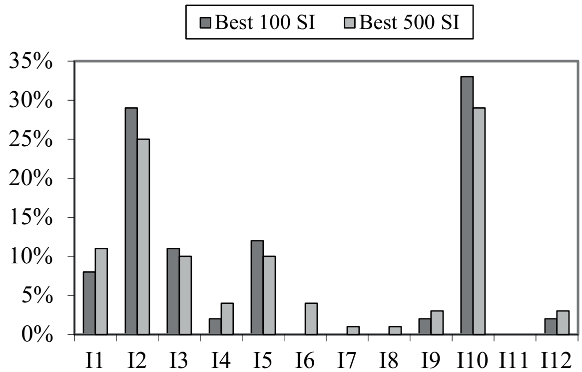

Fig. 4. Indicator frequency distribution with dependencies
(Source: created by the authors)

However, when analysing the indicator frequency distribution without considering indicator dependencies, the indicators I_1, I_4 and I_6 are most critical with over 30% and 20% respectively (see Fig. 5). In addition, the distribution does not represent the complexity of sustainability but focuses on selected indicators which results from the defined boundaries. Based on these, the normalised values of these indicators can be calculated which are comparatively weak. These facts also confirm the results represented in Table 6.

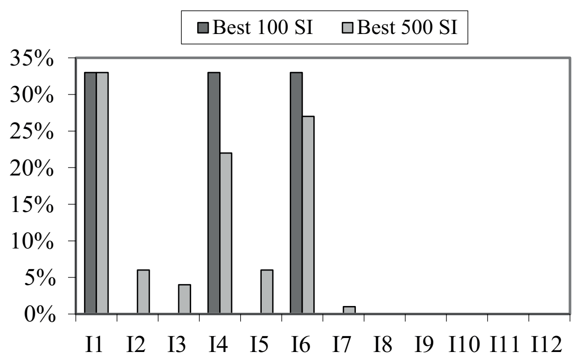

Fig. 5. Indicator frequency distribution without dependencies
(Source: created by the authors)

7. Discussion

The maximum sustainability index with dependencies is 93.94%. The index cannot reach 100% because the improvement percentages are limited to ±20%. When increasing these percentages, a sustainability index of 100% could be achieved. However, it can be argued that an improvement of over 20% of an indicator in a single step is unrealistic. The sustainability index with the same indicators but without dependencies is only 67.48%.

When determining the highest sustainability index without dependencies, the critical indicators change. Nevertheless, this index is lower than the one with dependencies (80.88% compared to 85.65%). Therefore, it can be argued, that the indicator dependencies may have a positiv effect on overall sustainability because they exploit the synergy effects.

In addition, the dependencies also affect the critical indicators. Since the indicators may influence one another, the importance of individual indicators increase or decrease according to their dependency structure. Therefore, the critical indicators with and without dependencies differ. It is important to consider these dependencies in order to manipulate the indicators that have the greatest affect in order to be most effective.

Consequently, indicator dependencies have a significant influence on overall sustainability and on the determination of critical indicators that a company should focus on when improving sustainability performance.

8. Conclusions

The proposed method shows that indicator dependencies have a severe influence on the sustainability index of a company and therefore on its performance. Consequently, dependencies are critical issues when looking at sustainable performance and thus need to be considered.

Although, dependencies are not easy to identify and it is impossible to determine them precisely, it is important to take the time and effort to consider and integrate them when measuring performance and identifying internal actions.

Consequently, the method is designed to be company specific and can be used for internal purposes only and not for external purposes such as benchmarks. Therefore, the method can provide information on where to start within a company. This fact justifies the subjective determination of the input data that is needed to use the proposed method successfully.

Nonetheless, the authors stress the fact that it is vital to integrate indicator dependencies when determining sustainability although they are difficult to determine and little research has been conducted. Therefore, it is important to persue this topic in further research.

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