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System Synthesis by Maximizing Sustainability Net Present Value

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This contribution presents a new concept for multi-objective systems synthesis which is based on a composite sustainability measurement called sustainability net present value (*SNPV*). This is an extension of the recently developed metric sustainability profit (Zore et al., 2016). *SNPV* is a metric composed of economic, environmental and social efficiency, expressed in monetary terms and is defined from the wider macro-economic perspective as well as from an individual company's micro-economic view. By using *SNPV*, it is possible to obtain answer regarding the advisability of a particular investment in terms of sustainability. The presented concept is illustrated by two examples of biofuel supply networks: i) a company's supply network for existing biogas production, and ii) a larger-scale biofuel supply network. Both burdening and unburdening alternatives were considered in the comparative study. Maximal *SNPV* occurs at the appropriate trade-off between economic, environmental and social aspects and yields a solution with alternatives selected in order to provide the highest economic profitability, environmental unburdening and new job opportunities, considering the time value of the money involved.

1. Introduction

In recent decades, more and more attention has been oriented towards preserving the environment and natural resources, as well as sustainable development in general. In addition to the environment, the social aspect of sustainability has recently become of greater importance, owing to high unemployment, increasing numbers of people living below the poverty line and other factors (Gontkovićova et al., 2015). However, the most important criterion for companies is still the economic aspect (Seay, 2015).

Exploitation of renewable resources, cleaner energy production, waste minimization and more closed circuits (Lieder and Rashid, 2016) are important objectives of today's developed society. Since the efficiency of renewable resources depends on local natural resources and other fluctuating conditions, the energy sector expects a greater diversity of fuels in the future (Moriarty and Honnery, 2016). For future sustainable development, it is important to identify and select those investment alternatives that are optimal from the perspective of sustainability, in order to maximize economic value, to unburden the environment and increase the number of jobs. It is also crucial to assess the viability of investments in the longer term across the entire system's lifetime, considering the time value of money, i.e. in terms of net present value (*NPV*). *SNPV* considers the fact that the *NPV* establishes a suitable compromise between a process's profitability and the long-term sustainable cash flow. Moreover, it was shown by Novak Pintarič and Kravanja (2015) that NPV is also the most appropriate economic objective for multi-objective optimization, since among the varying economic criteria, it provides the most balanced solutions from the economic, environmental and production efficiency perspectives.

Synthesis of sustainable systems is in general a complex, multi-objective problem, as it should provide good solutions from the economic, environmental and social viewpoints (Azapagic et al., 2016). There do, however, exist many alternatives that compete for optimal solutions. It is thus very important to develop and apply the most suitable criterion for the selection of sustainable alternatives in order that profitability, environmental efficiency and social justice be appropriately reflected thereby.

In this paper, a new metric for measuring sustainability, termed *SNPV*, is proposed. It is defined from two perspectives: from the micro-economic or the company's point of view, and from the wider, macro-economic perspective. It should be noted that the main ideas and assumptions behind *SNPV* are obtained from the recently-developed metric called sustainability profit (Zore et al., 2016), now extended to account for the entire lifetime of the system. In a system's synthesis, by maximizing *SNPV* an optimal balance between economic-, eco- and social *NPV*s can be achieved.

The concept of *SNPV*, from the micro- and macro-economic viewpoints, is demonstrated and discussed in two cases: i) the synthesis of a biogas supply network from animal waste (Drobež et al., 2011), and ii) the synthesis of a larger-scale supply network for the production of biofuels, applied to Central Europe (modified from Čuček et al., 2014).

2. Concept of sustainability net present value

Sustainability net present value (*SNPV*) is a composite measurement of economic, environmental and social efficiency, expressed in monetary terms and defined as the sum of economic *NPV* (NPV^{Economic}), eco-*NPV* (NPV^{Eco}), and social *NPV* (NPV^{Social}). It is evaluated as the difference between *SNPV* after an alternative is selected ($SNPV^{\text{New}}$) and the *SNPV* of a previous or "old" alternative ($SNPV^{\text{Old}}$), and thus corresponds to the incremental *SNPV* of selecting an alternative. *SNPV* is calculated as an accumulation of yearly cash flows *FC*, represented as the multiplication of *FC* by the present value annuity factor $f_{\text{PA}}(r_{\text{d}})$, decreased by the initial investment:

$$\begin{aligned} SNPV &= NPV^{\text{Economic}} + NPV^{\text{Eco}} + NPV^{\text{Social}} \\ &= -I^{\text{Economic}} - I^{\text{Eco}} - I^{\text{Social}} + (FC^{\text{Economic}} + FC^{\text{Eco}} + FC^{\text{Social}})\, f_{\text{PA}}(r_{\text{d}}) \\ &= -I^{\text{Tot}} + FC^{\text{Sustainability}}\, f_{\text{PA}}(r_{\text{d}}) \end{aligned} \tag{1}$$

Economic, eco- and social *NPV*s are defined differently from the micro and macro-economic perspectives. The macro-economic level represents a broader level, and can be viewed from a range of perspectives: local, regional, governmental/state, production sector, national, multinational or global. In the current study, the macro-economic level considers the production sector together with state income/outcome, since these are both important for the viability and progress of society. On the other side, the micro-economic level represents only the company's perspective.

SNPV defined at the micro-economic level ($SNPV^{\text{Micro}}$):

$$\begin{aligned} SNPV^{\text{Micro}} = {} & -I^{\text{Economic}} - I^{\text{Eco}} - I^{\text{Social}} + \\ & \left(\begin{aligned} & R + R^{\text{subsidy}} - E - E^{\text{eco tax}} - E^{\text{tax}} && \text{economic,} \\ & + \left(\sum_{t \in T} \sum_{i \in R_t^{\text{UNB, Micro}}} q_{m_i}^{\text{R}_{\text{UNB, consumed}}} \cdot c_{i,t}^{\text{R}_{\text{UNB}}} + \sum_{t \in T} \sum_{j \in P_t^{\text{UNB, Micro}}} q_{m_j}^{\text{P}_{\text{UNB, consumed}}} \cdot f_j^{\text{S/P}_{\text{UNB}}} \cdot c_{j,t}^{\text{S}} \right) - && \text{environmental,} \\ & \left(\sum_{t \in T} \sum_{i \in R_t^{\text{B Micro}}} \left(q_{m_i}^{\text{R}_{\text{B, tot}}} - q_{m_i}^{\text{R}_{\text{UNB, consumed}}}\right) \cdot c_{i,t}^{\text{R}_{\text{B}}} + \sum_{t \in T} \sum_{j \in P_t^{\text{B Micro}}} q_{m_j}^{\text{P}_{\text{B}}} \cdot c_{j,t}^{\text{P}_{\text{B}}} \right) \\ & - \sum_{t \in T} N_t^{\text{Jobs}} \cdot c_s^{\text{Company}} && \text{social part} \end{aligned} \right) f_{\text{PA}}(r_{\text{d}}) \end{aligned} \tag{2}$$

and at the macro-economic level ($SNPV^{\text{Macro}}$):

$$\begin{aligned} SNPV^{\text{Macro}} = {} & -I^{\text{Economic}} - I^{\text{Eco}} - I^{\text{Social}} + \\ & \left(\begin{aligned} & R - E && \text{economic,} \\ & + \left(\sum_{t \in T} \sum_{i \in R_t^{\text{UNB Macro}}} q_{m_i}^{\text{R}_{\text{UNB}}} \cdot c_{i,t}^{\text{R}_{\text{UNB}}} + \sum_{t \in T} \sum_{j \in P_t^{\text{UNB Macro}}} q_{m_j}^{\text{P}_{\text{UNB}}} \cdot f_j^{\text{S/P}_{\text{UNB}}} \cdot c_{j,t}^{\text{S}} \right) && \text{environmental,} \\ & - \left(\sum_{t \in T} \sum_{i \in R_t^{\text{B Macro}}} q_{m_i}^{\text{R}_{\text{B}}} \cdot c_{i,t}^{\text{R}_{\text{B}}} + \sum_{t \in T} \sum_{j \in P_t^{\text{B Macro}}} q_{m_j}^{\text{P}_{\text{B}}} \cdot c_{j,t}^{\text{P}_{\text{B}}} \right) \\ & + \sum_{t \in T} N_t^{\text{Jobs}} \left(s_t^{\text{Gross}} - s_t^{\text{Net}}\right) + \sum_{t \in T} N_t^{\text{Jobs}} \cdot c_s^{\text{UNE, State}} - \sum_{t \in T} N_t^{\text{Jobs}} \cdot \left(c_s^{\text{EMP, State}} + c_s^{\text{Company}}\right) && \text{social part} \end{aligned} \right) f_{\text{PA}}(r_{\text{d}}) \end{aligned} \tag{3}$$

Specific parts are explained in greater detail below. Maximal *SNPV* occurs at the trade-off point where the best solution from the economic, environmental and social viewpoints is obtained.

Economic *NPV* cash flow is defined at the micro-economic level ($FC^{\text{Economic Micro}}$) as revenues (*R*) plus subsidies (R^{subsidy}) as financial incentives for producing more sustainable systems, reduced by the costs of labor, energy, raw materials and production (E), ecological tax due to waste and emissions $(E^{\text{eco tax}})$, and tax on profit (E^{tax}).

At the macro-economic level ($FC^{\text{Economic Macro}}$), it is defined as revenues (R), reduced by the costs of labor, energy, raw materials and production (E). Neither tax on economic profit nor subsidies are taken into account at the macro-economic level because these are cancelled out, as they represent outcome/income at the company level and vice versa at the governmental level.

Eco-*NPV* cash flow (FC^{Eco}) is defined as the difference between eco benefit (EB) as the provision in monetary terms for unburdening the environment, and eco cost (EC) as the investment for preventing the burdening of the environment when an alternative is selected. EB and EC represent the unburdening and burdening effects of raw materials, technology, transport, products, energy and waste, related to a selected alternative. They are calculated by using the eco-cost coefficients (Delft University of Technology, 2016) for raw materials i from an index set of unburdening R^{UNB} and burdening R^{B} for technology t ($c_{i,t}$) and for products j from an index set of unburdening P^{UNB} and burdening P^{B} for technology t ($c_{j,t}$) and are proportional to mass flows of raw materials q_{m_i} and products q_{m_j} . $f_j^{\text{S/P}_{\text{UNB}}}$ represents a substitution factor which represents the ratio between amounts of previously substituted and currently substituted products (see, e.g., Zore et al., 2016).

The difference in FC^{Eco} between the macro- and micro-economic perspectives is that, at the micro-economic level, a company is now responsible only for its own wastes, emissions and products. Converting their own harmful wastes into raw materials for green products is an example of unburdening, while preserving them causes burdening. In addition, a company can also earn provision for unburdening of the environment from its own green products; however, only from those consumed within the company. The unburdening effect in EB^{Micro} is thus calculated only for wastes that are converted into green products within the new process, and only for those new green products that are produced within the selected process and spent anywhere within a company complex as substitutes for previously used, environmentally more harmful materials, energy or services. The burdening effects in EC^{Micro} are then calculated only for the unspent part of the wastes ($q_{m_i}^{\text{R}_{\text{B, tot}}} - q_{m_i}^{\text{R}_{\text{UNB, consumed}}}$) which must be treated, together with all other burdening effects related to new products. Note that the eco-*NPV* from the micro-economic perspective is usually significantly smaller than that from the macro-economic viewpoint because a company usually does not earn any profit by increasing other companies' eco-*NPV*. Tax on eco-profit levels is not taken into account at any level.

Social *NPV* at the macro-economic level combines the governmental and production sector's contributions to improving the social state of a nation. The view from the company's perspective corresponds to the contribution of the company to the improved social status of employees and other people living in the local area. Social NPV's cash flow at the microeconomic level ($FC^{\text{Social Micro}}$) is thus negative, since there are no social incomes expressed in monetary terms. It consists of the social costs SC that represent the social support by a company of its employees and is defined as the product of the number of new employees or new jobs N_t^{Jobs} and an average company's social charge $c_{\text{s}}^{\text{Company}}$ per employee. The SC related to a company represents outcomes that a company spends on activities to improve the social status of its employees and the neighboring community, such as team building events, excursions, holiday housing facilities for workers, sponsorship of sport clubs, cultural activities, etc.

On the other hand, social *NPV* cash flow at the macro-economic level ($FC^{\text{Social Macro}}$) can be defined as the social security contributions paid by employees and employers (SS), plus social unburdening effects due to new jobs created (SU), minus social cost (SC). SS is presented as the difference between average gross s_t^{Gross} and net salaries s_t^{Net} in a production sector, with technology t, multiplied by N_t^{Jobs}. As new jobs are created, a state budget is uncharged for the social transfers needed to support the unemployed who are now newly employed people. SU is thus defined as the product of N_t^{Jobs} and the average state social transfer $c_{\text{s}}^{\text{UNE, State}}$ for unemployed people. SC represents the social support of the state and a company for employees and is defined as the product of N_t^{Jobs} and the sum of an average state social transfer $c_{\text{s}}^{\text{EMP, State}}$ and an average company's social charge $c_{\text{s}}^{\text{Company}}$ per employee. State social help comprises various social transfers, child allowance, social assistance, state scholarships, health insurance and other forms of benefit. Tax on social profit is not taken into account at any level.

3. Illustrative Case Studies

Two illustrative case studies are presented in order to demonstrate the proposed concept of *SNPV* from the micro- and macro-economic perspectives. The first one is a company's supply network producing biogas from various raw materials under different anaerobic conditions with alternative facilities (Drobež et al., 2011). The second presents a heat-integrated biorefinery supply network for the production of biofuels and food, accounting for various biomass sources and different conversion technologies applied to Central Europe (modified from Čuček et al., 2014). The details regarding case studies can be found in the cited references.

3.1 First Case Study – Biogas Production

For details regarding economic and other data, see Drobež et al., 2009. Table 1 shows the variability of solutions obtained when maximizing economic and sustainability *NPV*s, from both the micro- and macro-economic perspectives. The objective values in the corresponding columns are shown in bold. Note that at the company level both solutions are the same. However, large differences between measurements are obtained at the macro-economic level and when maximization of economic *NPV* is carried out from a micro- and a macro-economic view. This is the result of including taxes and subsidies at the micro-economic level, while excluding them at the macro-economic level; thus, different alternatives are preferred. Table 2 further presents some details obtained when maximizing different *NPV*s.

Table 1: Main results when maximizing different NPVs for biogas production

Maximization criteria (M€/y)	$NPV^{Economic\ Micro}$	$SNPV^{Micro}$	$NPV^{Economic\ Macro}$	$SNPV^{Macro}$
$NPV^{Economic\ Micro}$	**28.65**	28.65	3.52	13.29
$NPV^{Eco\ Micro}$	26.79	26.79	0.65	27.02
$NPV^{Social\ Micro}$	- 1.09	- 1.09	- 0.97	- 1.70
$SNPV^{Micro}$	54.36	**54.36**	3.20	38.61
$NPV^{Economic\ Macro}$	- 8.44	- 8.44	**4.25**	- 8.88
$NPV^{Eco\ Macro}$	24.30	24.30	0.65	32.60
$NPV^{Social\ Macro}$	2.26	2.26	1.12	2.71
$SNPV^{Macro}$	18.12	18.12	6.01	**26.44**

Table 2: Some details regarding solutions obtained by maximizing different NPVs for biogas production

Maximization criteria	$NPV^{Economic\ Micro}$	$SNPV^{Micro}$	$NPV^{Economic\ Macro}$	$SNPV^{Macro}$
Revenue (M€/y):	3.29	3.29	2.37	3.79
- electricity	1.58	1.58	-	0.98
- heat	1.10	1.10	-	0.64
- solid products:	-	-	2.37	2.17
- organic fertilizer:	0.61	0.61	-	-
Cost (M€/y)	1.94	1.94	1.68	2.85
Subsidies and tax (M€/y)	4.72	4.72	-	2.73
Investment (€)	2.28	2.28	0.22	1.92
Raw material used (t/y)	122,861	122,861	22,922	116,151
Generated power (MW)	4.21	4.21	-	2.62
Processes	thermophilic process		-	thermophilic process
	-	-	rendering plant	
Additional processes	reconstruction of pig farm		-	reconstruction of pig farm
	closed water system		-	open water system
Number of workers				
- in construction	5.78	5.78	-	4.04
- biogas operating	20.69	20.69	-	15.58
- rendering plant operating	-	-	23.75	21.76
- sum	26.47	26.47	23.75	41.38

Maximization of economic *NPV*: Producing electricity from biogas without subsidies is not profitable, meaning that at the macro-economic level, the selected alternative consists only of a rendering plant which sells solid products such as meat, bone and feather meal, tallow and animal fat. On the other hand, when subsidies are included, at the micro-economic level, a biogas production process under thermophilic conditions and reconstruction of a pig farm are selected.

Maximization of *SNPV*: The best alternative from both levels consists of a thermophilic process with a rendering plant and additional processes such as reconstruction of existing pig farms. The *SNPV* is much greater at the micro-economic level, mainly because of the taxes and subsidies that a company receives. The main difference between the two of them in terms of processes is the differing treatment of wastewater. The solution at maximal $SNPV^{Micro}$ prefers ultrafiltration and reverse osmosis with a closed water system, and the solution at maximal $SNPV^{Macro}$ prefers wastewater treatment at a central wastewater treatment plant – thus a closed water system. Selection of these alternatives has a significant impact, especially on investment size and amortization. From a macro-economic viewpoint, it is preferable to avoid the use of organic fertilizer. From the $SNPV^{Macro}$ viewpoint, the solution with the maximal number of workers working in a supply network (41) is obtained. Finally, since the $SNPV^{Macro}$ is positive, the project complies with the sustainability criterion.

3.2 Second Case Study – Biorefinery Supply Network

Table 3 shows the main results regarding different measurements obtained from a larger-scale biorefinery supply network when maximizing various *NPVs*. The objective values in the corresponding columns are shown in bold. The economic *NPV* is significant, and at the micro-economic level much higher than at the macro-economic level. This is again a result of subsidies, which represent a significant part of the *NPV*. On the other hand, *SNPV* is negative from the micro-economic perspective, while positive from the macro-economic one. The main differences are from environmental viewpoint, where environmental impacts relating to food are negative from both perspectives, while in terms of biofuels are negative at micro-economic level (companies profit only from the treatment of their own waste and from only those "green" products consumed within the company), and positive at macro-economic level (eco-profit is due to treatment of all the waste consumed and "green" products produced). Additionally, Table 4 presents some details regarding the results from maximizing different *NPVs*.

Table 3: Main results when maximizing different NPVs for larger-scale biorefinery supply network

Maximization criteria (M€/y)	$NPV^{Economic\ Micro}$	$SNPV^{Micro}$	$NPV^{Economic\ Macro}$	$SNPV^{Macro}$
$NPV^{Economic\ Micro}$	**143,123**	114,868	143,079	143,086
$NPV^{Eco\ Micro}$	-147,652	-119,045	-147,537	-147,533
$NPV^{Social\ Micro}$	-2,193	-1,790	-2,181	-2,205
$SNPV^{Micro}$	-6,723	**-5,967**	-6,638	-6,652
$NPV^{Economic\ Macro}$	95,280	74,201	**95,334**	95,270
$NPV^{Eco\ Macro}$	-49,430	-34,236	-49,430	-49,335
- food	-72,198	-74,470	-72,545	-71,325
- biofuels	22,768	40,234	23,115	21,990
$NPV^{Social\ Macro}$	2,272	1,899	2,272	2,314
$SNPV^{Macro}$	48,122	41,864	48,176	**48,249**

Table 4: Some details obtained by maximizing different NPVs for larger-scale biorefinery supply network

Maximization criteria (M€/y)	$NPV^{Economic\ Micro}$	$SNPV^{Micro}$	$NPV^{Economic\ Macro}$	$SNPV^{Macro}$
Economic investment	13,458.91	12,825.75	13,276.19	13,223.41
Raw materials (kt/y)/ Area used (%):				
- corn grain	18,679.42 / 3.62	18,679.42 / 3.55	18,679.42 / 3.60	18,679.42 / 3.62
- corn stover	11,207.65 / [a]3.62	11,207.65 / [a]3.55	11,207.65 / [a]3.60	11,207.65 / [a]3.62
- wheat	28,073.28 / 5.93	28,073.28 / 5.81	28,073.28 / 5.93	28,073.28 / 5.93
- wheat straw	28,634.74 / [b]5.93	28,634.74 / [b]5.81	28,634.74 / [b]5.93	28,634.74 / [b]5.93
- miscanthus	7,462.42 / 0.45	-	7,418.53 / 0.46	7,460.97 / 0.45
- forest residue	0.26 / 0.004	43.47 / 0.64	0.33 / 0.004	0.37 / 0.004
- cooking oil	1,171.41	1,171.41	1,171.41	1,171.41
Biofuels (kt/y) / Demand for fuel (%):				
- gasoline substitutes	10,024.54 / 27.40	7,756.52 / 21.49	10,003.52 / 27.35	10,011.76 / 27.37
- diesel substitutes	4,177.93 / 10.00	4,177.93 / 10.00	4,177.93 / 10.00	4,182.11 / 10.01
- hydrogen	945.78	710.89	945.78	946.61
Number of workers	26,595	22,201	26,558	26,581
Optimality gap (%)	1.18	2.80	1.88	4.72

[a] – corn stover uses the same land as corn, [b] – wheat straw uses the same land as wheat

From Table 4, it can be seen that the required demands of fuels (10 % of gasoline and diesel substituted by biofuels) are both satisfied at 100 % satisfaction of the demand for food.

Maximization of economic *NPV*: investments are slightly higher at the micro-economic level. At both levels, the minimum required amount of biodiesel is produced, and slightly more than 27 % of gasoline substitutes are produced. The solutions in terms of raw materials used and fuels produced are similar; however, from the macro-economic perspective, less miscanthus and more forest residue is used.

Maximization of *SNPV*: From the micro-economic perspective, *SNPV* is negative because of the negative eco- and social costs. The demands are at least satisfied with the lowest number of employees (22,201). On the other hand, the macro-economic perspective stimulates greater production and a higher number of employees (26,581). The differences in terms of biomass and waste used are especially related to the use of miscanthus and forest residue. Miscanthus is not selected from the micro-economic perspective, but a significant amount of it is selected when optimized from the macro-economic perspective. On the other hand, larger amounts of forest residue are selected from the micro-economic level than from the macro-economic one. This is the result of a trade-off between utilizing forest residue as a raw material for biofuel production and additional afforestation (see also, Zore et al., 2016).

4. Conclusions

In this study the concept of *SNPV* as an extended version of sustainability profit was introduced and demonstrated on two case studies of supply networks. *SNPV* includes the three pillars of sustainability - economic, environmental and social - all expressed by monetary value and composed into a single monetary metric. *SNPV* enables the creation of systems that are optimal in terms of sustainability across the entire life of the system. The concept of *SNPV* was developed and demonstrated from both the wider macro-economic perspective and a company's micro-economic perspective.

Results from both case studies show that technologies using renewable energy sources are sustainable from both the micro-economic and the macro-economic perspectives. In the above two case studies, the $SNPV^{Macro}$, which combines both a company's perspective and the governmental view, yields two positive outcomes, indicating that the production of biogas from organic waste, as well as biofuel production at the middle-EU regional level can satisfy 100 % of food demand while being sustainable from combined economic, environmental and social point of view.

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