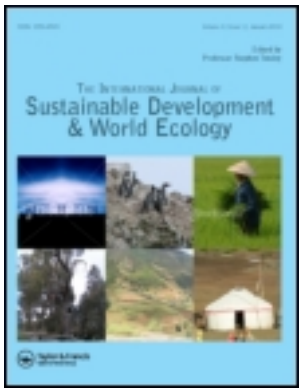

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Principal sustainability components: empirical analysis of synergies between the three pillars of sustainability

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Principal sustainability components: empirical analysis of synergies between the three pillars of sustainability

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Starting from the concept of three fundamental sustainability dimensions (environmental, social, and economic), this study investigated professional contributions to sustainability by means of principal component analysis (PCA). Graduates from the Environmental Sciences program ($N = 542$) at ETH Zurich described their best professional contributions to sustainable development. Next, they evaluated whether their best practice example contributed to achieving any of the five environmental, social, and economic objectives of the Swiss national sustainability strategy. These judgments served as the basis for a PCA aiming to identify *principal sustainability components* (PSCs) covering typical synergies between sustainability objectives within and transcending the three fundamental dimensions. Three PSCs capturing important synergies were identified. PSC 1 *Product and Process Development* reflects how ecological innovation and modernization can generate social and economic benefits and at the same time facilitate the reduction in use of as well as the responsible use of natural resources. PSC 2 *Education and Social Economics* reflects how educational activities and sociocultural sustainability initiatives can simultaneously promote income and employment, social and human capital, and free personal development. PSC 3 *Protection of Nature and Humans* covers the synergetic benefits which protection of natural spaces and biodiversity and the reduction of environmental risks have for the protection of health and safety of the population. The study also revealed that integration of environmental, social, and economic aspects is often connected to conflicts between these dimensions. However, contributions which consider the economic situation of future generations or enhance social and human capital achieved considerable integration but showed no inclination toward such conflicts.

Keywords: sustainability; pillars; dimensions; synergies; integration; economic; social; environmental

Sustainable development and its three pillars

Sustainable development has been adopted by the United Nations as a guiding principle for economic, environmental, and social development that aspires to meet 'the needs of the present without compromising the ability of future generations to meet their own needs' and an 'equitable sharing of the environmental costs and benefits of economic development between and within countries' (United Nations 1987: 1). According to WCED (1987), sustainability entails protection of the environment and natural resources as well as to provide social and economic welfare to the present and to subsequent generations. Sustainable development is also understood as one that is socially just and ethically acceptable. Sustainability has thus been acknowledged as a major normative regulation principle for contemporary society which includes a long-term ethical relationship of present generations with those of the future (Laws et al. 2004; Scholz 2011). Sustainability is an integrative concept which considers environmental, social, and economic aspects as three fundamental dimensions. These three dimensions have been denoted as pillars of sustainability, which reflect that responsible development requires consideration of natural, human, and economic capital or colloquially speaking the planet, people, and profits (Elkington 1997; Kajikawa 2008; Schoolman et al. 2012). However, approaches aiming to balance these three pillars have been criticized since they involve different types of values (e.g., biodiversity, beauty of landscape vs. costs, profits vs. equity, health and cultural values, etc.) that are not directly commensurable relative to each other (Hirsch Hadorn 1999; Mieg 2010). Furthermore, controversial interests of different stakeholders frequently conflict within a single pillar of sustainability (i.e., social conflicts; economic conflicts; conflicts over environmental issues; or preferences), and therefore balancing their interests regarding one pillar is sometimes more in the foreground than to balance social, economic, and environmental aspects (Kyburz-Graber et al. 2006).

The metaphor of balancing the three pillars does not appropriately account for the complex interrelationships between human activities and the environment as conceptualized in theories on human–environment systems (Kates et al. 2001; Scholz 2011; Schoolman et al. 2012). This study thus takes a different perspective by using the three pillars as the basis for the search of synergies between important goals of sustainable development. The three dimensions can mutually influence each other in positive as well as in negative ways. Thus, striving for positive synergies between them represents a crucial task of sustainability-oriented decision making. Accordingly, the focus of this study is not on questions of trade-offs between the pillars such as – *What are the financial costs*

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for environmental protection we are ready to pay? – but on win–win questions such as – *How can socioeconomic output and environmental quality be maximized conjointly?*

The view that an encompassing positive integration of the three sustainability pillars is needed to effectively facilitate sustainable development has, for example, been expressed in the sustainability strategy of the Government of Western Australia (2003). It states that sustainability requires 'new synergies to be identified as well as "systems thinking" to produce simultaneous outcomes for the economy, community and environment' (Government of Western Australia 2003: 73), and 'economic, social and environmental factors be integrated [. . .] seeking mutually supportive benefits with minimal trade-offs' (Government of Western Australia 2003: 30). From this perspective, the main challenge of sustainable development as defined in the Brundtland Report (WCED 1987) would be to fulfill the needs of current and future generations through simultaneous environmental, social, and economic improvement. Many such synergies have been discovered and investigated by researchers or acknowledged in public discourse. For example, high environmental quality, scenic beauty, and biodiversity allow for regional economic income through sustainable tourism from which local communities may profit (e.g., Gurung 2008); sustainable construction allows for reduction in the use of nonrenewable energy resources and hence economic savings (e.g., Vatalis et al. 2011), and the development of innovative technologies for generating power from renewable energy sources such as wind or sun is broadly acknowledged to bear the potential to generate workplaces and trigger economic growth while saving nonrenewable resources and reducing CO_2 emissions (e.g., Dalton and Lewis 2011).

However, it has not been systematically examined so far, which aspects of the three pillars are typically connected with each other in practice in ways involving such positive synergies. Such an analysis shall be accomplished here on the basis of reports on actual contributions to sustainable development accomplished by graduates of a sustainability-oriented university curriculum.

Scope of the study

In order to empirically investigate positive synergies between the three pillars of sustainability, this study analyzes best practice examples from graduates of the Environmental Sciences program at ETH Zurich for professional contributions to sustainability with reference to the Swiss sustainability strategy (Schweizerischer Bundesrat 2002). This strategy formulated 15 sustainability goals in total, 5 goals for each of the 3 pillars. The graduates judged their own professional contributions to sustainable development toward these goals. These responses provide the basis for the investigation of typical fields of synergies between the different sustainability objectives by means of a factorial principal component analysis (PCA). This data-driven approach shall provide insights into the actual (typical or prevalent) goal structures of sustainability-oriented projects, measures, and innovations based on the analysis of concrete sustainability engagement of environmental professionals. These graduates completed a broad and interdisciplinary sustainability-oriented curriculum, which combines profound natural science education with environmental technology and social scientific courses, including law and economics. It also offers possibilities for in-depth specializations in different scientific subjects and various environmental or human–environment systems (Frischknecht 2000; Hansmann 2009). It was known beforehand that these graduates work in a broad variety of professional domains. Thus, their responses allow for an investigation into sustainability-oriented professional activities in diverse topical areas (Hansmann et al. 2010; Mieg et al. 2012). Based on their educational background and professional experience, the graduates can be considered as sustainability experts to a certain extent (Mieg 2008, 2009). These aspects make the elicited sample of graduates particularly suitable for an explorative empirical investigation of synergies between the three pillars of sustainability in professional practice, a topic of utmost importance for sustainable development. A further aspect of sustainability practice that will be investigated is the question of how the emergence of conflicts between the sustainability dimensions is related to their integration.

Method

Design of the graduate survey addressing contributions to sustainability

A web-based survey of ETH graduates of Environmental Sciences analyzed their professional development and contributions to sustainability since graduation. The questionnaire elicited information on the graduates (e.g., gender, age, and the year of graduation), their professional activities (e.g., relatedness of work to sustainability, branch of activity), and asked for examples of personal professional contributions to sustainable development after graduation. The latter should allow for insights into sustainability-oriented professional activities in concrete rather than abstract terms.

Each graduate briefly described his or her best practice example in their own words and subsequently answered a set of standardized items serving to classify and evaluate it. The graduates thus assigned their example to the appropriate topical field(s) of a predefined list with 19 categories (including, e.g., energy, nature and landscape, climate, water, soil, air, education, and also a category 'other fields of activity') and specified the year in which their personal professional engagement for the contribution was at its maximum. Finally, they evaluated their best practice example as to whether

– a systematic integration or balancing of ecological, economic, and social aspects of sustainability took place (*yes* vs. *no*);

– conflicts between these three sustainability dimensions emerged (*yes* vs. *no*);
– it contributed to achieving the 15 goals comprised in the Swiss strategy for sustainable development (Schweizerischer Bundesrat 2002).

For each of the five ecological, economic, and social sustainability objectives of the strategy, the graduates separately judged whether their best practice example contributed to achieving it (*yes* vs. *no*). A PCA was applied on these responses to analyze which sustainability objectives were frequently achieved together in best practice contributions as reflected in high loadings of certain objectives on a common principal component. A possible outcome in this regard was that components which load exclusively on the sustainability objectives of one of the three pillars would emerge from the PCA. This would indicate a lack of synergies and integration between the three pillars. However, since objectives of the three sustainability dimensions can be simultaneously targeted – as has been outlined in the Introduction – the expectation was that the emergent loading pattern of the objectives on the principal components would reveal distinctive areas of synergies and integration within the pillars, as well as transcending their borders. The principal components resulting from the PCA will be denoted as principle sustainability components (PSCs).

Participants of the survey

A total of 1081 students of Environmental Sciences graduated from ETH between 1992 and 2005. More than half of them ($N = 567$) visited the survey webpage and responded at least to the first question. Among these participants, 542 persons (96%) were professionally active at the time of the survey. The predominant branches were research (21%); environmental, planning, and engineering offices (15%); public administration (15%); finance and insurance (10%); education (8%); and non-governmental organizations (NGOs) (5%). The remaining 26% worked in diverse further domains.

On average, participants were M = 36.7 years old (Md = 37, SD = 4.3) and the distribution of the year of graduation of the survey participants was similar to that of all graduates from 1992 to 2005 (χ^2-test, $df = 13$, $p = 0.43$). The gender distribution of the survey participants was with 33% females and 67% males likewise that among all graduates of the addressed years with 34% females.

Results

The analyses focus on the best practice examples of the graduates for professional contributions to sustainability. In a first step, the distribution of the contributions over topical domains will be presented. Subsequently, it was analyzed which of the 15 objectives of the Swiss sustainability strategy were addressed and whether conflicts between the triple line dimensions emerged and systematic efforts for integrating or balancing them were made. Then, the PCA identifying PSCs that reflect fields of synergies between sustainability objectives is reported.

Topical domains of the best practice contributions to sustainable development

Participants were asked whether their current job is directly related to fostering sustainable development. On a five-point rating scale (1 = no, 2 = rather no, 3 = rather yes, 4 = yes, 5 = yes, very strongly), this relationship was rated on average with M = 3.1 corresponding to the answer 'rather yes'. Consistent with this, a clear majority of participants were able to provide a description of their best example for a professional contribution to sustainable development. When assigning their best practice contribution to topical domains graduates could choose one or more domains since these categories were not strictly disjunctive. The distribution of the 373 contributions over the 19 predefined topical domains is depicted in Figure 1. Accordingly, 38% of the best practice examples were related to energy, followed by 34% connected to nature and landscape, and 31% with connections to the areas climate and water. The domains of soil (24%), air, and education (both 21%), environmental management, and waste (both 19%) were also quite frequently covered by the examples.

Contribution to the objectives of the Swiss strategy for sustainability

The percentages of best practice examples contributing to the five environmental, economic, and social objectives of the Swiss sustainability strategy are shown in Figure 2.

Considering environmental objectives, most examples contributed to the responsible use of renewable resources (69%) followed by the protection of the natural environment (65%) and the reduction of the use of nonrenewable resources (59%). Considering economic sustainability objectives, the largest ratio was observed for the improvement of the economic situation of future generations (50%), and amongst social aspects, protection of health and safety of the population (60%) was supported by most examples.

The best practice contributions addressed on average 2.6 ecological objectives, 1.7 economic, and likewise 1.7 social objectives of the Swiss sustainability strategy. In line with the environmental focus of the university program, environmental objectives were thus covered significantly more frequently than either economic or social objectives (both paired sample t-tests, $p < 0.001$).

Systematic integration and conflicts between ecological, economic, and social aspects of sustainability

According to the graduates' answers, 47% of the best practice contributions involved a systematic integration or balancing of ecological, economic, and social aspects of sustainability, and in 46% of the examples a conflict

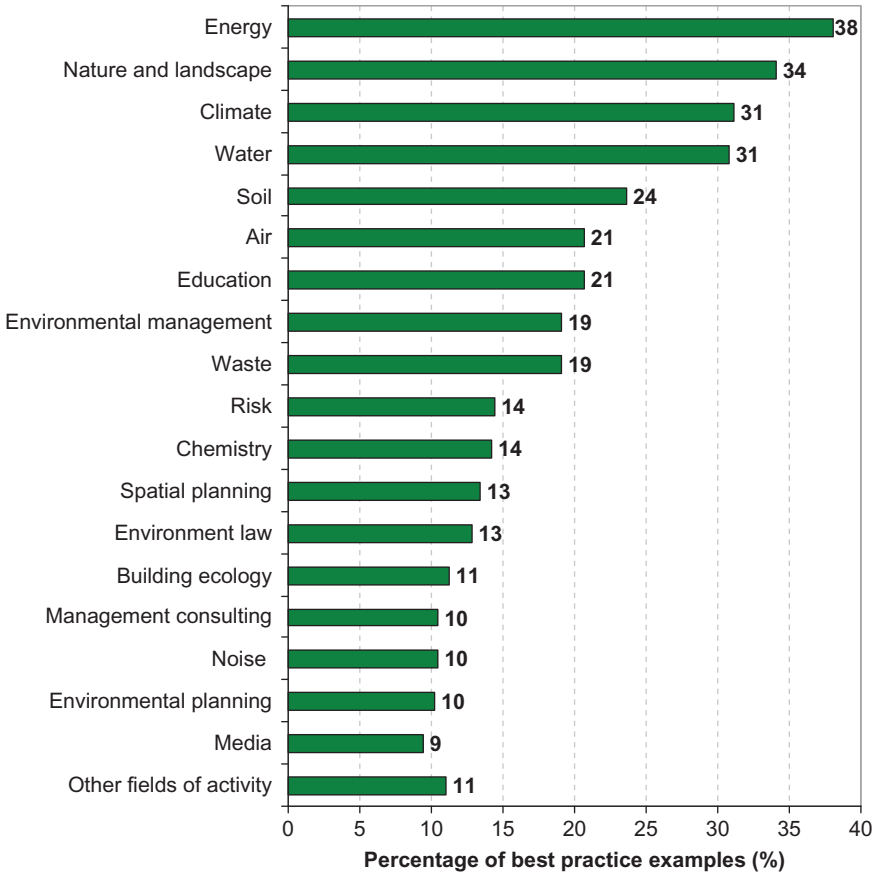

Figure 1. Percentage of best practice examples contributing to sustainability in different topical domains ($N_{examples} = 373$).

between the three dimensions was evident. The occurrence of conflicts between the dimensions and their systematic integration is interconnected. In 63% of the examples with conflicts between the dimensions, efforts were taken aiming at their systematic integration. In contrast, systematic efforts toward balancing the three dimensions occurred only in 34% of the examples with no such evident conflicts. The statistical relationship between integration and conflict was clearly significant (χ^2-test, $df = 1$, $\chi^2 = 32.2$; $p < 0.001$).

In a further analysis, the percentage of best practice examples with efforts toward systematic integration and with occurrence of conflicts between ecological, economic, and social sustainability aspects was compared separately for the examples addressing each of the 15 specific sustainability objectives. Two of the corresponding McNemar tests turned out significant. Accordingly, contributions which enhanced social and human capital (integration in 65.1%, occurrence of conflicts in 43.0% of examples, $p < 0.01$) or promoted the economic situation of future generations (integration in 59.6%, occurrence of conflicts in 50.0% of examples, $p < 0.05$) involved significantly more frequently an integration of the three pillars than conflicts between them.

PCA of addressed sustainability objectives

PCA reduces a set of variables to a limited number of principal components which underlie the correlations between the original variables. In order to search for fields of synergies between the ecological, economic, and social sustainability objectives, a PCA was conducted to identify PSCs. The gradient of the eigenvalues of successively extractable components suggested the extraction of three PSCs as the third extractable component 3 still showed a eigenvalue of $\lambda = 1.6$, hence considerably larger than 1 (Bortz 1999). The component loading matrix for these components which resulted after varimax rotation is shown in Table 1 with substantial loadings (>0.4) printed boldly.

Accordingly, on PSC 1 the responsible use of renewable resources and the reduction of use of nonrenewable resources loaded substantially together with promoting the innovative power of the economy, consideration of externalities in the market, considering the economic situation of future generations, and juridical equality and certainty. PSC 1 was thus understood to reflect sustainability-oriented *Product and Process Development* and hence named accordingly.

On PSC 2, the social objective education and free personal development loaded most highly followed by sustaining cultural and societal values and the two economic aspects generating income and employment and enhancing social and human capital. PSC 2 was therefore named *Education and Social Economics.*

PSC 3 covered the aspects protection of natural spaces and biodiversity, protection of the natural environment, protection from environmental hazards/reduction of risks,

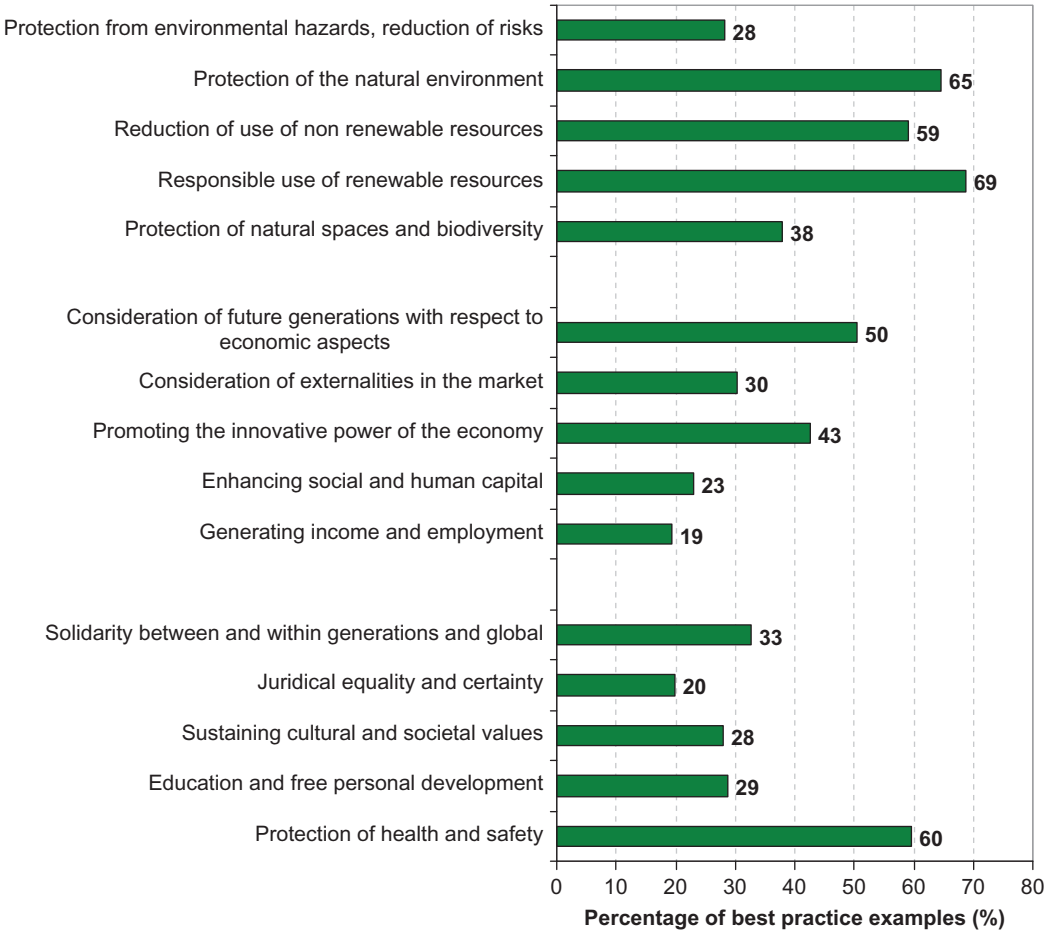

Figure 2. Percentage of best practice examples addressing a total of 15 ecological, economic, and social aspects of sustainability ($N_{examples} = 373$).

Table 1. Rotated component loading matrix of a PCA with regard to 15 sustainability objectives covered or not covered by 373 best practice examples.

	PSC		
Fifteen specific sustainability objectives	1	2	3
Ecological objectives			
Protection of natural spaces and biodiversity	−0.21	0.35	**0.61**
Responsible use of renewable resources	**0.58**	0.12	0.16
Reduction of use of nonrenewable resources	**0.63**	0.07	−0.27
Protection of the natural environment	−0.02	0.08	**0.75**
Protection from environmental hazards, reduction of risks	0.08	−0.07	**0.63**
Economic objectives			
Generating income and employment	0.19	**0.61**	0.02
Enhancing social and human capital	0.22	**0.63**	0.02
Promoting the innovative power of the economy	**0.66**	0.09	−0.01
Consideration of externalities in the market	**0.58**	−0.05	−0.01
Economic situation of future generations	**0.56**	0.05	0.27
Social objectives			
Protection of health and safety	0.26	−0.02	**0.47**
Education and free personal development	−0.01	**0.78**	−0.06
Sustaining cultural and societal values	−0.10	**0.74**	0.18
Juridical equality and certainty	**0.43**	0.10	0.38
Solidarity between and within generations and global	0.37	0.30	0.20
Component names (a posteriori)	Product and Process Development	Education and Social Economics	Protection of Nature and Humans

Note: Varimax rotation method with Kaiser normalization has been used, and component loadings of >0.4 have been printed in bold.

and protection of health and safety of the population. PSC 3 was thus named *Protection of Nature and Humans*.

Inclinations of topical domains to PSCs

In order to analyze the sustainability orientation of the examples provided in the 19 different topical domains with respect to PSC 1 *Product and Process Development*, PSC 2 *Education and Social Economics*, and PSC 3 *Protection of Nature and Humans*, the average component scores were calculated separately for the examples of each topical domain, as shown in Table 2. Some examples of best practice contributions scoring high on each PSC are provided in Table 3 to give an impression of their topical diversity and orientation.

Many best practice contributions in the topical domains of energy and climate are considerably oriented toward PSC 1 *Product and Process Development*. Sustainability contributions in the domains of environmental management and waste as well as in further topical domains, including environmental law, building ecology, management consulting, and environmental planning, likewise tended to score considerably positive on PSC 1. Best practice contributions loading high on PSC 1 often involved the development and implementation of sustainability-oriented products, facilities, or processes. Many examples of ecological innovation and modernization in the form of technological innovation, improved methods for sustainability-oriented assessment, or environmental management in economically relevant areas such as energy, industries, and finance are found among these examples.

Contributions with high inclinations to PSC 2 *Education and Social Economics* were often found in the topical domains of nature and landscape, education and media, as well as in the residual category of 'other fields of activity'. Best practice examples loading high on PSC 2 included activities in ecological and sustainability education on different levels (schools, universities, general public), as well as efforts for the sustainability-oriented transformations of the sociocultural and working sphere, for instance, by means of fair trade labels or sustainability-oriented development projects. Contributions in the topical domain of media also scored high on PSC 2. This can be regarded as tied to the educational function of media, which by conveying sustainability-oriented values and ecological knowledge also enhances human and social capital.

Actually, the topical field of media – as a sole topical field – scored markedly positive ($\geq$0.3) on all three PSCs. This finding is plausible as media may play an overarching role by covering sustainability-oriented contributions corresponding to all three components.

Best practice contributions loading high on PSC 3 *Protection of Nature and Humans* were most often found in the topical domains of nature and landscape, water, and soil. The topical areas of risk, environmental law, chemistry, as well as spatial and environmental planning are also showing a considerable inclination to PSC 3. Best practice contributions loading high on PSC 3 were, for example, concerned with the development of nature parks, soil and flood protection, emission reduction, sustainable forestry, and environmental impact assessment.

Discussion

PSCs and the three pillars of sustainability

It is commonly acknowledged that fostering sustainable development requires consideration of ecological, economic, and social aspects (WCED 1987). Consistent with this, the Swiss government formulated five objectives

Table 2. Average component scores (Cs) of examples in 19 topical domains on PSC 1 *Product and Process Development*, PSC 2 *Education and Social Economics*, and PSC 3 *Protection of Nature and Humans*.

	PSC 1 Product and Process Development M(Cs1)	PSC 2 Education and Social Economics M(Cs2)	PSC 3 Protection of Nature and Humans M(Cs2)	$n_{\text{contributions}}$
Energy	**0.5**	0.0	−0.4	142
Nature and landscape	−0.3	**0.4**	**0.6**	127
Climate	**0.4**	0.0	−0.3	116
Water	0.2	0.0	**0.5**	115
Soil	0.1	0.1	**0.7**	88
Air	0.2	−0.2	0.2	77
Education	−0.1	**0.6**	−0.1	77
Environmental management	**0.4**	−0.2	0.2	71
Waste	**0.5**	−0.2	0.3	71
Risk	0.1	−0.3	**0.7**	54
Chemistry	0.3	−0.4	**0.6**	53
Spatial planning	0.1	0.3	**0.4**	50
Environmental law	**0.5**	−0.2	**0.7**	48
Building ecology	**0.5**	−0.3	0.1	42
Management consulting	**0.6**	0.2	0.1	39
Noise	**0.4**	−0.1	0.3	39
Environmental planning	**0.5**	0.1	**0.5**	38
Media	**0.4**	**0.5**	0.3	35
Other fields of activity	−0.1	**0.4**	−0.3	41

Note: Component scores correspond to *z*-scores, and average scores of $\geq$0.4 have been printed in bold.

Table 3. Brief descriptions of examples of graduates' best practice contributions to sustainable development with high component scores (Cs ≥ 1.6)[a] on PSC 1 *Product and Process Development*, PSC 2 *Education and Social Economics*, and PSC 3 *Protection of Nature and Humans*.

PSC 1 Product and Process Development (Cs1 ≥ 1.6)
Our company constantly analyzes companies with regard to sustainability in connection with financial criteria. Through our strong position, we contribute strongly to more sustainable management of enterprises and better sustainability reporting in particular to investors (2009; banks and insurances; Cs1 = 2.3, Cs2 = −0.4, Cs3 = 0.2)[b].
Implementation of public policy measures within the domain of energy such as thermal protection of buildings; choice of appropriate heating systems; and so on (2005; public administration; Cs1 = 2.2, Cs2 = −0.8, Cs3 = −0.4).
As environmental/financial consultant, I advised the Croatian Ministry of Environment on the implementation of a fund for environment and energy efficiency. In consequence, the government invested large amounts, especially in the area of waste disposal (2003; environmental, planning, and engineering offices; Cs1 = 1.2, Cs2= 2.2, Cs3 = 0.9).
I promote through publicity, lobbying, and campaigns that the canton Schwyz (finally) adopts an energy law and that the 'climate initiative' gets accepted in Switzerland (2009; environmental NGO; Cs1 = 2.1, Cs2 = −0.9, Cs3 = 0.5).
Contribution to the inclusion of market-based instruments (in particular emission trading) in the implementation of environmental laws (2009; consulting; Cs1 = 1.9, Cs2 = −1.0, Cs3 = 0.7).
PSC 2 Education and Social Economics (Cs2 ≥ 1.6)
Development of a project for the sustainable development of a valley in the Himalaya in cooperation with the Research Institute for Organic Agriculture (FiBL) (2005; university/research; Cs1 = 0.1, Cs2 = 2.6, Cs3 = 0.4).
Conclusion of contracts for the extensive management of protected biotopes with farmers (2008, public administration; Cs1 = −2.0, Cs2 = 2.6, Cs3 = −0.2)
Documentation of two highly successful United Nations Children's Fund (UNICEF) projects in Indonesia for the reduction of incidences of maternal death as good practice examples. [. . .] reporting aimed/served to convince government and other NGOs from the programs to promote their more widespread implementation (2009; health sector; Cs1 = −1.1, Cs2 = 2.5, Cs3 = −1.1).
[. . .] work in an organization for the integration of youth with various types of problems into professional life (2000; education (outside university); Cs1 = −1.1, Cs2 = 2.5, Cs3 = −1.1).
I initiated and currently lead the research project Nachhaltigkeitsorientierte Gemeindeführung (sustainability-oriented municipality) (NOGF) (see http://www.nogf.ch) (2007; university/research; Cs1 = 1.6, Cs2 = 2.2, Cs3 = 1.4).
PSC 3 Protection of Nature and Humans (Cs3 ≥ 1.6)
Execution of environmental impact assessments and compilation of corresponding reports (Umweltverträglichkeitsprüfungen (environmental compatibility analyses) (UVPs) according to Swiss environmental laws) (2009; environmental, planning, and engineering offices; Cs1 = −0.2, Cs2 = −1.0, Cs3 = 2.3).
I cooperated in the evaluation of NADUF [Nationale Daueruntersuchung der Fliessgewässer (national continuous investigation of running waters)] time series: among other things, this study could show the effectiveness of the prohibition of phosphate detergents for the reduction of the phosphorus load and eutrophication of running waters (progress control of the measure) (1996; university/research; Cs1 = 1.2, Cs2 = −0.9, Cs3 = 2.3).
Sustainable flood protection for seven municipalities along the river Mosel in Luxembourg: contribution to economics (e.g., protection of infrastructure and trade) and ecological revaluation (2003; environmental, planning, and engineering offices; Cs1 = −0.6, Cs2 = 0.1, Cs3 = 2.1).
Contribution to sustainable forestry through location of adequate tree species choice (2008; university/research; Cs1 = −0.6, Cs2 = 0.1, Cs3 = 2.1).
When teaching soil sciences, I sensitize the students for problems connected to the use of land. Ground contamination, soil compaction, and erosion are central topics of our instruction. The students, who later on accomplish environmental compatibility analyses or work as ground protection specialists in the context of construction projects, shall make reasonable decisions based on this knowledge (2009; university/research; Cs1 = −0.4, Cs2 = −0.7, Cs3 = 2.0).

Notes: [a]Component scores represent *z*-scores, thus contributions with a component score >1.6 roughly correspond to the top 5% with highest loading on PSC 1, 2, 3.
[b]Year of graduate's main activity for the contribution, professional domain, and component scores have been provided in brackets.

for each of these three pillars when developing the national sustainability strategy (Schweizerischer Bundesrat 2002). These objectives were used in this study to investigate synergies between ecological, economic, and social sustainability objectives. University graduates of an Environmental Sciences program described best examples of their professional contributions to sustainable development and specified to which of the 15 objectives they contributed. A corresponding PCA analysis identified three PSCs which all transcended the three dimensions of sustainability. Accordingly, each PSC reflects interrelationships between elements of the three pillars in practice and indicates potentials for positive synergies between them.

PSC 1 *Product and Process Development* covers positive synergies between reduced and more responsible use of natural resources, promotion of innovation, consideration of externalities in the market, economic situation of future generations, and fostering juridical equality and certainty. Best practice examples loading very high on this component illustrate how sustainability-oriented projects, measures, products, or processes can contribute to the simultaneous achievement of these goals. Many sustainability contributions in the topical field of energy tended to score high on PSC 1. This is plausible as measures increasing the use of renewable energy in the form of wind, water, or solar power are connected to reductions in the use of nonrenewable resources and tend to be connected with innovation and reduction of externalities in particular in the form of greenhouse gas emissions. Economic consideration of such externalities tends, in turn, to facilitate market access for these renewable energy sources. High PSC 1 scores in the topical fields of building ecology, waste, noise, environmental management, and planning reflect ecological modernization of economy and society through increasing energy efficiency, for instance, in the building sector, or through sustainable treatment of waste, reduction of noise emissions, and in relation to further aspects of environmental management and planning. High PSC 1 scores in the topical field of environmental law reflect the crucial role which standards, norms, and laws play for ecological reorientation and modernization, and an adequate consideration of externalities in the market.

PSC 2 *Education and Social Economics* captures sustainability contributions allowing for synergetic achievement of sociocultural goals, namely education, free personal development, and sustaining values together with the economic goals of generating income and employment and enhancing social and human capital. Many best practice examples scoring high on PSC 2 were found in the topical fields of education and nature and landscape. This reflects that sustainability education serves protection of nature and at the same time, projects serving the protection of natural spaces and biodiversity can serve educational objectives and promote environmental literacy of the population (e.g., nature experience parks). Furthermore, PSC 2 shows how various sustainability-oriented contributions simultaneously promote social responsibility and equality, foster social and human capital, and generate income and employment, for example, through introduction of fair trade labels or in regional sustainable development projects involving the local population.

PSC 3 *Protection of Nature and Human*s reflects that many sustainability-oriented contributions serving environmental and nature protection at the same time decrease environmental hazards and risks and are thus also protecting the health and safety of the human population. The topical fields of sustainability contributions scoring high on this component, namely nature and landscape, water, soil, chemistry, environmental law, spatial planning, and environmental planning refer to domains where these synergies are important. The best practice contributions scoring high on PSC 3 include activities for environmental management, as well as protection of natural spaces and landscape which focuses on nature protection together with the protection of humans, for instance, from flooding, avalanches, or landslides. Others involve impact assessments or environmental protection, regulation, and control measures in urban environments and industries.

Integration and conflicts between the three pillars of sustainability

In nearly half of the best practice examples, efforts to systematically integrate or balance the three pillars of sustainability were undertaken. An interesting finding regarding integration of the three dimensions was that it often coincided with the occurrence of conflicts between them. This could be due to conflicts between the three dimensions leading to systematic efforts for their integration, or the other way around, conflicts could actually arise when efforts to balance ecological, economic, and social aspects of a sustainability issue are made. In any case, the finding suggests that resolving conflicts is often an essential part of integrating and balancing the three sustainability dimensions.

In this context, an interesting explorative finding was that best practice examples which consider the economic situation of future generations and/or enhance social and human capital tend to allow for integration while circumventing conflicts between the three pillars. Both findings appear plausible. The consideration of the economic situation of future generations rather refers to conflicts between generations than to conflicts between ecological, social, and economic aspects of sustainability. For instance, achieving ecological aims in the present (e.g., through strict ecological regulations and conservation of natural resources) may have synergetic positive effects on the economic situation of future generations, even though it may hamper short-term economic growth. Enhancing social and human capital also has the potential to promote sustainability in an integrative way (OECD Education Ministerial Meeting 2010; Šlaus and Jacobs 2011; Mieg et al. 2012). However, to fulfill this potential the development of such capital needs to be linked to sustainability education and individual, organizational, and societal sustainability learning (United Nations Educational, Scientific and Cultural Organization 2002; Hansmann 2010). Not all individual

and social learning processes improve the resilience of human–environment systems and the 'co-adaptive systemic capacity of agents to anticipate and deal with the unintended, undesired, and irreversible negative effects of development' (Tàbara and Pahl-Wostl 2007: 1).

Limitations, additional research needs and conclusion

One limitation of this study results from the environmental orientation of the graduates' study program which was linked to a prevalence of environmentally oriented contributions to sustainability. The environmental focus of the program may have influenced the results of the PCA. Therefore, a similar investigation based on sustainability contributions made by professionals with other academic or nonacademic educational backgrounds would be desirable in order to investigate whether the same PSCs would be found. A second limitation is given by possibly subjectively biased judgments of the graduates when valuating their best practice examples. This could only be resolved when independent evaluators assess sustainability contributions on the basis of standardized assessment criteria. Finally, the explorative character of this research needs to be mentioned. Since no explicit a priori hypotheses have been formulated with regard to the loading patterns of the PSCs, further research is needed to confirm them. Nevertheless, the three PSCs identified in this research possess considerable face validity as they reflect synergies between goals that appear consistent with each other, and because the sustainability-oriented contributions scoring high on these PSCs were found in topical fields that offer plausible ways for achieving corresponding synergies. This suggests that these PSCs can indeed be helpful and provide orientation for the search after positive synergies between environmental, social. and economic aspects of sustainability.

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