Green Finance

Green Finance, 3(1): 28–45.
DOI: 10.3934/GF.2021003
Received: 17 December 2020
Accepted: 20 February 2021
Published: 23 February 2021

http://www.aimspress.com/journal/GF

Research article

Responsible consumption and production in the European Union. A partial order analysis of Eurostat SDG 12 data

Lars Carlsen*

Awareness Center, Linkøpingvej 35, Trekroner, DK-4000 Roskilde, Denmark

* **Correspondence:** Email: LC@AwarenessCenter.dk; Tel: +4520480213.

Abstract: The UN Sustainable Development Goal 12, responsible consumption and production, is a key element in a sustainable development of our planet as it is closely linked to the exploitation of renewable and non-renewable resources. The present study focuses on five main indicators selected by Eurostat as key factors for the development of the SDG 12, i.e., 1: resource productivity, 2: average CO_2 emissions from new passenger cars, 3: circular material use rate, 4: generation of waste excluding major mineral wastes and 5: consumption of toxic chemicals for the 27 member states of the European Union, the data being analyzed applying partial ordering methodology that constitutes an advantageous decision support tool. Based on the first 4 indicators the 27 EU member states have been mutually ranked finding France, Italy, and Malta as the best and Bulgaria and Estonia as the worst among the 27 countries in complying with the SDG 12 targets. Studying the temporal development, a slightly positive tendency was observed. The most important indicator, looking at the whole EU appears to be the generation of waste, whereas, e.g., the CO_2 emission apparently is the key issue for France and Bulgaria, whereas the circular material use rate is the most important in the case of Greece. The temporal development of the consumption of toxic chemicals was separately analyzed disclosing that the amount of non-toxic waste has increased whereas a decrease in chemicals hazardous to human health and to the environment was noted. The results constitute important for authorities and regulator in their effort to select actions in order better to comply with the SDG 12 targets.

Keywords: sustainability; SDG 12; consumption; production; EU; partial ordering; ranking; indicator importance

JEL Codes: C3, C6, C8

1. Introduction

The latest compilation of the progress in sustainable development in Europe is found in the 2020 Eurostat report "Sustainable development in the European Union. Monitoring report on progress towards the SDGs in an EU context" (Eurostat, 2020a) where the overall goal is by 2030 to *achieve the sustainable management and efficient use of natural resources* (UNDP, 2020). Sustainability comprises three main pillars, i.e., economically viable decisions, environmentally sound decisions, and socially equitable decisions. The present study applies Eurostat data for five out of six main indicators discussed in the report for SDG 12 (Eurostat, 2020a) for the period 2007 to 2017 (Eurostat, 2020b, c, d, e, f). The 6^{th} main indicator, i.e., "Gross value added in the environmental goods and services sector" (Eurostat, 2020g) will not be treated here due to lacking data for several of the year coved. Hence, the 5 main indicators included in this study are:

- Consumption of toxic chemicals (Eurostat, 2020b)
- Resource productivity (Eurostat, 2020c)
- Average CO_2 emissions from new passenger cars (Eurostat, 2020d)
- Circular material use rate (Eurostat, 2020e)
- Generation of waste excluding major mineral wastes (Eurostat, 2020f)

It is noted that these indicators virtually focus on the environmental part of sustainability and only indirectly with the economic part through the resource productivity, which is defined as the gross domestic product divided by domestic material consumption. Obviously, the financial aspects should not be neglected. Thus, Tseng et al. has studied financial aspects of sustainable supply chain (Tseng et al, 2018, 2019).

The selection of these main indicators for SDG 12 is nevertheless obvious. Hence, production of toxic chemicals, as well as the average CO_2 emissions from new passenger cars appear as important indicators in relation both to sustainable production and consumption. Further, the general production of waste parallel to an increase resource productivity and circular material use rate obviously work towards a higher degree of sustainability both in relation to production and to consumption. The interlink with other SDGs should be emphasized. SDG 13, Climate action, is obvious (CO_2) emission and SDG 11, Sustainable cities, and communities (Waste) and SDG 3, Good Health and Well-being (toxic chemicals) may here serve as illustrative examples.

In the Eurostat report (Eurostat, 2020a) the development in the single indicators is treated separately. However, to obtain a more comprehensive picture of the sustainable production and consumption the group of indicators (here 5) should be taken into account simultaneously. To do so, often an aggregation of the single indicators into one overall indicator is done. However, although this leads to a complete linear ordering of the studied objects, as here, e.g., the EU member states, valuable information concerning the influence of the single indicators may be lost due to compensation effects (Munda, 2008). As such partial order methodology constitutes an advantageous decision support tool for authorities and regulators in their attempt to select focus areas and allocate resources as well as to avoid pitfalls in their work to improve the situation in order better to comply with the SDG 12 target.

The paper is structured by a methodology section followed by a result and discussion section that further is subdivided in two: a) an overall analysis to what extent the 27 EU member states (cf. Table 1) comply with the SDG 12 taken the 4 indicators Resource productivity, Average CO_2 emissions from new passenger cars, Circular material use rate and Generation of waste excluding major mineral wastes simultaneous into account for the years 2010, 2014 and 2017, respectively and b) an analysis of the consumption of toxic chemical for the years 2004 to 2019 at a European Union scale (excluding United Kingdom); the paper finalizes with some conclusions and outlook.

Table 1. Country codes.

Country	Codes	Country	Codes	Country	Codes
Austria	AUT	France	FRA	Malta	MLT
Belgium	BEL	Germany	DEU	Netherlands	NLD
Bulgaria	BGR	Greece	GRC	Poland	POL
Croatia	HRV	Hungary	HUN	Portugal	PRT
Cyprus	CYP	Ireland	IRL	Romania	ROU
Czechia	CZE	Italy	ITA	Slovakia	SVK
Denmark	DNK	Latvia	LVA	Slovenia	SVN
Estonia	EST	Lithuania	LTU	Spain	ESP
Finland	FIN	Luxembourg	LUX	Sweden	SWE

2. Methods

2.1. Indicators and Data

The indicators being included in the study is summarized and described in Table 2. The CCH indicator has 2 subcategories: non-Hazardous waste (nonHaz) and Hazardous waste (Haz), the latter further being subdivided in wastes hazardous to the human health (HazHea) and to the environment (HazEnv), respectively. In Table 3 the data for the 27 EU member states are given for the 4 indicators RPR, CO_2, CMUR and WAS, respectively for the years 2010, 2014 and 2017, respectively (Eurostat, 2020c, d, e, f). It should be noted that for the indicators CO_2 and WAS negatives are given, thus securing an identical orientation of the indicators, i.e., the higher the better, i.e., contribution positively to the sustainable production and consumption.

Table 4 shows the four indicator values for the European Union and for Greece (GRC) for the years 2010 to 2017 (Eurostat, 2020c, d, e, f). Again, the indicators CO_2 and WAS are given as negatives to obtain an identical orientation of the indicators, i.e., the higher the better. In Table 5 the applied data for the hazardous waste analyses is given. It should be emphasized that all data are given with as negatives as higher values reflect less sustainability. Thus, this will correspondingly be visualized in the Hasse diagram where the least sustainable years will appear in the lower part of the diagrams. The nonHaz has been calculated by subtracting the Haz from the total Haz + nonHaz. It should be noted that HazHea and Hazenv to some extent overlap and as such the sum does not equal Haz (Eurostat, 2020b).

It should be noted that the data applied in the present study provided by Eurostat do not look at specific products but summarizes overall figures for the European Union as such as well as for the single member states.

It should further be emphasized that in all cases the data are taken as reported by Eurostat (2020b, c, d, e, f), i.e., the data are accepted as true values. In other word any, not reported, possible data uncertainty nor data noise has not been taken into account in the calculations.

Table 2. Indicators; the descriptions are adopted from the respectively references (see below).

Indicator	Abbr.	Description	Orientation
Consumption of chemicals by hazardousness[1]	CCH	This indicator measures the volume of aggregated consumption of toxic chemicals, expressed in million tonnes. Consumption = production + imports – exports (million tonnes)	The lower the better
Resource productivity[2]	RPR	Resource productivity is gross domestic product (GDP) divided by domestic material consumption (DMC). DMC measures the total amount of materials directly used by an economy (Euro per kilogram, chain linked volumes (2010))	The higher the better
Average CO_2 emissionsfrom new passenger cars[3]	CO_2	The indicator is defined as the average carbon dioxide (CO_2) emissions per km by new passenger cars in a given year (g CO_2 per km)	The lower the better
Circular material use rate[4]	CMUR	The circular material use rate (CMUR) measures the share of material recovered and fed back into the economy in overall material use. The CMR is defined as the ratio of the circular use of material to the overall material use. (% of material input for domestic use)	The higher the better
Generation of waste excluding major mineral wastes [5]	WAS	The indicator measures all waste generated in a country. Major mineral wastes, dredging spoils and soils are excluded (kg per capita)	The lower the better

Note: [1] Eurostat, 2020b, [2] Eurostat, 2020c, [3] Eurostat, 2020d, [4] Eurostat, 2020e, [5] Eurostat, 2020f.

Table 3. Indicators values for the indicators RPR, CO_2, CMUR and WAS for the 27 EU member states for the years 2010, 2014 and 2017, respectively.

		2010				2014				2017			
Country	ID	RPR	CO_2	CMUR	WAS	RPR	CO_2	CMUR	WAS	RPR	CO_2	CMUR	WAS
Austria	AUT	1.843	−144.0	6.6	−1903	1.925	−128.5	10.0	−1838	1.992	−120.7	11.6	−1885
Belgium	BEL	2.211	−133.4	12.6	−3619	2.579	−121.3	18.2	−3116	2.883	−115.9	17.8	−3444
Bulgaria	BGR	0.315	−158.9	2.1	−2002	0.294	−135.9	2.7	−2474	0.321	−126.2	5.1	−2812
Croatia	HRV	na	na	na	na	1.123	−115.8	4.6	−723	1.158	−113.1	5.1	−886
Cyprus	CYP	0.841	−155.8	2.0	−1042	1.447	−129.8	2.2	−757	1.268	−122.2	2.2	−887.5
Czechia	CZE	0.934	−148.9	5.3	−1182	1.008	−131.6	6.9	−1118	1.097	−124.1	8.1	−1243
Denmark	DNK	2.087	−126.2	8.0	−1915	2.047	−110.2	9.1	−1805	1.998	−107.1	8.0	−1716
Estonia	EST	0.464	−162.0	8.8	−8612	0.485	−140.9	11.0	−9514	0.474	−132.8	8.7	−9338
Finland	FIN	1.020	−149.0	13.5	−4517	1.109	−127.4	7.3	−2508	1.103	−118.2	2.2	−2582
France	FRA	2.544	−130.5	17.5	−1505	2.673	−114.2	17.8	−1439	2.775	−110.4	18.6	−1476
Germany	DEU	2.031	−151.1	11.0	−1713	2.041	−132.5	10.7	−1908	2.248	−127.2	11.6	−1885
Greece	GRC	1.278	−143.7	2.7	−2016	1.337	−108.2	1.4	−1928	1.559	−108.8	2.4	−1402
Hungary	HUN	1.012	−147.4	5.3	−1156	0.832	−133.0	5.4	−1214	0.873	−125.6	6.6	−1109
Ireland	IRL	1.623	−133.2	1.7	−2704	2.004	−117.1	1.9	−1666	2.371	−111.6	1.6	−1688
Italy	ITA	2.350	−132.7	11.6	−1674	3.099	−118.1	16.8	−1751	3.33	−113.3	17.7	−1823
Latvia	LVA	0.891	−162.0	1.2	−627	0.860	−140.4	5.3	−1001	0.873	−128.8	6.6	−724
Lithuania	LTU	0.727	−150.9	3.9	−983	0.758	−135.8	3.8	−1119	0.714	−127.4	4.8	−1318
Luxembourg	LUX	3.677	−146.0	24.1	−3008	3.738	−129.9	11.2	−1617	3.383	−127.0	8.9	−2488
Malta	MLT	2.227	−131.2	5.4	−814	1.526	−115.3	10.3	−946	1.827	−111.0	6.7	−1183
Netherlands	NLD	3.350	−135.8	25.3	−2626	3.732	−107.3	26.6	−2529	4.457	−108.3	29.9	−2576
Poland	POL	0.5611	−146.2	10.8	−1754	0.618	−132.9	12.5	−1979	0.639	−127.6	9.5	−2101
Portugal	PRT	0.9145	−127.2	1.8	−1087	1.0959	−108.8	2.5	−1123	1.078	−104.7	1.8	−1232
Romania	ROU	0.4537	−148.5	3.5	−1168	0.3735	−128.2	2.1	−1050	0.39	−120.6	1.8	−1097
Slovakia	SVK	0.9489	−149	5.1	−1230	1.0871	−131.7	4.8	−1166	1.171	−126.1	5.1	−1519
Slovenia	SVN	1.1085	−144.4	5.9	−1865	1.3422	−121.3	8.4	−1604	1.482	−119.6	8.5	−1468
Spain	ESP	1.8223	−137.9	10.4	−1332	2.6323	−118.6	7.7	−1428	2.784	−115	7.4	−1540
Sweden	SWE	1.81	−151.3	7.2	−1969	1.7449	−131	6.5	−1901	1.793	−122.3	6.5	−2136

Table 4. Indicator values for the European Union and for GRC for the years 2010–2017.

	European Union				Greece			
Year	RPR	CO_2	CMUR	WAS	RPR	CO_2	CMUR	WAS
2010	1.7255	−139.6	10.7	−1720	1.2783	−143.7	2.7	−2016
2011	1.6655	−135.3	10.3	−1720	1.2916	−132.7	2.2	−2033.5
2012	1.7913	−132	11.1	−1720	1.309	−121.1	1.9	−2051
2013	1.8387	−126.4	11.2	−1727.5	1.3562	−111.9	1.9	−1989.5
2014	1.846	−123.1	11.1	−1735	1.3373	−108.2	1.4	−1928
2015	1.8944	−119.1	11.2	−1749	1.3918	−106.4	2	−1627
2016	1.9345	−117.6	11.4	−1763	1.4766	−106.3	2.3	−1326
2017	1.9332	−118	11.2	−1790.5	1.5585	−108.8	2.4	−1402

Table 5. Data on the consumption of chemicals by hazardousness—EU aggregate.

Year	nonHaz	HazHea	HazEnv
2004	−80.3	−241.4	−83.9
2005	−82.8	−248.9	−88.9
2006	−84.7	−243.5	−87.0
2007	−88.2	−251	−91.0
2008	−76.1	−238.6	−92.4
2009	−68.8	−203.5	−76.1
2010	−79.1	−232.4	−86.4
2011	−80.2	−222.5	−84.6
2012	−82.3	−216.9	−79.9
2013	−80.8	−215.9	−80.0
2014	−81.8	−220.0	−80.4
2015	−84.9	−215.9	−77.7
2016	−85.9	−212.1	−75.1
2017	−87.9	−216.8	−74.3
2018	−89.8	−217.6	−75.7
2019	−86.5	−216.2	−78.4

2.2. Partial ordering—the basics

The basis for partial ordering is the relation among the objects to be ordered where the combined data are analyzed without additional presumptions or pretreatments. The only mathematical term in this context is "≤" (cf., e.g., Annoni et al., 2015; Bruggemann and Patil, 2011; Bruggemann and Voigt, 2008; Carlsen, 2018; Carlsen and Bruggemann, 2013, 2014, 2018; Newlin and Patil, 2010; Voigt et al., 2013). Thus, the "≤" relation is the basis for a comparison of objects and constitutes a graph, the so called Hasse diagram (see below). Two objects are connected with each other if and only if the relation $x \le y$ holds. However, since each object is characterized by a series of indicators r_s the obvious questions is how $x \le y$ should be understood. As a given object, x, is characterized by the a set of indicators $r_s(x)$, $s = 1,...,m$, it can be compared to another object y, characterized by an identical set of indicators $r_s(y)$, if

$$r_s(x) \leq r_s(y) \text{ for all } s = 1,\ldots,m \quad (1)$$

It is obvious that Equation (1) is a rather strict requirement for having a comparison as at least one indicator value of object x must be lower (the remaining lower or at least equal) to those of object y. In more technical terms: Let X be the group of objects studied, i.e., X = {O1, O2, O3, ……, On}, then object Oy will be ranked higher than object Ox, i.e., Ox < Oy if at least one of the indicator values for Oy is higher than the corresponding indicator value for Ox and no indicator for Oy is lower than the corresponding indicator value for Ox. On the other hand, if $r_s(Oy) > r_s(Ox)$ for some indicator s and $r_t(Oy) < r_t(Ox)$ for some other indicator t, Oy and Ox will be called incomparable (notation: Oy ∥ Ox) due to the mathematical contradiction expressed by the conflicting indicator values. A set of comparable objects is called a chain, whereas a set of mutually incomparable objects is called an antichain. In cases where all indicator values for two objects, Oy and Ox, are equal, i.e., $r_s(Oy) = r_s(Ox)$ for all s, the two objects will be considered as equivalent, i.e., Ox ~ Oy, which in ranking terms means that they will have the same rank.

2.3. The Hasse diagram

The Equation (1) is the basis for the Hasse diagram technique (HDT) (Bruggemann and Carlsen, 2006a; Bruggemann and Patil, 2011; Bruggemann and Carlsen, 2006b). Hasse diagrams are visual representation of the partial order. In the Hasse diagram comparable objects are connected by a sequence of lines (Bruggemann and Carlsen, 2006a, b; Bruggemann and Patil, 2011; Brüggemann and Münzer, 1993; Brüggemann and Voigt, 1995; Bruggemann and Voigt, 2008). Thus, sets of comparable objects, i.e., fulfilling eqn. 1 are called chains that in the diagram are connected with lines, whereas sets of mutually incomparable objects, i.e., not fulfilling eqn. 1 are called antichains.

In the diagram the single objects are positioned in levels, typically arranged from low to high (bottom to top in the diagram). A general rule is that objects are located a high in the diagram as possible. Thus, isolated objects will be by default at the top level of the diagram. It is important to make sure that the orientation of the single indicators are identical, e.g., that high values correspond to “good” whereas low values correspond to “bad”. In practice this is done by multiplying indicator values by −1 in case where high and low values correspond to “bad” and “good”, respectively (cf. 2.5). In the present study the highest located object/country will be assigned rank 1 indicating the “best”.

The module mHDCl7_1 of the PyHasse software (vide infra) was used for the basic partial ordering calculations and the associated construction of the Hasse diagrams.

2.4. Sensitivity—indicator importance

The relative importance of the single indicators in play can be determined through a sensitivity analysis (Brüggemann et al., 2001). The basic idea is to construct partial ordered sets (posets) excluding the single indicators one at the time. Subsequently, the distances from these posets to the original poset are determined. The indicator, whose elimination from the original poset leads to the maximal distance to the original one, in other words causing the highest degree of changes in the Hasse diagram is most important for the structure of the original partial order. As the effect of elimination single indicators is studied, this kind of sensitivity analysis can be called “indicator-related sensitivity”.

In a recent paper Bruggemann and Carlsen (2021) reported an attempt to verify the authenticity of the calculated sensitivity data, i.e., to verify that the values correspond to real, i.e., non-random effects. The calculated sensitivities, $W_i$calc, were normalized to the number of possible connections between the objects, n, i.e., n(n−1)/2. The single normalized sensitivities $w_i = 2xW_i calc/n(n-1)$. Eventually the w_i data are compared to an estimated limit (Bruggemann and Carlsen, 2021). The $W_i$calc values were calculated by the sensitivity23_1 module of the PyHasse software (vide infra).

2.5. Average ranking

Looking at the Hasse diagram, the level structure constitutes a first approximation to ordering. However, as all objects in a level automatically will be assigned identical orders such an ordering will obviously cause many tied orders. Obviously, it is desirable with a degree of tiedness as low as possible. Hence, ultimately a linear ordering of the single objects is desirable. However, when incomparable objects are included in the study, this is obviously not immediately obtainable. Partial order methodology provides a weak order, where tied orders are not excluded. This is obtained by calculating the average order of the single objects as, e.g., described by Bruggemann and Carlsen (2011) and Bruggemann and Annoni (2014).

The average rankings were calculated applying the LPOMext8_5 (Bruggemann and Carlsen, 2011) and BubleyDyer11_1 (Bubley and Dyer, 1999) modules of the PyHasse software (vide infra). The latter module further allows the calculation of the probability for a given object to be ranked higher than any incomparable object as well as the probabilities for the single objects to take a specific rank.

2.6. Software

All partial order analyses were carried out using the PyHasse software (Bruggemann et al., 2014). PyHasse is programmed using the interpreter language Python (version 2.6). Today, the software package contains more than 100 specialized modules and is available upon request from the developer, Dr. R.Bruggemann (brg_home@web.de).

K-means clustering is based on a custom-made script in R applying the “cluster” and “fpc” libraries and run under R x64 2.15.3.

3. Results and discussion

3.1. Partial ordering and average ranking

To elucidate the development of responsible consumption and production within the European Union taking the four main indicators RPR, CO_2, CMUR and WAS simultaneous into account partial ordering appears as an attractive methodology. Hence, based on partial ordering methodology it is possible to elucidate the trend within the EU as well as within the single member states. Hasse diagrams constitute here an advantageous way to visualize the mutual relations between the member states (Figure 1).

A visual inspection of the three Hasse diagrams corresponding to the partial ordering of the 27 member states for the years 2010 (Figure 1A), 2014 (Figure 1B) and 2017 (Figure 1C) gives the first indication of the mutual ranking between the states. Further, the inspection shows a broadening of the diagrams although the number of incomparabilities vs comparabilities remains virtually constant by 264/61, 296/55 and 298/53, respectively with an increasing number of states in the top level indicating an increasing number of states develops positively in relation to comply with the targets of SDG 12 (UNDP, 2020). In addition, a first indication of which states are in the top and in the bottom is obtained.

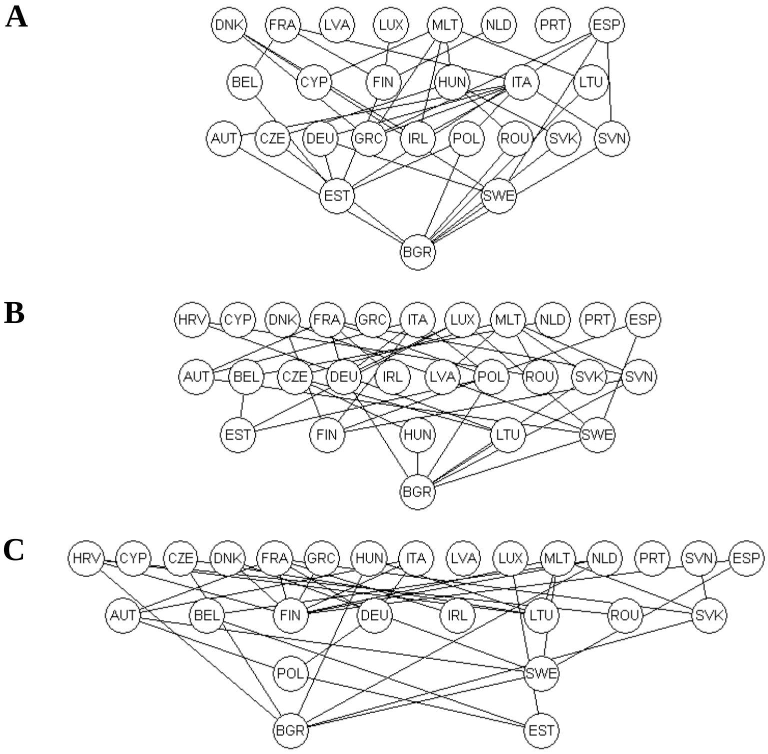


Figure 1. Hasse diagrams visualizing the partial ordering of the 27 EU member states for A: 2010, B: 2014 and C: 2017.

A deeper insight in the actual ranking of the 27 member states can obviously be obtained by deriving the average rankings (cf. sect. 2.4) that is a weak ordering of the 27 states taking all 4 indicators into account simultaneously. Due to the incomparabilities several strict linear orders (linear extensions) will comply with the partial ordering eventually leading to the average ranking being based on the probabilities for the single states to occupy different positions (ranks). In Table 6 the derived average ranks of the 27 EU member states for the years 2010, 2014 and 2017 are given corresponding to the Hasse diagrams (Figures 1A, B and C).

It is emphasized that the results summarized in Table 6 show only the mutual ranking of the 27 EU member states for each of the three years. Thus, comparing the single years does not give information concerning the development in the single countries. It should be noted that for 2010 the data for Croatia (HRV) are incomplete; thus, the average rank for HRV could not be obtained.

Table 6. Average ranking of the 27 EU member states for the years 2010. 2014 and 2017 based on partial ordering including all 4 indicators (RPR, CO_2, CMUR, WAS).

	2010		2014		2017	
	Rank value	*Rank*	*Rank value*	*Rank*	*Rank value*	*Rank*
AUT	16.000	15	14.417	14	10.857	13
BEL	13.000	10	14.667	16	14.667	18
BGR	25.334	26	26.387	27	25.985	27
CYP	16.667	16	14.000	11	14.000	16
CZE	17.117	18	9.533	9	8.500	9.5
DEU	11.669	9	19.083	21	13.350	14
DNK	5.850	5	7.383	7.5	7.450	6.5
ESP	5.138	4	7.383	7.5	7.450	6.5
EST	24.309	25	24.106	26	25.025	26
FIN	18.067	21	23.708	25	24.665	25
FRA	2.068	1	2.922	2	2.945	1
GRC	21.829	24	14.000	11	10.500	11
HRV	na	na	6.633	5	5.583	4
HUN	7.700	8	18.033	20	8.500	9.5
IRL	20.983	23	17.333	18.5	17.333	19
ITA	4.731	3	3.861	3	3.851	2
LTU	14.500	14	19.733	22	22.817	24
LUX	7.667	6.5	5.967	4	10.500	12
LVA	13.500	11.5	17.333	18.5	14.000	16
MLT	2.622	2	2.720	1	4.929	3
NLD	7.667	6.5	7.333	6	5.717	5
POL	13.650	13	14.400	13	19.719	22
PRT	13.500	11.5	14.000	11	14.000	16
ROU	17.117	18	20.000	23	18.167	20
SVK	17.117	18	15.167	17	19.183	21
SVN	17.800	20	14.550	15	8.250	8
SWE	20.271	22	22.202	24	21.700	23

Note: [1] In complete data for Croatia (HRV) for 2010.

Table 6 clearly disclose that France (FRA), Malta (MLT) and Italy (ITA) for all three years takes the top 3 positions, thus being the three countries with the most responsible consumption and production within the Union based on the analysis simultaneously bringing the four main indicators RPR, CO_2, CMUR and WAS into play. On the other hand, it is also disclosed that Bulgaria (BRG) and Estonia (EST) for all three years are found at the bottom position among the European countries, thus with the least responsible consumption and production.

Further Table 6 elucidates that countries like Greece (GRC), Czechia (CZE) and Slovenia (SVN) within the European have significantly improved their responsible consumption and production moving from the 24th to the 11th place, 18th to 9th place and 20th to 15th to 8th place, respectively, whereas pronounced declines are noted for Belgium (BEL), Lithuania (LTU), Luxembourg (LUX) and Poland (POL).

3.2. Temporal development 2010–2017

To disclose the temporal develop of responsible consumption and production within the European Union as well as within single member states datasets the data for the European Union as well as for GRC as an exemplary country case have been analyzed (Table 4). Figure 2 displays the corresponding Hasse diagrams.

The diagram displayed in Figure 2A, is a priori of rather low information with only 2 levels with, in total 3 comparisons and 25 incomparisons, leaving very few possibilities for conclusions apart from the fact that apparently year 2012 was better than the years 2010 and 2011, which should be d expected if a general improvement prevailed and the 2016 is better than 2017, which contradicts a positive development. It should be emphasized that the ratio between the number of objects studied and the number of indicators may turn out as crucial (Sørensen et al., 2000). Thus, if the number of indicators relative to the number of objects studied is too high the number of incomparisons unambiguously will increase. On the other hand, the Hasse diagram for the development in Greece over the years 2010–2017 appears much more informative with 12 comparabilities and 16 incomparabilities, respectively. This is further substantiated by the corresponding average ranks. Here (Table 7) it is noted that in the case of the EU combined 2010 and 2011 are assigned the same rank as is 2013–2015, whereas in the case of GRC all years are assigned individual ranks. In the case of GRC it is further noted that the year 2010 appears as an isolated element (cf. Figure 2) meaning that in all relations to the other years an indicator conflict prevails. Analyzing the temporal development for GRC (cf. Table 4) it can be disclosed that year 2010 is an atypical year due to an unexpected high CMUR value.

The blurred picture for the ranking of the years 2010–2017 for the EU combined is further substantiated by looking at the actual probabilities for the single years to occupy a specific rank as derived from a large number of randomly generated linear extensions (here 309) (Bubley and Dyer, 1999) (Table 8), i.e., the best year appears to be 2012 with a probability of 0.389 and the worst year 2017 with a probability 0.276. However, it is virtually not possibly to draw any firm conclusions.

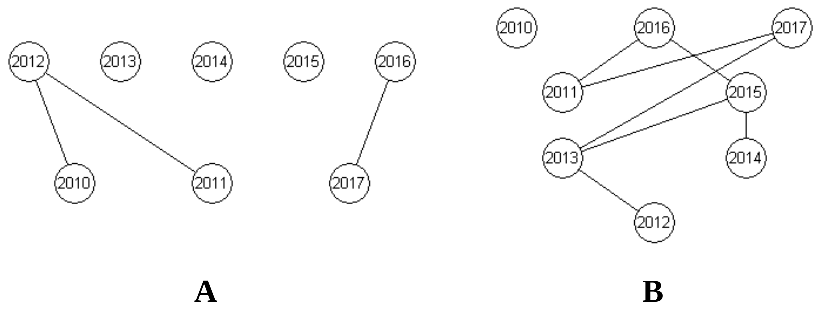


Figure 2. Hasse diagrams visualizing the development for A: the European Union and B: GRC over the years 2010–2017 including all 4 indicators (RPR, CO_2, CMUR, WAS).

Table 7. Average rank 2010–2017 based on partial ordering including all 4 indicators (RPR, CO_2, CMUR, WAS).

	EU combined		Greece	
Year	Rank value	Rank	Rank Value	Rank
2010	5.833	6.5	4.500	4
2011	5.833	6.5	6.083	6
2012	2.25	1	7.333	8
2013	4.5	4	5.667	5
2014	4.5	4	6.167	7
2015	4.5	4	3.033	3
2016	3	2	1.393	1
2017	6	8	2.233	2

Table 8. Probabilities of the single years to occupy specific ranks for the EU combined for the years 2010–2017.

	Rank probability							
year	1	2	3	4	5	6	7	8
2010	0	0.045	0.095	0.147	0.129	0.171	0.226	0.184
2011	0	0.042	0.103	0.121	0.176	0.168	0.184	0.203
2012	0.389	0.292	0.139	0.1	0.061	0.016	0	0
2013	0.134	0.132	0.111	0.137	0.129	0.137	0.118	0.1
2014	0.113	0.103	0.171	0.126	0.145	0.113	0.105	0.121
2015	0.121	0.142	0.121	0.121	0.139	0.126	0.113	0.113
2016	0.239	0.218	0.187	0.142	0.097	0.087	0.026	0
2017	0	0.024	0.071	0.103	0.121	0.179	0.224	0.276

3.3. Indicator importance

Obviously of interest is a knowledge of the influence of the single indicators on the average ranking (cf. sect. 2.3) as such information may serve as decision support for authorities and regulating body to focus on specific areas to improve the overall responsible consumption and production in the country. In the following we will focus on the most significant indicators for the EU combined and for three specific countries, i.e., FRA, GRC and BGR as examples of countries being overall ranked in the top, in the middle and in the bottom of the 27 member states, respectively. It should be noted that the indicator importance for the single countries may differ from the indicator importance derived for the combined EU. In Table 9 the calculated overall importance of the single indicators for the 27 EU member states as well as for the EU combined.

It is immediately seen that apparently WAS is the most important indicator when describing the responsible consumption and production for the European Union, the values in bold are significant, i.e., non-random numbers, the limiting values for a 4-indicator system being 0.205 (Bruggemann and Carlsen, 2021). Thus, normalized sensitivity values below 0.205 may be ascribed to randomness due to the calculation procedure (Bruggemann and Carlsen, 2021). However, although that the waste problem apparently on an overall evaluation appears as the major obstacle to achieve responsible consumption and production with the EU as such variations from country to country prevail.

Table 9. Comparison of the normalized sensitivity data for the partial ordering of the member states 2010, 2014 and 2017 as well as the combined EU date for the period 2010−2017.

	Member states 2010		Member states 2014		Member states 2017		EU combined 2010–2017	
n	26[1]		27		27		8	
n(n−1)/2	325		351		351		28	
limit[2]	0.205		0.205		0.205		0.205	
property	$W_i$calc	w_i	$W_i$calc	w_i	$W_i$calc	w_i	$W_i$calc	w_i
RPR	6	0.018	11	0.031	14	0.040	0	0.000
CO_2	17	0.052	27	0.077	22	0.063	0	0.000
CMUR	37	0.114	63	0.179	54	0.154	1	0.036
WAS	115	**0.354**	110	**0.313**	98	**0.279**	23	**0.821**

Note: Values in bold are significant, i.e., non-random numbers. [1] for 2010 some data for Croatia was missing, [2] Bruggemann and Carlsen, (2021).

Looking at the temporal development for FRA, GRC and BGR for the period 2010–2017 we find that the most important indicators are CO_2, CMUR and CO_2, respectively. In these three cases the WAS indicator apparently plays only an insignificant role—if at all.

3.4. Temporal development of the consumption of toxic chemicals 2004–2019

As it by 2020 is a major goal to achieve an "environmentally sound management of chemicals and all wastes throughout their life cycle, in accordance with agreed international frameworks, and significantly reduce their release to air, water and soil in order to minimize their adverse impacts on human health and the environment" (Target 12.4) (UNDP, 2020) it is of interest to elucidate the temporal development of the consumption of toxic waste in the Union. The present study has retrieved data for the period 2004 to 2019, however on a European scale only (Table 5). In Figure 3 the Hasse diagram based on the 3 indicators nonHaz, HazHea and HazEnv and for 2 indicators HazHea and HazEnv, respectively, are shown based on the data in Table 5. The estimated average ranks for the single years are given in Table 10.

It is obvious (Table 10 and Figure 3A) that the year 2009 appears at the top rank due to rather low indicator values for all three indicators; especially the surprisingly low nonHaz indicator is probably the main reason that 2009 is found as being incomparable to any other years. On the other hand, rather high indicator values make the year 2007 the worst with rank 16. Also, the rather low rank of 2018 and 2019 should be noted as a result of an increasing nonHaz.

It is obvious (Table 10 and Figure 3A) that the year 2009 appears at the top rank due to rather low indicator values for all three indicators; especially the nonHaz indicator is surprisingly low probably the main reason that 2009 is found as being incomparable to any other years. On the other hand, rather high indicator values make the year 2007 the worst with rank 16. Also, the rather low rank of 2018 and 2019 should be noted as a result of an increasing nonHaz.

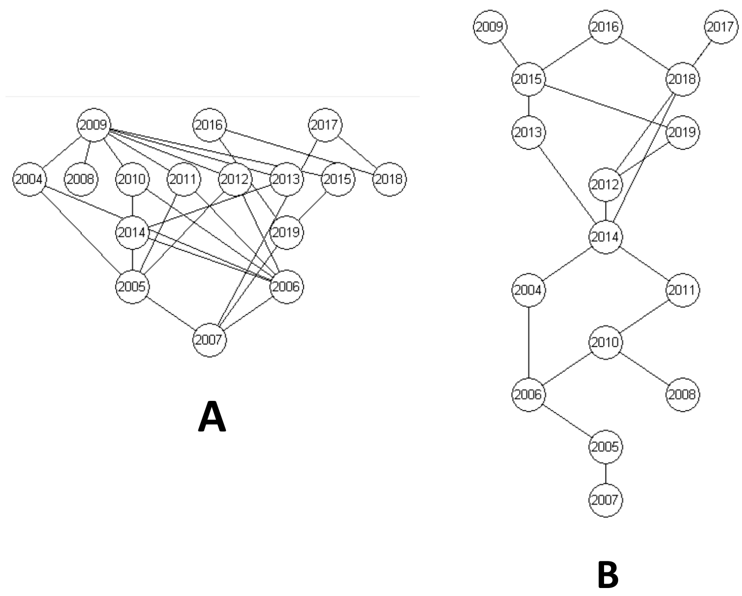
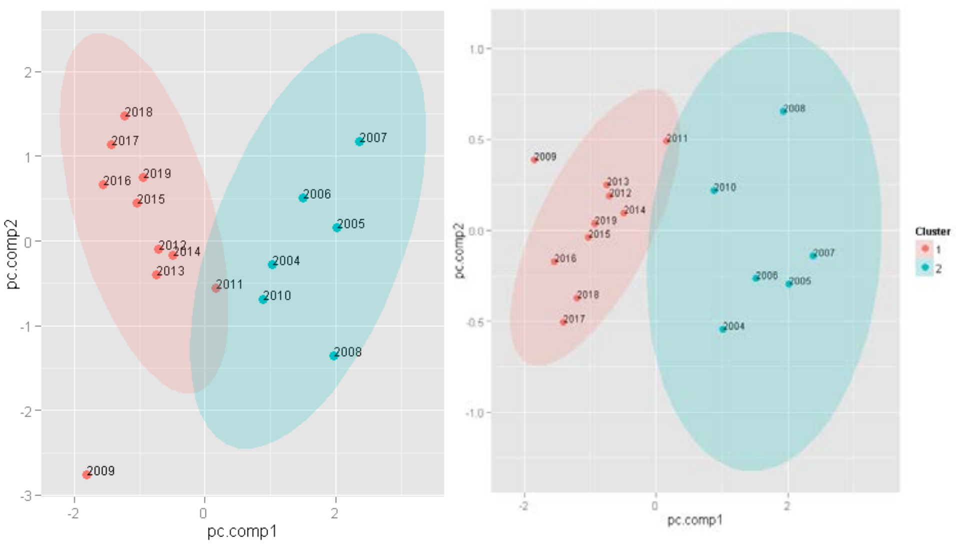


Figure 3. Hasse diagrams visualizing the development for the consumption of chemicals by hazardousness over the years 2004–2019; A: including all 3 indicators (nonHaz, HazHea, HazEnv) and B: 2 indicators (HazHea, HazEnv).

Table 10. Average ranking of the consumption of chemicals by hazardousness for the year 2004–2019 based on nonHaz, HazHea and HazEnv and HazHea and HazEnv, respectively.

	3 indicators		2 indicators	
Year	Rank value	Rank	Rank value	Rank
2004	6.333	5	11.2	11
2005	13.606	14	14.6	15
2006	13.606	15	13.4	13
2007	15.852	16	15.8	16
2008	9.5	11	14.25	14
2009	1.232	1	1.867	2
2010	6.333	6	11.5	12
2011	6.333	7	10.25	10
2012	6.333	8	7.55	8
2013	4.852	3	6.55	7
2014	8.229	10	9	9
2015	6.483	9	3.833	4
2016	4.2	2	1.533	1
2017	5.417	4	2.75	3
2018	12.417	13	6.25	6
2019	12	12	5.733	5

Based on the Hasse diagram shown in Figure 3A the importance of the single indicators (cf. sect. 2.3) was estimated. Unambiguously the nonHaz indicator was the most important. Eliminating the nonHaz from the group of included indicators resulted in the Hasse diagram shown in Figure 3B. The year 2007 is still found at the lowest rank (Table 10) due the high indicator values where the top is now occupied by year 2016 followed by 2009—again a visualization of the indicator values.



A **B**

Figure 4. K-means clustering visualizing the development for the consumption of chemicals by hazardousness over the years 2004–2019; A: including all 3 indicators (nonHaz, HazHea, HazEnv) and B: 2 indicators (HazHea, HazEnv).

An alternative approach to visualizing the consumption of chemicals by hazardousness for the years 2004 to 2019 is by a cluster analysis. In Figure 4 the K-means clustering of the data given in Table 5 is visualized.

It is immediate noted that in both cases the year 2009 is found as an outlier away from any of the two cluster further substantiating the effect of the rather low indicator values. Further it is noted that the years virtually is divided into two groups including 2004–2010 and 2011–2019, excluding 2009, reflecting the general tendency to lower values for the 3 indicators (Table 5) seen for the latter years and thus indicating the overall route to an improved and sustainable consumption of chemicals.

4. Conclusions and Outlook

Partial order methodology constitutes an advantageous decision support tool to analyze multi-criteria datasets as illustrated in the present paper focusing on responsible consumption and production within the European Union based on four main indicators: resource productivity, average CO_2 emissions from new passenger cars, circular material use rate and generation of waste excluding major mineral wastes. Further, a fifth indicator, consumption of chemicals by hazardousness, is treated separately. The ultimate goal is by 2030 to achieve the sustainable management and efficient use of natural resources.

Partial ordering has been applied to rank the 27 EU member states based on a simultaneous inclusion of all 4 indicators. The ranking gives a picture of the situation the 27 member states relative to each other. It has been shown that France, Malta and Italy apparently are the three countries with having the best responsible consumption and production whereas Bulgaria and Estonia are found in the other end of the spectrum.

Analyzing the indicator importance, it is disclosed that looking the EU as a whole the most important indicator is the generation of waste. This is in accordance with the fact that the waste problem constitutes a significant problem throughout Europe. An important part of the waste problem is associated with food waste that constitutes an illustrative Hence, an "equivalent to 1.3 billion tonnes worth around $1 trillion is estimated as the annual food waste that ends up rotting in the bins of consumers and retailers, or spoiling due to poor transportation and harvesting practices, which actually adds up to an estimated one third of all food produced" (UNDP, 2020). It is worthwhile in this connection to mention the link to SDG 2, Zero hunger, as "almost 1 billion people go undernourished and another 1 billion hungry" (UNDP, 2020). A major goal is by 2030 to "halve per capita global food waste at the retail and consumer levels and reduce food losses along production and supply chains, including post-harvest losses" and in more general terms "substantially reduce waste generation through prevention, reduction, recycling and reuse" (UNDP, 2020). Immediately, based on the current analyses significant work are still to be done to reach the goal by 2030.

It is emphasized that for the single countries the temporal development in their responsible consumption and production not necessarily is controlled by waste generation. Thus, France, Greece and Bulgaria serve as exemplary cases, and it is found that in the case of France and Bulgaria the most important indicator for the temporal development is the average CO_2 emission from new passenger cars, whereas in the case of Greece it apparently is the circular material use rate. Overall the CO_2 emission is decreasing in the EU during the period from 2007 with ca. 157.5 g CO_2/km to 2018 with 119,6 g CO_2/km, although stagnant during 2015–2018, even with slight increase; the 2021 goal is 95 g CO_2/km (Eurostat, 2020d).

A special issue is the hazardous waste. Analysis of the waste according to hazardousness revealed that the amount of non-hazardous waste is the most important and unfortunately an increase in this type of waste is noted during the years 2004–2019, whereas a decrease in waste hazardous to the human health and to the environment is decreasing during the same period. Based on the here presented data the major goal, states by the UNDP (2020) by 2020 to have an "environmentally sound management of chemicals and all wastes throughout their life cycle, in accordance with agreed international frameworks, and significantly reduce their release to air, water and soil in order to minimize their adverse impacts on human health and the environment" by 2020 is by far not achieved.

The results of the present study can immediately be as decision support for future direct action in the different countries as authorities and regulators are provided with data that pinpoint focus areas for action.

Finally, it should be noted that the here presented analyses constitute and exemplary case applying available data for SDG 12. Similar analyses can immediately be performed for, e.g., the other SDGs to the extent where suitable and reliable data are available.

Conflict of interest

The author declares no conflicts of interest in this paper.

References

Annoni P, Bruggemann R, Carlsen L (2015) A multidimensional view on poverty in the European Union by partial order theory. *J Appl Stat* 42: 535–554.

Bruggemann R, Annoni P (2014) Average heights in partially ordered sets. *MATCH Commun Math Comput Chem* 71: 117–142.

Bruggemann R, Carlsen L (2006a) *Partial Order in Environmental Sciences and Chemistry*, Springer, Berlin. Available from: https://www.springer.com/gp/book/9783540339687.

Bruggemann R, Carlsen L (2006b) Introduction to partial order theory exemplified by the evaluation of sampling sites, In: Bruggemann R and Carlsen L (Eds.), *Partial Order in Environmental Sciences and Chemistry*, Springer, Berlin, 61–110.

Bruggemann R, Carlsen L (2011) An improved estimation of averaged ranks of partial orders. *MATCH Commun Math Comput Chem* 65: 383–414.

Bruggemann R, Carlsen L (2021) Attempt to test impact values for multi-indicator systems—exemplified by gender equality. *Qual Quant*.

Bruggemann R, Münzer B (1993) A Graph-Theoretical Tool for Priority Setting of Chemicals. *Chemosphere* 27: 1729–1736.

Bruggemann R, Patil GP (2011) *Ranking and Prioritization for Multi-indicator Systems—Introduction to Partial Order Applications*, Springer, New York.

Bruggemann R, Voigt K (1995) An Evaluation of Online Databases by Methods of Lattice Theory. *Chemosphere* 31: 3585–3594.

Bruggemann R, Voigt K (2008) Basic Principles of Hasse Diagram Technique in Chemistry. *Comb Chem High Throughput Screen* 11: 756–769.

Bruggemann R, Carlsen L, Voigt K, et al. (2014) PyHasse Software for Partial Order Analysis: Scientific Background and Description of Selected Modules, In: Bruggemann R, Carlsen L, and Wittmann J (Eds), *Multi-indicator Systems and Modelling in Partial Order*, Springer, New York, 389–423.

Bruggemann R, Halfon E, Welzl G, et al. (2001) Applying the Concept of Partially Ordered Sets on the Ranking of Near-Shore Sediments by a Battery of Tests. *J Chem Inf Comp Sci* 41: 918–925.

Bubley R, Dyer RM (1999) Faster random generation of linear extensions. *Discr Math* 201: 81–88.

Carlsen L (2018) Happiness as a sustainability factor. The World Happiness Index. A Posetic Based Data Analysis. *Sustain Sci* 13: 549–571.

Carlsen L, Bruggemann R (2013) Partial order methodology a valuable tool in chemometrics. *J Chemometrics* 28: 226–234.

Carlsen L, Bruggemann R (2014) The "Failed State Index" Offers More than Just a Simple Ranking. *Soc Indic Res* 115: 525–530.

Carlsen L, Bruggemann R (2018) Environmental perception in 33 European countries an analysis based on partial order. *Environ Dev Sustain* 22: 1873–1896.

Eurostat (2020a) Sustainable development in the European Union. Monitoring report on progress towards the SDGs in an EU context, 2020 Edition. Available from: https://ec.europa.eu/eurostat/statistics−explained/index.php/Sustainable_development_in_the_European_Union.

Eurostat (2020b) Consumption of toxic chemicals. Available from: https://ec.europa.eu/eurostat/tgm/table.do?tab=table&init=1&language=en&pcode=sdg_12_10&plugin=1.

Eurostat (2020c) Resource productivity and domestic material consumption (DMC). Available from: https://ec.europa.eu/eurostat/tgm/table.do?tab=table&init=1&language=en&pcode=sdg_12_20&plugin=1.

Eurostat (2020d) Average CO_2 emissions from new passenger cars. Available from: https://ec.europa.eu/eurostat/tgm/table.do?tab=table&init=1&language=en&pcode=sdg_12_30&plugin=1.

Eurostat (2020e) Circular material use rate. Available from: https://ec.europa.eu/eurostat/tgm/table.do?tab=table&init=1&language=en&pcode=sdg_12_41&plugin=1.

Eurostat (2020f) Generation of waste excluding major mineral wastes. Available from: https://ec.europa.eu/eurostat/tgm/table.do?tab=table&init=1&language=en&pcode=sdg_12_50&plugin=1.

Eurostat (2020g) Gross value added in environmental goods and services sector. Available from: https://ec.europa.eu/eurostat/tgm/table.do?tab=table&init=1&language=en&pcode=sdg_12_61&plugin=1.

Munda G (2008) Social Multi-Criteria Evaluation for a Sustainable Economy. Springer-Verlag, Berlin. Available from: https://www.springer.com/la/book/9783540737025 (Accessed Dec. 2020).

Newlin J, Patil GP (2010) Application of partial order to stream channel assessment at bridge infrastructure for mitigation management. *Environ Ecol Stat* 17: 437–454.

SDG (2017) Sustainable Development Goals. Available from: https://sdgs.un.org/goals (Accessed Dec. 2020).

Sørensen PB, Mogensen BB, Carlsen L, et al. (2000) The influence of partial order ranking from input parameter uncertainty. Definition of a robustness parameter *Chemosphere* 41: 595–601.

Tseng ML, Wu KJ, Hu J, et al. (2018) Decision-making model for sustainable supply chain finance under uncertainties *Int J Product Econ* 205: 30–36.

Tseng ML, Lim KM, Wu KJ (2019) Improving the benefits and costs on sustainable supply chain finance under uncertainty. *Int J Product Econ* 218: 308–321.

UNDP (2020) Goal 12 Targets. Available from: https://www.undp.org/content/undp/en/home/sustainable-development-goals/goal-12-responsible-consumption-and-production/targets.html (Accessed Dec. 2020).

Voigt K, Bruggemann R, Scherb H, et al. (2013) Organochlorine Pesticides in the Environment and Humans Necessity for Comparative Data Evaluation, In: Wittmann J. and Müller M (Eds), *Simulation in Umwelt−und Geowissenschaften*, Workshop Leipzig 2013, Shaker-Verlag, Aachen, 9–22.

AIMS Press

© 2021 the Author(s), licensee AIMS Press. This is an open access article distributed under the terms of the Creative Commons Attribution License (http://creativecommons.org/licenses/by/4.0)