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Review

Qualitative models of complex sustainability systems using integrations of equations and equationless knowledge items generated by several experts☆

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ABSTRACT

Highly non-linear, partially subjective, inconsistent, vague and multidimensional sustainability systems are often prohibitively difficult to study using numerical and/or verbal and consequently fuzzy quantifiers. Oversimplified or highly specific quantitative models are sometimes obtained and their practical applicability is therefore limited. Moreover, definitions of some ecological and consequently sustainability indicators are unclear and difficult to quantify by their very nature. This is the reason why the least information intensive descriptions must be incorporated into sustainability models developments. Time trends, e.g. *increasing*, are such information non-intensive descriptors. There are just three trend/qualitative values used to quantify variables and their derivatives: *plus/increasing*; *zero/constant*; *negative/decreasing*. The qualitative quantifiers are the key elements of qualitative models. Qualitative sustainability knowledge items are available in forms of equations with unknown numerical values of relevant constants and in equationless forms such as heuristics. For example – *the unsteady state behaviour of a temperature is described by a dumped oscillation equation, however, the relevant equation's constants are not known; return on equity is increasing more and more rapidly*. A qualitative model must be developed when the relevant complex quantitative model must be heavily simplified. The key information input in sustainability analysis is expert knowledge. A consensus among experts is often not reached because of substantial subjectivity of experts' knowledge. Qualitative model solutions are discrete sets of scenarios. Different unions U and intersections ∩ of sets of qualitative solutions can be used to model unachievable consensuses among experts to identify a meaningful compromise. The case study presents a model generated by one expert. It is based on integration of one qualitative equation and 23 equationless relations using 13 variables e.g. return on equity, consumption of renewable energy, productivity of labour. The result is represented by 7 scenarios and 8 transitions among them. A set of five modifications of the sustainability model is studied.

Contents

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1. Introduction

The concept of sustainability has evolved into definitions of the three pillars of sustainability, namely social, economic and environmental, see e.g. Bredeweg et al. (2009), Moldan et al. (2012). There is no universally accepted definition or assessment technique of sustainability. This is due to the interdisciplinary nature of sustainability; see e.g. Phillis et al. (2011), Mattor et al. (2014). However, in reality sustainability problems are much more complex; aspects such as social well-being, culture, political situation must also be taken into account, e.g. *public mood*. Moreover, not merely soft sciences but hard sciences as well must be incorporated. For example, engineering tasks specify important constraints if ecological problems are solved, see e.g. Shokravi et al. (2014). Deep knowledge items reflect undisputed elements of the corresponding theory. The law of gravity is an example. This law has no exceptions. This is a typical feature of deep knowledge items. Soft sciences such as, for example, economics, sociology and ecology are only very rarely based on deep knowledge items. A shallow knowledge item is usually a heuristic or a result of a statistical analysis of observations and has (many) exceptions, see e.g. Oliveira and Rezende (2013). Shallow knowledge items are often available as verbal descriptions based merely on trends – *decreasing*, *constant*, *increasing* (Ahn and Kim, 2009).

For example:

If ecological investments are decreasing then water pollution is increasing.

EIs suffer from similar information shortages problems as overwhelming majority of sustainability related problems. Therefore such information non-intensive quantifications as trends are often used.

The following types of pairwise trend relations between variables X and Y are considered in Kandziora et al. (2013).

$$\begin{array}{ll} \text{An increase in } (X) \text{ has a supporting effect on } (Y) & (a) \\ \text{The interactions can have supporting or reducing effects} & (b) \\ \text{An increase in } (X) \text{ has a reducing effect on } (Y) & (c) \end{array} \quad (1)$$

To formalise a trend analysis the following generalised pairwise relations set inspired by Table 9 in Kandziora et al. (2013) is studied:

		X	Y
1	SUP	EC	EP
2	SUP	EC	SC
3	SUP	EC	CNR
4	SUP	EC	BWF
5	SUP	EC	ME
6	RED	EP	SC
7	RED	EP	CNR
8	RED	EP	ME
9	SUP	SC	CNR
10	SUP	SC	BWF
11	SUP	SC	ME
12	SUP	CNR	ME
13	SUP	BWF	ME
14	SUP	HE	BIO

(2)

where the relations SUP and RED are defined as follows:

SUP	if X is going up (down) then Y is going up (down) as well; generalised supporting effects, see (a) (1)
RED	if X is going down (up) then Y is going up (down) as well; generalised reducing effects, see (c) (1)

and

Exergy capture	EC
Entropy production	EP
Storage capacity	SC
Cycling nutrient and loss reduction	CNR
Biotic water flows	BWF
Metabolic efficiencies	ME
Heterogeneity	HE
Biodiversity	BIO

The trend model (2) has 14 pairwise trend relations and is based on 8 variables.

There are 3^8 different scenarios based on all 8 variables. The reason is that three trend quantifiers exist: *increasing*, *constant*, *decreasing*. Each possible scenario is confronted with the model (2) to identify all feasible scenarios.

The following set of scenarios is obtained:

	EC	EP	SC	CNR	BWF	ME	HE	BIO
1	c	c	c	c	c	c	i	i
2	c	c	c	c	c	c	c	c
3	c	c	c	c	c	c	d	d

(3)

where

c	constant
i	increasing
d	decreasing

It is clear that because of the model (2) there are no changes of the following set of variables:

{EC, EP, SC, CNR, BWF, ME}

The second solution, see (3), is the steady state one; all 8 variables are constant.

If the following relations

$$(1, 6, 8, 10, 11) \quad (4)$$

are removed from the trend model (2) then the following set of trend solutions is obtained:

	EC	EP	SC	CNR	BWF	ME	HE	BIO
1	i	d	i	i	i	i	i	i
2	i	d	i	i	i	i	c	c
3	i	d	i	i	i	i	d	d
4	c	c	c	c	c	c	i	i
5	c	c	c	c	c	c	c	c
6	c	c	c	c	c	c	d	d
7	d	i	d	d	d	d	i	i
8	d	i	d	d	d	d	c	c
9	d	i	d	d	d	d	d	d

(5)

It is clear that the set of trends (3) is a subset of the set (5). If just the following set of relations (6), (8), (10) is removed from the