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APPLICATION OF MULTI-CRITERIA ANALYSIS IN THE EVALUATION OF BIOGAS PLANTS WITH RESPECT TO THE STABILITY OF THE AGRICULTURAL SYSTEM

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Abstract

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As a result of the interconnection and globalization of access to information, scientific expertise and new technologies across the world, development of society is now progressing at a skyrocketing pace. Production in businesses is reaching maximum possible levels. This paper focuses on systemic evaluation of the interrelations among production processes of agricultural businesses running biogas plants. It represents a comprehensive proposal of a model instrument for comparison of production options in relation to available input materials in agricultural businesses. Interconnection of the economic, environmental and social factors is of growing significance for strategic progress along the lines of sustainable development of society. The objective of this paper is to propose and to describe the practical application of a multi-criterion model as an instrument of decision-making processes with a view to establishing a procedure for comparison of available input materials for biogas plants from the viewpoint of maintaining the stability of systemic interrelations in the agricultural sector in the context of sustainable development.

Keywords: renewable energy sources, sustainable development, multi-criterion analysis, systemic interrelations, agricultural business entities, tools of management, biogas plants

INTRODUCTION

As a result of the interconnection and globalization of access to information, scientific expertise and the resulting need to introduce new technologies across the world, development of society is now progressing at a skyrocketing pace. Ongoing growth of production and the related economic effectiveness of business operations are reaching maximum possible levels, making it possible to increase the living standards of the population and to improve the quality of human life. On the other hand, management tools and organizational instruments that would make it possible to evaluate all the associated interrelations in the overall context of the system at society-wide level are not available so far. Plans for development of new technologies fail to pay regard to their impact on the environment and, consequently, on the population's health, social situation and esthetic quality of the affected neighbourhoods, and society intervenes only after damage has been done as a result of disruptions of the interrelations within the system. Application and implementation of environmental activities in production processes will clearly have a bearing on the management and organizational structures both in individual businesses and on the nationwide or pan-European scale.

The arising trend of linking the society's environmental interests with production processes in individual businesses is a sign of a commencing effort to establish an integrated information base for decision-making managerial activities. This concept and its introduction into practical policies in businesses has been dealt with by many authors

in papers elaborating on environmental cost accounting and reporting in businesses (Hájek, 2011), corporate governance and environmental management (Hřebíček *et al.*, 2013). Use of an integrated information and reporting system is also essential for the application of the environmental policies of public administration authorities to management processes (Šauer *et al.*, 2012). Pursuant to the ongoing development and the need for modifications of the factors of evaluation of the output effects within the framework of the entire society system, accounting systems in businesses are being adjusted and converted into accounting of sustainable development that needs to respond, *inter alia*, to the requirements of the tools of environmental policies and their application to management systems of agricultural businesses. In the practical operation of businesses, however, the efforts to meet these requirements have not yet attained the desired level of interconnection and data about the specific flows of material – that are needed as sources of information for the charting of management tools – are not available so far in the needed categorizations.

Introduction of environmental activities and their linkage with environmental accounting associated with the application of environmental policies has been impeded by insufficient analyses of the available technologies not only within particular business operations, but also in relation to the environment where appraisal by means of the accounting system is truly difficult (Zimmermannová, 2011). Here we see a need to introduce systemic model structures as instruments of a well-founded approach to managerial decision-making at society-wide level.

Evaluation of the effectiveness of business entities from the viewpoint of system sustainability is a current issue that has been addressed with increasing frequency not only at the level of public administration but also in individual businesses. Adjustment of the methods and instruments to management processes and establishment of mutual connections in the fields of economy, social welfare, environment protection as well as corporate governance (Hřebíček *et al.*, 2011) serves business entities as a supporting tool in their decision-making. The issue is of a comprehensive nature and the process of its solution raises again and again new, continuously developing questions as regards both practical measures applied in businesses and drafting of economic policies at the level of public administration.

The aforementioned areas thus provide a basis for the latest methods of evaluation of the performance of individual business entities from the viewpoint of sustainability (Hřebíček *et al.*, 2011). The first step toward assessing sustainable performance in businesses consists in defining the values and indicators that portray chronological development, i.e. indicators of sustainability (Křen *et al.*, 2011). In the process of evaluating the effectiveness of individual businesses, multi-criterion decision-making methods provide a comprehensive picture of the business and the associated systemic interrelations (Paras, 1999). Newly introduced approaches must respect the stability of the agricultural system. The Czech Republic's integration into the European Union has brought major changes in the conditions for economic effectiveness of agricultural businesses. Technical and technological changes in production processes have been accompanied by deterioration of biological, physical and chemical properties of the soil, which, in turn, has resulted in alterations of its water and air regime. This phenomenon – an inseparable component of bio-diversity – causes irreversible changes to the structure and stability of the constitution of the soil within the framework of the agricultural system. Decision-making processes associated with the introduction of new technologies often fail to pay regard to the system-wide linkages and interrelations that can have adverse effects on the related environmental and social circumstances. New technologies thus need to be assessed in a comprehensive systemic manner, so at to prevent consequences harming the environment and society.

This paper focuses on systemic evaluation of the interrelations among production processes, requirements of the population as regards quality of life and the condition and development of bio-diversity in the environment within the scope of agricultural businesses running biogas plants. It represents a comprehensive proposal of a model instrument for comparison of production options in relation to available input materials in agricultural businesses and a direct follow-up to the methodical analysis of this subject (Šišková, 2013).

MATERIALS AND METHODS

This paper starts from the need to apply a management tool consisting in systemic evaluation of the economy-environment relations within the agricultural system from the viewpoint of sustainable development of society when new technologies for utilization of renewable energy sources are introduced. The objective of this paper is to propose, and to describe the practical application of, a multi-criterion model for comparison of available input materials for biogas plants from the viewpoint of maintaining the stability of systemic interrelations in the agricultural sector in the context of sustainable development.

The principal purpose of this paper is to create a systemic multi-criterion model as an instrument for evaluation and comparison of production options according to the input materials that are available for the selected biogas plants in agricultural businesses. The model is constructed on the basis of systemic audits of selected material flows and interrelations in agricultural biogas plants. Through a set of selected criteria, the model analyzes these factors in

relation to the businesses' ability to contribute to the stability of the agricultural system along the lines of sustainable development of society. The result is a multi-criterion model for comparison of the available production options designed to assess the impact of the production process on the stability of the agricultural system along the lines of sustainable development both for individual businesses and for universal use on a wider scale for comparative and decision-making methods at the level of public administration.

The methodological approach applied in the proposed model focuses on evaluation of the underlying aspects of systemic economy-environment relations in an agricultural biogas plant. A systemic multi-criterion analysis is employed for evaluation of economy-environment interrelations in the production area Ω determined by functions W = f(s, Q, k) referring to the development of the structure, quality and usability of biomass and Y = f(XQ_z, XS_z) transforming the volume and structure of the biomass, and a general model is created for objective evaluation of the economic and social position of the examined entities in relation to the maintenance of a stable environment.

The methodical process of the systemic analysis is based on a detailed audit of the interrelations within a selected agricultural business that runs a biogas plant. In-depth systemic across-the-board evaluation will produce a concrete picture of the interrelations among input materials, the chosen technologies and the effect at the point of output and determine the critical areas in the examined entity. The resulting analysis will provide a basis for identification and selection of the evaluation criteria. A systemic examination will pay regard to the complex nature of the interrelations within the examined system and provide a basis for the identification of an optimum number of the criteria to be considered within the context of the methodical processes of a multi-criterion analysis (MCA).

An important phase in the process of constructing a multi-factor model consists in a quantified determination of the specific comparative weight of the individual criteria according to the methods of systemic analysis. The constructed model applies both the variant of homogeneous weight and the variant of different criteria having different influence. The non-homogeneous criteria are determined through the Fuller Triangle method that is based on the quantification of binary relations of superiority and inferiority among the individual criteria within the examined system.

The alternatives chosen for charting the process of comparison of input materials are the basic production options of a biogas plant according to the availability of input materials in the selected businesses, their variability and substitutability (Wilson's stock-keeping theory model). The measure of substitutability of the production options is tested by means of a systemic method pursuant to the Markov matrix.

The indices obtained in this manner serve as the basis for the construction of a model of a multi-criterion comparative analysis that compares the selected biogas plants at the level of the chosen system effectiveness for the proposed general production options as regards input materials (V_1 – haylage and silage grain, V_2 – haylage rape-seed and grass substance, V_3 – haylage and silage maize and V_4 – other waste biomass).

Two agricultural businesses – Krásná Hora Agricultural Cooperative and Komorno, a. s., a joint-stock company – have been selected for the application of the data sources of the proposed model of multi-criterion comparison of production options in biogas plants. The data that are needed for evaluation of the proposed multi-criterion model are obtained from publicly available accounting documents and records (Balance Sheets, Profit and Loss Statements, Annual Reports) and through expert consultations in the businesses.

MCA–KOSA program system has been employed for the practical application of the multi-criterion analysis in the process of evaluation of the production options applied in agricultural biogas plants. The following system evaluation methods have been used within the framework of the program:

1) The **AGREPREF** method, consisting in systemic evaluation of the applicable options that are compared according to an order of preference, from the best to the worst, based on the parameters of the characteristic that determines how many other options rank below the one that is under consideration:
   - Preference $\alpha = 0.6$;
   - Indifference $\beta = 0.4$.
2) The **WSA** method (Weighted Sum Approach), based on the principle of maximized utility, determines which option has attained the maximum level of utility on the linear function basis.
3) The **TOPSIS** method, based on the selection of the option that is closest to the ideal and farthest from the baseline (i.e. the worst) alternative.
4) The **ORESTE** method, consisting of two steps: first, determination of the distance of each criterion from a fictitious point of origin that is marked 0; second, ordering of the options on the basis of an analysis of preference based on generation by a computer program (preference, indifference, anomalies):
   - P – Preference $\alpha = 0.7$;
   - I – Indifference $\beta = 0.09$;
   - N – Anomalies $\tau = 3.5$.
5) The **MAPPAC** method, using an analysis based on specification of the ratios between the indices of preference for every two options according to each criterion.

I: Proposed model of MCA in the process of evaluation of the production options (variants) in biogas plants

Characteristic			AC	AC	SC	SC	AC	ASC	AC	AC	SC	SC	AC	AC	SC	AC	AC	SC
Units			mil. Kč	mil. Kč	x	x	%	x	t	x	x	x	mil. Kč	mil. Kč	x	mil. Kč	%	x
Criteria			K1	K2	K3	K4	K5	K6	K7	K8	K9	K10	K11	K12	K13	K14	K15	K16
Krásná Hora	Grain	V_{11}	95	12.5	1	9	1.1	0.9	1400	5	9	8	3.7	6.6	9	15.6	98	8
	Rape-seed.	V_{12}	95	11.1	2	8	2.1	0.7	2800	6	9	7	3.9	6.8	8	14.7	96	7
	Maize.	V_{13}	95	11.2	6	9	1.05	0.65	8400	7	9	9	4.6	7.1	9	15.5	98	9
	Other	V_{14}	95	10.9	1	7	0.5	0.8	1400	5	9	6	4.1	6.7	7	14.5	95	6
Komorno	Grain	V_{21}	85	12.6	1.5	9	1.3	0.85	2400	5	9	9	5.1	7.1	9	16.8	97	8
	Grass.	V_{22}	85	11.6	0.5	9	1.7	0.75	800	7	9	7	5.3	7.3	9	16.8	97	8
	Maize.	V_{23}	85	14.4	7	8	1.1	0.9	11200	8	9	9	4.8	7.6	8	17.1	99	9
	Other.	V_{24}	85	10.8	1	8	1.8	0.8	1600	6	9	7	3.7	6.8	7	15.9	95	7
Type of criteria			MIN	MIN	MAX	MAX	MIN	MIN	MAX	MAX	MAX	MAX	MAX	MIN	MAX	MAX	MAX	MAX
Homogeneous weight			0.062	0.062	0.062	0.062	0.062	0.062	0.062	0.063	0.062	0.062	0.062	0.062	0.062	0.062	0.062	0.062
Comparative weight – Specific scales by Fuller			0.067	0.075	0.092	0.0416	0.05	0.033	0.075	0.05	0.075	0.067	0.083	0.067	0.04	0.067	0.075	0.042

Source: Author's research (2013)

To achieve truly objective results, the multi-criterion analysis of the evaluation of the production options has been performed in two instances differing according to the weight of the criteria. The first evaluation process applied the selected criteria with a homogeneous weight, while the second used comparative weights of the criteria specified according to the Fuller Triangle method.

RESULTS

Pursuant to the performed systemic analysis of the interrelations between, and evaluation of, the critical sections of the production process in agricultural biogas plants, the following structure of the criteria to be considered for the application of a multi-criterion analysis (MCA) has been proposed:

K_1: total volume of capital (millions Kč – absolute criterion);

K_2: annual expected operating costs (millions Kč – absolute criterion);

K_3: available structure of input material (scale criterion);

K_4: expected measure of stability of the operation in the annual production cycle (scale evaluation);

K_5: probability of the occurrence of faults (absolute criterion – %);

K_6: the Markov equation of possible structural transition between conditions (aggregate summary criterion);

K_7: available volume of the input material in tons (t – absolute criterion);

K_8: probability of the generation of a critical quantity of the supply of input material – stochastic Wilson model of the stock-keeping theory applied in relation to the structure of the input material;

K_9: stability of the distal circuit of collection of input material (scale evaluation);

K_{10}: total energy production output of the biogas plant (scale evaluation);

K_{11}: measure of the actual production effect (sales revenue minus expenditures) (millions Kč – absolute criterion);

K_{12}: measure of the structure of primary factors (i.e. the costs structure of the operation) – comprehensive cost structure (millions Kč) in relation to the accounting system of the business;

K_{13}: the criterion of stability of the production (scale evaluation);

K_{14}: net production effect (profit/loss) pursuant to the Profit and Loss Statement according to accounting standards (millions Kč – absolute criterion);

K_{15}: expected measure of realization of outputs in prices estimated for the period to come (absolute criterion – %);

K_{16}: measure of reliability of the operation in variants of possible adaptability of the technology of the production of the target product (scale evaluation).

II: *Evaluation of the methods used in the MCA of the production options (variants) in biogas plants*

	Method AGREPREF		Method WSA		Method TOPSIS		Method ORESTE		Method MAPPAC	
	Index Dh	Rank	Benefit	Rank	Distance from baseline variants	Rank	Values „ri“	Rank	Sigma	Rank
MCA of the Production Options in Biogas Plants – 1st evaluation process, with homogeneous weight of the criteria										
V11	–1	**5**	0.4875	**5**	0.255175166	**8**	1073	**5**	1.8336946	**5**
V12	–2	**6**	0.400376923	**7**	0.398928584	**5**	1115.5	**6**	1.3225329	**6**
V13	4	**1**	0.7495625	**1**	0.579382345	**1**	839.5	**1**	5.2673708	**1**
V14	–2	**6**	0.290996154	**8**	0.47396202	**3**	1206	**8**	0	**8**
V21	0	**3**	0.620657692	**4**	0.361106539	**7**	968	**3**	3.3301817	**3**
V22	0	**3**	0.623930769	**3**	0.378507148	**6**	1018	**4**	2.7499387	**4**
V23	3	**2**	0.705875	**2**	0.578278679	**2**	901.5	**2**	4.068139	**2**
V24	–2	**6**	0.412186538	**6**	0.465998418	**4**	1134.5	**7**	0.7058039	**7**
MCA of the Production Options in Biogas Plants – 2nd evaluation process, with specific comparative weights of the criteria										
V11	–1	**5**	0.463868415	**5**	0.23523146	**8**	1064.5	**6**	1.773174207	**5**
V12	–2	**6**	0.388049084	**7**	0.344673715	**7**	1063.5	**5**	1.300793675	**6**
V13	3	**1**	0.727183417	**2**	0.623632282	**2**	935.5	**1**	5.127612769	**1**
V14	–3	**8**	0.303525449	**8**	0.387767815	**4**	1114.5	**8**	0	**8**
V21	2	**3**	0.616988846	**3**	0.36232981	**5**	981	**3**	3.381276861	**3**
V22	0	**4**	0.598946969	**4**	0.34742885	**6**	1050	**4**	2.619134056	**4**
V23	3	**1**	0.738566463	**1**	0.673927125	**1**	955	**2**	4.206446359	**2**
V24	–2	**6**	0.415135463	**6**	0.409337844	**3**	1092	**7**	0.689718357	**7**

Source: MCA–KOSA program system, according to the analyzed data (2013)

The individual criteria were paired with concrete data collected from accessible sources in the examined businesses – Krásná Hora Agricultural Cooperative and Komorno, a. s. (Tab. I) and a multi-criterion analysis was performed. The obtained results were evaluated in the context of the available expert knowledge relating to the designated production options using available resources. Through the MCA-KOSA computer program, the proposed production options were ranked according to the measure of their suitability for sustainable development of the agricultural system (Tab. II).

Assessment of supplementary information obtained through the AGREPREF method has revealed that the two interrelations matrices reflecting the two approaches using the considered criteria with either constant or variable weight show, in comparison, only a minimum of differences. Most of the aforementioned interrelations are indifferent, which demonstrates a high level of homogeneity of the subject matter.

Tab. II clearly indicates that the method described above that was used for analysis of the input resources has rated options V_{13} and V_{23} – i.e. use of maize silage and haylage maize – as the best in both businesses that were subjected to comparison, Krásná Hora Agricultural Cooperative and Komorno, a. s. This corresponds with the general theoretical knowledge relating to this production option.

Evaluation based on the WSA method with the use of supplementary information for this method has revealed that the results are in agreement, without any significant differences, in both instances of analysis, i.e. with criteria being applied with both homogeneous and specific comparative weight. Drawing on the supplementary data and the detailed analysis, the results have proved that the choice of qualification coefficients has been correct and that the weight ratios between the individual variants are identical.

The results of the TOPSIS method indicate that the ideal and the baseline variants produce identical figures but differences appear in the structure of the ratio coefficients of the relations between the individual options and the considered criteria. Detailed analysis of the results compiled in the supplementary information tables enables us to discern recognizable differences in the second and third digits after the decimal point, which means that differences do not exceed the level of one-digit numbers of percents.

In view of the quality of the inserted quantitative data, these differences can be considered insignificant. From the viewpoint of the evaluation made through the TOPSIS method, the project can be regarded as consistently homogeneous and conceived with sufficient relevance to the substance of the examined subject matter.

The ORESTE method employs within the structure of supplementary information not only a matrix of the order or preference but also a computer matrix of normalized preference intensities. The parameters chosen for both types of calculation (first, homogeneous weight; second, calculated comparative weights) are identical ($\alpha = 0.071$, $\beta = 0.0089$ and $\tau = 3.5$); these

have been generated through the chosen step of computation by a special algorithm of the MCA-KOSA computer program for the assignment of pseudo-random quantities of stochastic corrections. The supplementary information compiled through the ORESTE method, with regard to the generated pseudo-random quantities of supplementary analysis, produces results that are identical along the diagonal. This means that the specific ORESTE method has demonstrated a great measure of indifference, i.e. a relatively high measure of independence of the inserted data, with the stipulated degree of divergence.

Within the MAPPAC method, the supplementary information presents the interrelations between the so-called preference aggregates (preferential aggregated indices). To ensure correctness in an integrated calculation, the ratio of criteria for substitution relations of the compared variants must show zero values on the principal diagonal – a requirement that was met in both instances of evaluation with the two different approaches to the weight of the criteria. The supplementary information of the MAPPAC method is a matrix with 8 columns and 8 rows (i.e. a square matrix) and is related to the structure of indices of mutual preferences among the individual options derived from the calculated ideal values. A detailed analysis of this matrix reveals that the discrepancies occurring therein do not exceed 1–7%; in view of the quality of the inserted input data, this again clearly testifies to a high measure of consistency of the project.

CONCLUSION

The results of the evaluation of the applied analysis justify the conclusion that the created model evaluates the proposed general production options in the examined business entities in accordance with the attained level of expert knowledge and that the constructed model is ready for use and fully applicable to decision-making processes relating to the needs as regards substitution of input materials for the examined biogas plants.

When applying decision criteria, we should not, however, fail to consider the fact that the process of anaerobic fermentation, which is based on the proposed general input resources of biomass, is a living biochemical process that is always influenced by a number of other factors that cannot be specified even by means of chemical analyses of the used materials (Michálek *et al*., 2013). Data about the utilization rate of methane that are mentioned in numerous publications are not always identical; and certain intervals must be allowed for in the planning made for specific conditions of concrete businesses (Straka *et al*., 2006, 2013). Concrete data need to be adjusted to the location of the business, the climatic conditions, the variety, the phase of the harvest, the livestock in the location, the mode and the quality of their feeding, the current state of the soil as regards temperature and water regime, the manner of storage of the used material, etc. (Nasir *et al*., 2012; Karafiát *et al*., 2012).

From the viewpoint of the chosen methodological approach, the presented paper offers comprehensive general directions on the ways in which the constructed model can be quantified for purposes of the operation of biogas plants with regard to the internal conditions within the production facility as well as the external economic environment.

The aforementioned conclusions of the evaluation of the multi-criterion model are in line with contemporary methods of application of environmental measures in businesses (Hřebíček *et al*., 2013) which proceed from the premise that environment protection must be coupled with favourable economic effect. Well-founded expectation of benefit both to the environment and to the economic development has been a precondition for the application of environmental methods in practice. Allowances made for environmental effects always have consequences affecting in the course of time the interrelations within the entire system, and these must be considered in the overall evaluation (changes in the assortment of crops in the rotation of the sowing pattern, changes in the qualitative structure of soil, water regime, emissions, etc.). Economic evaluation requires that the proposed measures should bring benefit and early return on the financial investment. Assessment of the process needs to pay regard to the capital expenses of the operation and the changes therein, energy and material savings, the related costs of waste treatment and the estimated development of prices and technologies. The aforementioned aspects are considered in the choice of criteria in the proposed multi-criterion model of comparison and evaluation of the production options in biogas plants.

Construction of biogas plants brings significant economic benefits to business entities. At the same time, it involves an inherent necessity to carry out principal changes in the structure of the production. The operation of biogas plants necessitates major structural adjustments in the production process, especially in crop farming (sowing patterns) but also in the structure of residual factors, i.e. in the processing of waste products from existing livestock production, etc. These factors have been largely neglected or underestimated in economic analyses until now. The structure of residues and source factors of numerous waste products generated in both crop farming and livestock production can significantly contribute to overall economic profitability of the operation of a biogas plant and its

output. A crucial role is played here by the approach to the concept of, and to the mode of substitution in, the structure of the input factors for the operation of biogas plants, their proper appraisal and tools for their integration into the accounting and reporting procedures of a business entity for decision-making purposes. Maize that is used as a preferred input material for agricultural biogas plants at present is, in the systemic perspective, a resource of limited capacity within the framework of the applicable sowing patterns. The proposed multi-criterion model will make it possible to identify – at the level of managerial decision-making – optimum substitute input resources according to the possibilities available to individual businesses by means of an overall systemic analysis of the existing interrelations within the agricultural system as a whole along the lines of sustainable development of society.

The proposed model multi-criterion analysis represents a systemic approach to the resource base of biogas plants and its use can be applied in decision-making processes both at the basic level in individual business entities and in society-wide decision-making concerning restructuring of the agricultural sector at the local and regional levels, with a view to creating new job opportunities and securing energy supply.

The result of the performed analysis is a comparative quantitative model of the effectiveness of the operation of a selected biogas plant with respect to sustainable stability of the agricultural sector; the model considers different combinations of options of input resources of a biogas plant in relation to systemic economic-environmental changes in the production structure of a business entity. The model serves as an instrument of decision-making processes in business entities; its application can be easily linked with the accounting relating to material flows as an integrated source of data.

Advancement of system sustainability requires constant enhancement of expert knowledge and availability of relevant data. Environmental education and promotion of environment protection is an inseparable component of universal education as well as of expert training within the entire schools system. Inclusion of cross-sectoral projects focusing on sustainable development into scientific and research programs pursued by university scholars is one of the principal objectives of the Government Program of Environmental Education in the Czech Republic. The development of an integrated approach and transition to a sustainable way of life must be backed by a growing awareness and participation on the part of the general public. Future development in this area is expected to consist in growing interconnection between scientific research and practical application of its results in businesses. Progress toward sustainable development requires improved access to information, better quality and greater relevance of data and their general availability. Uniting existing information systems into a uniform integrated set of data files will be a helpful step in the process of implementing and applying instruments of management in the practice of business entities.

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