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A CONCEPTUAL FRAMEWORK FOR SUSTAINABILITY ASSESSMENT FOR TECHNOLOGY

Abstract. Technology assessment is being increasingly employed in both the public and private sectors. Technology assessment is defined as a process consisting of analyses of technological developments and their consequences as well as a debate on the basis of these analyses. Inquiries into technological developments ad their implications cannot be based on purely technical considerations but needs to adopt more complex perspectives. While traditional forms of technology assessment focused on individual technologies, current physical, technical and political realities necessitate a more systemic/holistic view, focusing on the long-term directions of social change and their impacts on a variety of sustainability. It has been acknowledged that technology and society co-evolve. The paper provides information and knowledge on existing methods and their connections with the environmental, economic and social implications which are used for the assessment of sustainability of technology. This article seeks to provide some clarification by reflecting on the different approaches described in the literature as being forms of sustainability assessment in terms of their potential contributions to sustainability. Currently available methodologies for the assessment of the sustainability cover environmental parameters in a single integrated approach, like environmental impact assessment (EIA). Many of these are actually have been extended to incorporate social and economic considerations as well as environmental ones, reflecting a "triple bottom line" approach to sustainability. Each of the methods differs a set of generic criteria and indicators under the following broad categories: technological suitability, environmental considerations (in terms of resources and emissions, risks etc.), economic concerns, and social considerations. Application of LCA-based methodology to assess painting technology verifies the usability of the framework for sustainability assessment of technology. The conceptual framework for sustainability assessment of technology demonstrated through the paper verifies the application and usability of the methods used.

Keywords: technology assessment, sustainability, framework of technology assessment, LCA

ZARYS KONCEPCJI OCENY ZRÓWNOWAŻONEGO ROZWOJU W OCENIE TECHNOLOGII

Streszczenie. Ocena technologii jest coraz częściej stosowana zarówno w sektorze publicznym, jak i prywatnym. Ocena technologii jest definiowana jako proces składający się z analiz technologii i ich konsekwencje rozwoju i stosowania określonych technologii, procesy rozwoju technologii. Liczne zapytania o rozwój technologii nie mogą opierać się na względach czysto technicznych, ale wymagają bardziej złożonych perspektyw. Podczas gdy tradycyjne formy oceny technologii skupiają się na indywidualnych technologiach, obecne realia techniczne i polityczne wymagają bardziej systemowego/holistycznego spojrzenia, skupiającego się na długoterminowych kierunkach zmian społecznych i wewnętrznych zróżnicowaniach. Uznano, że technologia i społeczeństwo są współzależne. Artykuł dostarcza informacji i wiedzy na temat istniejących metod i ich współzależności, które są wykorzystywane do oceny stopnia zrównoważenia technologii. Odzwierciedlając różne podejścia opisane w literaturze, niniejszy artykuł ma na celu zarysowanie koncepcji metody oceny technologii pod kątem potencjalnego jej wpływu na zrównoważony rozwój. Obecnie dostępne metody oceny technologii uwzględniają parametry środowiskowe w jednolitym zintegrowanym podejściu, na przykład ocenę wpływu na środowisko (EIA). Wiele z nich zostało faktycznie poszerzonych o aspekty społeczne i ekonomiczne, a także środowiskowe, co odzwierciedla podejście zrównoważonego rozwoju, tj. „triple bottom line". Każda z metod różni się zbiorem ogólnych kryteriów i wskaźników ujętych według różnych kategorii: przydatność technologiczna, względy środowiskowe (zasoby, emisja, zagrożenia itp.), aspekty ekonomiczne i względy społeczne. Zastosowanie metodyki opartej na cyklu życia produktu (LCA) do oceny technologii malowania ma na celu weryfikację przydatności tego narzędzia do oceny technologii w aspekcie zrównoważonego rozwoju.

Słowa kluczowe: ocena technologii, zrównoważony rozwój, koncepcja oceny technologii, LCA

1. Introduction

Technology has helped extend the human lifespan and has been the instrumental in improving the standard of living through increased productivity. Some technology solves environmental problems today, because of an almost universal reluctance by governments and those who advise them to make the social and political changes that would be necessary to reduce growth in production and consumption[1]. At times a rapid technology assessment provided establishing priorities by taking into consideration needs, costs, and potential success. From the other hand, technology should be assessed and designed with a view to their normative anchor points: high level of protection to the environment and human health,

[1] Beder S.: The role of Technology in Sustainable Development. "Technology and Society", Vol. 13(4), 1994, p. 14-19, https://www.uow.edu.au/~sharonb/RoleTech.html, 15.03.2017.

sustainability, and societal desirability. And the question remains, how to assess technology taking into consideration the sustainability triangle without causing major social changes and without a rethinking of political priorities? Still, the actual measurements of technology assessment and sustainability remain an open question, and novel concepts and assessment framework, involving various different groups of people directly or indirectly interested are being developed. These questions have not heretofore been systematically addressed in the literature in this case.

Technology assessment (TA) concept is not new. The basic technology assessment definition given by Coates[2] reflects the dimension of studying the systematizing, social aspects and forecasting future issues. “Technology assessment is the systematic identification, analysis, and evaluation of the full range of social impacts, both beneficial and detrimental, which may result from the introduction of a new technology or changes in the application and utilization of existing technology”. “It is interesting to note that even though a number of agencies have not used the term "technology assessment", efforts such as environmental impact studies, national assessments, future studies, planning studies, social impact analysis, the development of social indicators, etc. are going forward[3]. Setting of research priorities on technology assessment with their anticipated impacts (negative or positive in terms of impact on consumers and communities) need to be subjected to a societal review. This implies broadening the review of research proposals beyond scientific excellence and including societal impacts[4].

Technology assessment definitions under various context have addressed in the literature on technology assessment. Several previous comparative studied have been carried out by Paschen and Smith[5], Cruz-Castro and Sanz-Menendez[6]. These studies focused strongly on conceptual definitions of technology assessment (TA) and on the early institutionalization of the new European bodies or agencies related to technology assessment approaches and methodologies. An “integrating concept” is the result of the global acknowledgment of connections between environmental and socio-economic issues as well as concerns for the future of humanity[7]. This approach represents the “three pillars” of sustainability: environmental, economic, and social values (TBL).

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[2] Coates J.: Technology Assessment – A Tool Kit. “Chemtech”, 1976, p. 372-383.

[3] OTA (Office of Technology Assessment): Technology Assessment in Business and Government. Summary and analysis. Congress of the States, Washington, D.C. 1977.

[4] Von Shomber R.: Prospects for Technology Assessment in a framework of responsible research and innovation, [in:] Dusseldorp M., Beecroft R. (eds.): Technikfolgen abschätzen lehren: Bildungspotenziale transdisziplinärer Methoden. VS Verlag für Sozialwissenschaften, Wiesbaden 2012, p. 39-61.

[5] Paschen H., Smith R.: Assessing Technology Assessment Institutions. OECD Symposium TA. Directorate for Science. “Technology and Industry”, OECD DST/SPR 89.20. Vienna 1989.

[6] Cruz-Castro L., Sanz-Menéndez C.: Politics and institutions: European parliamentary technology assessment. “Technological Forecasting and Social Change”, Vol. 72, No. 4, 2005, p. 429-448.

[7] Hopwood B., Mellor M., O'Brien G.: Sustainable development: mapping different approaches. “Sustainable Development”, Vol. 13, No. 1, 2005, p. 38-52; Azapagic A., Perdan S.: An integrated sustainability decision-support framework Part I: Problem structuring. “The International Journal of Sustainable Development & World Ecology”, Vol. 12, No. 2, 2005a, p. 98-111; Azapagic A., Perdan S.: An integrated sustainability decision-support framework Part II: Problem analysis. “The International Journal of Sustainable Development & World Ecology”, Vol. 12, No. 2, 2005a, 2005b, p. 112-131.

Technology assessment is intended to illuminate societal options and thereby provide a neutral and objective input into public decision-making"[8]. TA emerged initially in response to concerns about the environmental and social impacts of technological developments, and was established to serve the information needs of decision makers responsible for governing technology and its impacts. A complete TA is a comprehensive attempt to identify and describe a technology's entire range of side-effects as well as its policy options and alternatives. The results of TA are, in general, concrete recommendations to policy makers and therefore the original questioning a well as the area of potential impact is outside the scientific system researchers. The shortcomings of the "classical" TA approach can be summarized in the fact that the whole TA-process (starting from the "transformation" of the extra-scientific problem into a scientifically manageable research programme until the feedback of the recommendations into the policy making process) needs relevance decisions, evaluations, and the development of criteria.

The development of participatory TA can be described as the effort for TA to have a greater impact by handing over decisions based on values to society itself. Therefore practitioners of participatory TA could claim that their results find acceptance in science as well as stakeholders. In most participatory TA-approaches this is realized by a methodological combination of scientific and participatory discourses that influence each other in a positive way[9]. Constructive TA argues that the social issues need to be addressed by a co-creation process where social issues influence the design of the technology at a very early stage[10].

There are no formal structures for conducting complete TAs in the private sector with substantially different orientations toward TA. Private businesses are using TA as a part of the planning process, and to compete in the marketplace, while in public sector, general assessment of consequences of technological process, including unintended impacts is being used. There is also, in the public sector, a concern with understanding and trying to anticipate future events so that the introduction of new technologies does not cause, too many positive and negative surprises for society. With an informed understanding through TA of what the impacts are, the policy and decision makers in the governmental institutions can better exercise their responsibilities to the general public[11]. Government attempts to deal with the increasingly complex national and international technological issues. Governmental policy development activities with respect to technology require a general organizing concept like TA. This is especially so as the interrelatedness of the political and social environment is

[8] Coates V.T.: Technology and Public Policy: The Process of Technology Assessment in the Federal Government, Vol. I. Final Report. The George Washington University, Washington 1972.

[9] Decker M.: Interdisciplinarity in Technology Assessment: Implementation and its Chances and Limits. Springer-Verlag, Heidelberg-Berlin 2013.

[10] Schot J., Rip A.: The past and future of constructive technology assessment. "Technological Forecasting and Social Change", Vol. 54, No. 2/3, 1996, p. 251-268; Genus A., Coles A.: On constructive technology assessment and limitations on public participation in technology assessment. "Technology Analysis and Strategic Management", Vol. 17, No. 4, 2005, p. 433-443.

[11] OTA.: op.cit., s. 74-75.

better understood. For the other hand, For U.S. public health assessment organizations assessment does not focus on economic evidence, but tailoring assessments to the populations under the agency's purview. They tended to be more open and explicit than private. Health Technology Assessment (HTA) organizations about their processes and deliberations[12]. Difference between private and public technology assessment are presented by Nazarko[13]

The idea of evaluation technology appears in different contexts, moreover, not always under the same name. Medical technology as a challenge for technology assessment. The assessments related to public health interventions, emerging technologies and process technologies use diverse types of methodologies. Research on technology assessment curried out by Health Technologies Assessment agencies adopt, in practice, narrow definitions that focus on efficacy, safety and efficiency. For example, all technologies for drugs developed by agencies are better established and more systematic than for other technologies. Other technologies that are interesting for healthcare systems, including those related to public health, are limited in their assessments to the study of new medications, devices, procedures or medical care programs that require major investments of capital. However, the most popular a form of technology assessment in Europe in public sector seems to be today a Parliamentary Technology Assessment (PTA), which usually takes three common stages[14]: (1) identification of topics for consideration; (2) initial staff review, and (3) in-depth analysis of a specific technology.

Efforts to assess health technologies go back to the early 1980s when Office of Technology Assessment conducted many health care technology assessments[15]. The idea of technology assessment survived and began to develop in Europe creating European Technology Assessment Network. The increased interest by the European governments in the issue (technology assessment) can be met not only in the industry, but in the public sector[16].

The public sector has a two-pronged approach: gaining efficiencies and in its role as a public steward of resources"[17]. Other technology like military has not received major attention in the studies on technology assessment. It would be better to broaden the criteria of technology assessment beyond the strictly military context. In manufacturing, technology assessment is mainly used to analyze and compare production initiatives for decision-making about introducing new technologies or expanding the use of the existing ones. From these, many assessment methods have been developed which attempt to simplify the assessment of

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[12] Neumann P.J.: Lessons for Health Technology Assessment: It Is Not Only about the Evidence. "International Society for Pharmacoeconomics and Outcomes Research (ISPOR)", Vol. 12, No. 2, 2009, p. 45-48

[13] Nazarko Ł.: Technology assessment in construction sector as a Strategy towards Sustainability. "Procedia Engineering", Vol. 122, 2015, p. 290-295.

[14] OTA.: op.cit., s. 74-75.

[15] OTA (Office of Technology Assessment): First report on the Prospective Payment Assessment Commission (ProPAC). Washington, 1985.

[16] Norman J.V., Paschen H.: Parliaments and Technology: The Development of Technology Assessment in Europe. SUNY Press, New York 2000.

[17] Thompson C., as quoted in Government Technology's Public CIO magazine. Phoenix, Arizona 2008.

sustainability, introducing holistic approach[18]. A good example, Sustainability Assessment of Technologies (SAT) is used by a broad spectrum of stakeholders in different situations and at different levels of decision making: (strategic, financial, operational, community, enterprise)[19]. This kind of methodology lays down generic criteria and indicators, which can be customized for sector-specific applications, which could be end-of-pipe or waste management technologies; programs related to environmental health or provision of basic services and infrastructure such as roads, power, water etc. for strategic decision making In SAT, sustainability is addressed through specially designed methodology and criteria including integration of environmental soundness, social/cultural acceptability, and technical and economic feasibility. Therefore, the assessment process typically seeks to minimize "unsustainability" of technology, or to achieve TBL objectives.

Glasser and Charzanowski address technology assessment process as a sequence of questions related to medical technology[20]. The assessment was carried out taking into account four issues or questions: need, effectiveness, safety and cost. The timing of asking questions in the life-cycle of a technology and the adequacy of the answers determines the choice of methods, the assessment and the quality of the responses. Compared to other forms of technology assessment, technology assessment in social context (TASC) takes a social systems approach and incorporates insights and methods from social science theories[21]. Like, Participatory TA, TASC aims for a more thorough analysis of the social changes and consequences associated with technological developments, including the potential cumulative and indirect social changes. The fact that such methods are often inadequate for TA-related problems is due to the fact that their purpose was to provide knowledge as a basis for acting and decision-making concerning technology and its implementation in society. Hence, there is need to integrate political, ethical and societal judgement on the impact of technology results.

Reasons for the shortcoming are problems with using inadequacies in analytic tools or theoretical understanding, precise evaluation or institutional problems due to constrains upon the interests that each individual decision-maker is encouraged to treat as his own. Difficulties can be overcome by introducing technology assessment program. The specific literature on multi-criteria decisions (MCDA) methods does not discuss this aspect in particular, nevertheless, their structure does not limit the number and type of criteria to be used as input

[18] Kluczek A.: Application of Multi-criteria Approach for Sustainability Assessment of Manufacturing Processes. "Management and Production Engineering Review", Vol. 7, No. 3, 2016, p. 62-78.

[19] Chandak S.P.: Sustainablity Assessment of Technologies: Making the Right Choices. IETC-UNEP. 1st Stakeholder Consultative Workshop/Training Program of the Project on Converting Waste Agricultural Biomass to Fuel/Resources. Moneragala District, Sri Lanka 2009, http://www.unep.or.jp/ietc/WS/news-apr10/S2_3_DrSuryaPChandak.pdf, 12.04.2017.

[20] Glasser J.H., Chrzanowski R.S.: Medical technology assessment: adequate questions, appropriate methods, valuable answers. Health Policy. "The Challenge of Technology Assessment in Health Policy", Vol. 9, No. 3, 1988, p. 267-276.

[21] Russel A.W., Vanclay F.M., Aslin H.J.: Technology Assessment in Social Context: The case for a new framework for assessing and shaping technological developments. "Impact Assessment and Project Appraisal", Vol. 28, No. 2, 2010, p. 109-116.

parameters. In essence there are no alternatives to technology assessment techniques. Decision makers would decide to formalize and to implement technology assessment to accomplish the right selection among proposed technologies, or to work randomly without any specific methodology[22].

Methods used to sustainability assessment rely on key interactions and feedback mechanisms between infrastructure and surrounding environmental, economic, and social systems and uses sustainability criteria and indicators as a way of understanding and quantifying such interacting effects. For example, Environmental Technology Assessment is a procedure whereby proposed technology intervention is described and appraised in terms of its potential influence on the environment, implications for sustainable development and the likely cultural and socio-economic consequences.

However, as with many studies, its results are not always fully utilized. Technology is not independent of society either in its shaping or its effects. Presented deliberative related to private and public assessment are too lacking in continuity, detachment to provide a viable institutional basis for the support of the research that a sufficiently broad technology assessment conception. While traditional forms of technology assessment focused on individual technologies, current physical, technical and political realities necessitate a more systemic/holistic view, focusing on the long-term directions of social change and their impacts on a variety of sustainability. It has been acknowledged that technology and society co-evolve. LCA methods are seen as methods based on a well-established and standardized methodology[23], but still showing a limitation with respect to the range of sustainability issues they are able to address. They are seen not to perform well with respect to social, ethical and institutional issues of technology.

This article presents the current approach operating in the public and private sector. Starting from the current state of such research, the author attempts to discuss the new conceptual, theoretical framework for sustainability technology assessment and its contents.

Hence, it is necessary to consider how new framework of technology assessment, or elements of the methodology, might be applied in various levels (institutional, private) in terms of three stakeholder`s perspectives.

The goal of the paper is to provide potential users, decision makers or non-experts with a coherent methodological framework for sustainability technology assessment, including application-dependent methodological guidelines and data format requirements related to the quantification of sustainability impacts from technologies, based on a life cycle approach. The presented methodology is general expected to be used by a diverse target groups in different sectors.

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[22] Bakouros Y.: Technology evaluation. 2000, http://www.adi.pt/docs/innoregio_techn_evaluation.pdf, 20.09.2017.

[23] Sahely H.R., Kennedy C.A., Adams B.J.: Developing sustainability criteria for urban infrastructure systems. "Canadian Journal of Civil Engineering", Vol. 32, 2005, p. 72-85.

2. Reviews on sustainability assessment methodologies

The paper analyses the different approaches or methodologies of assessments developed which are used for the assessment of sustainability of technology.

Various types of assessing methods or ecosystems such as agricultural lands, forests, wetlands, urban regions, etc. were described by Oteng-Seifah and Adjei-Kumi[24].Currently available methodologies for the assessment of the sustainability in production cover economic and environmental parameters in a single integrated approach. Many of these are actually examples of "integrated assessment", derived from environmental impact assessment (EIA) but which have been extended to incorporate social and economic considerations as well as environmental ones, reflecting a "triple bottom line" (TBL) approach to sustainability[25].

Several different concepts and methods have been developed for the sustainability evaluations of particular processes, products, or activities[26]. Still, novel concepts and assessment framework are being developed. Common (sustainability) assessment methods concentrate on one of both topics only[27], where e.g. the LCA methodologies have all in one way or the other failed to achieve this requirement. Methods developed on the basis of "environment in general" "focus on environmental issues with policy, programme and infrastructure provision and LCA methods attempt to address social and economic issues in addition to environmental concerns, but in a piecemeal manner[28]. Leach et al.[29] extended beyond narrow, conventional forms of technology assessment to allow broader social appraisal of alternative – pathways to sustainability. Conventional assessment today are not often well designed for addressing human and ecological effects within complex systems or technologies[30].

[24] Oteng-Seifah S.A.E., Adjei-Kumi T.A.: Review of Urban Sustainability Assessment Methodologies. "International Conference on Whole Life Urban Sustainability and its Assessment", [in:] Horner M., Hardcastle C., Price A., Bebbington J. (eds.), Glasgow 2007.

[25] Pope J., Annandale D., Morriosn-Saunders A.: Conceptualizing sustainability assessment. "Environmental Impact Assessment Review", Vol. 24, 2004, p. 595-616.

[26] Jeswani H.K., Azapagic A., Schepelmann P., Ritthoff M.: Options for broadening and deepening the LCA approaches. "Journal of Cleaner Production", Vol. 18, 2010, p. 120-127; Jeswani H.K., Azapagic A.: Water footprint: methodologies and a case study for assessing the impacts of water use. "Journal of Cleaner Production", Vol. 19, 2011, p. 1288-1299; Bertoni M., Hallstedt S., Ola I.: A model-based approach for sustainability and value assessment in the aerospace value chain. "Advances in Mechanical Engineering", Vol. 7, No. 6, 2015, p. 1-19

[27] Skowrońska M., Filipek T.: Life cycle assessment of fertilizers: a review. "International Agrophysics", Vol. 28, 2014, p. 101-110.

[28] Oteng-Seifah S.A.E., Adjei-Kumi T.A.: op.cit.

[29] Leach M., Scoones I., Stirling A.: Pathways to sustainability: An overview of the STEPS Centre approach. STEPS Approach Paper. STEPS Centre, Brighton 2007.

[30] Gibson R.B.: Sustainability assessment: basic components of a practical approach. "Impact Assessment and Project Appraisal", Vol. 24, No. 3, 2006, p. 170-182.

To address this problem, integrative sustainability concept combines the disaggregation analysis necessary for an LCA with an evaluation of costs (including purchase price, installation cost, operating costs, and maintenance and upgrade costs). LCA as a standalone tool to evaluate environmental policy is not sufficient. The sustainability assessment of technologies was combined with a life-cycle approach (LCA and LCC)[31]. Combined LCA-LCC can be useful to evaluate environmental and economic aspects in life terms by assigning a price to different production/ operations elements. While LCA life cycle assessment is a product-oriented tool for the assessment of environmental implications, not considering economic impact, EIA is potentially an important instrument for furthering sustainability in public and private decision making[32]. The integration of sustainability and EIA is approached at three levels: (1) the conceptual addressing with a framework that depicts links between sustainability and impact assessment, (2) the regulatory redefining the intent and scope of EIA requirements, and (3) the applied integrating sustainability into each step of the EIA planning process[33].

Other approach, overall life cycle sustainability assessment (LCSA), combines standalone life cycle assessment techniques already in use, LCA, LCC and social Life Cycle Assessment (SLCA) addressing in a complementary way the three sustainability dimensions (environmental, economic and social)[34]. Hence, environmental LCC refers to an economic assessment that is consistent with LCA, and social (S)-LCA, likewise, an assessment of the social impacts along the entire life cycle of a product that fits to the environmental LCA[35]. The further development of LCSA mainly depends on the improvement of the life cycle methods. In this respect, a joint technique to broad the scope of life-cycle studies (LCA) on other dimensions of sustainability, is necessary. Effective LCA is based on a range of different environmental indicators. Achieving sustainable production requires that LCA focus on ecosystems with a shift away from a product point of view. The most important ecosystem parameter is the magnitude of the environmental effect, which typically depends on the amount of waste per unit area. Therefore, LCA must consider the technologies where industries are operating and the areas that provide the resources for that industry. Such a function area must be used for emission source. For the economic and social dimensions, there is still need for consistent and robust indicators and methods. Thus, having a

[31] ISO (International Organization for Standardization): ISO 14040: Environmental Management. Life Cycle Assessment. Principles and Framework. ISO, Genève 2006.

[32] WCED (World Commission on Environment and Development): Our Common Future. Oxford University Press, Oxford 1987; Hui I.K., He L., Dang C.: Environmental impact assessment in an uncertain environment. "International Journal of Production Research", Vol. 40, 2002, p. 373-388.

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[34] Wu R., Yang D., Chen J.: Social Life Cycle Assessment Revisited. "Sustainability", Vol. 6, 2014, p. 4200-4226; Finkbeiner M. Schau E.M., Lehmann A., Traverso M.: Towards Life Cycle Sustainability Assessment. "Sustainability", Vol. 2, 2010, p. 3309-3322.

[35] Klöpffer W., Ciroth A.: Is LCC relevant in a sustainability assessment? "International Journal of Life Cycle Assessment", Vol. 16, 2011, p. 99-101.

methodology to assess the impacts from various resources that were used during the production process is useful to combine with other methods. Other available assessment tools such as Cost Benefit Analysis (CBA)[36], Material Flow Analysis (MFA)[37] require high-level expert competence.

3. Conceptual framework for sustainability technology assessment

3.1. Sustainability Assessment Principles

It has been suggested that to be effective assessment processes for sustainability, some principles must be applied:

- The sustainability assessment is based on an explicit definition of sustainable development. The Brundtland`s definition is very general and requires interpretation for specific situation in various context[38]. It helps transparency if this interpretation is made explicit in specifying what will be considered a sustainable outcome[39]. The nature of a sustainable outcome addresses all three pillars: economic, social, environmental (TBL) and other relevant considerations.
- Selection of criteria are concluded based on data quality criteria stated by ISO 14040 standard. In addition, there is no established clear methods available to assess technology in a unified manner, especially in private sector. However for comparative methods which are disclosed to the public, LCA standard ISO14040 explicitly states that weighting method is allowed. The sustainability approach is, however, not a long stretch from comprehensive and ambitious forms of environmental impact assessment in which "environment" is defined to include social, economic, components and their interactions[40]. Hence, the objective of the LCA-based methods is durable betterment rather than mere mitigation of significant adverse effects. Sustainability criteria should effectively separate sustainable outcomes from unsustainable ones for the purposes of the assessment process, which would then ask whether or not these criteria have been met[41].

[36] Höjer M., Ahlroth S., Dreborg K.H., Ekvall T., Finnveden G., Hjelm O., Hochschorner E., Nilsson M., Palm V.: Scenarios in selected tools for environmental systems analysis. "Journal of Cleaner Production", Vol. 16, 2008, p. 1958-1970.

[37] Sendra C., Gabarrell X., Vicent T.: Material flow analysis adapted to an industrial area. "Journal of Cleaner Production", Vol. 15, 2007, p. 1875-1885.

[38] WCED (World Commission on Environment and Development): Our Common Future. Oxford University Press, Oxford 1987.

[39] Klemeš J.J., Cucek L., Kravanja Z.: Overview of environmental footprints, [in:] Klemeš J.J.: Assessing and Measuring Environmental Impact and Sustainability. Butterworth-Heinemann (Elsevier), Oxford, UK.

[40] Gaudreau K, Gibson R.: Illustrating integrated sustainability and resilience: a small-scale biodiesel project in Barbados. "Impact Assessment and Project Appraisal", Vol. 28, No. 3, 2010, p. 233-243.

[41] Pope J., Annandale D., Morriosn-Saunders A.: opt.cit., p. 595-616.

- Ethics – as a design factor of technology should not be seen as being only a constraint of technological advances. Incorporating ethical principles in the process of technology assessment can lead to well accepted technological advances. Introducing Codes of Conduct in contrast to regulatory interventions should allow a constructive steering of the assessment process. It enables the establishment of a proactive scientific and non-scientific community which identifies on risks and benefits in an early stage. Codes of Conduct are particular useful when risks are uncertain and when there is uncertain ground for legislative action (nanotechnology for example). From the other hand, due to the convergence of ICT with other technologies such as biotechnology, nanotechnology the principles should include ethical aspects which cover the phenomenon of converging technologies.

Next to the sustainability technology assessment principles described in the paper there are other principles outlined by Pintér et al.[42]. They provided the rationale for the revision of the principles, their detailed description and guidance for their application. Eight principles are: (1) Guiding vision; (2) Essential considerations; (3) Adequate scope; (4) Framework and indicators; (5) Transparency; (6) Effective communications; (7) Broad participation; and (8) Continuity and capacity.

3.2 Sustainability technology assessment procedure

Sustainability technology assessment procedure consists of five domains: approach to sustainability technology assessment, system boundary, decision context and methodological framework as well assessment.

[42] Pinter L., Hardib P., Martinuzzic A., Halla J.: Bellagio STAMP.: Principles for sustainability assessment and measurement. “Ecological Indicators”, Vol. 17, 2012, p. 20-28.

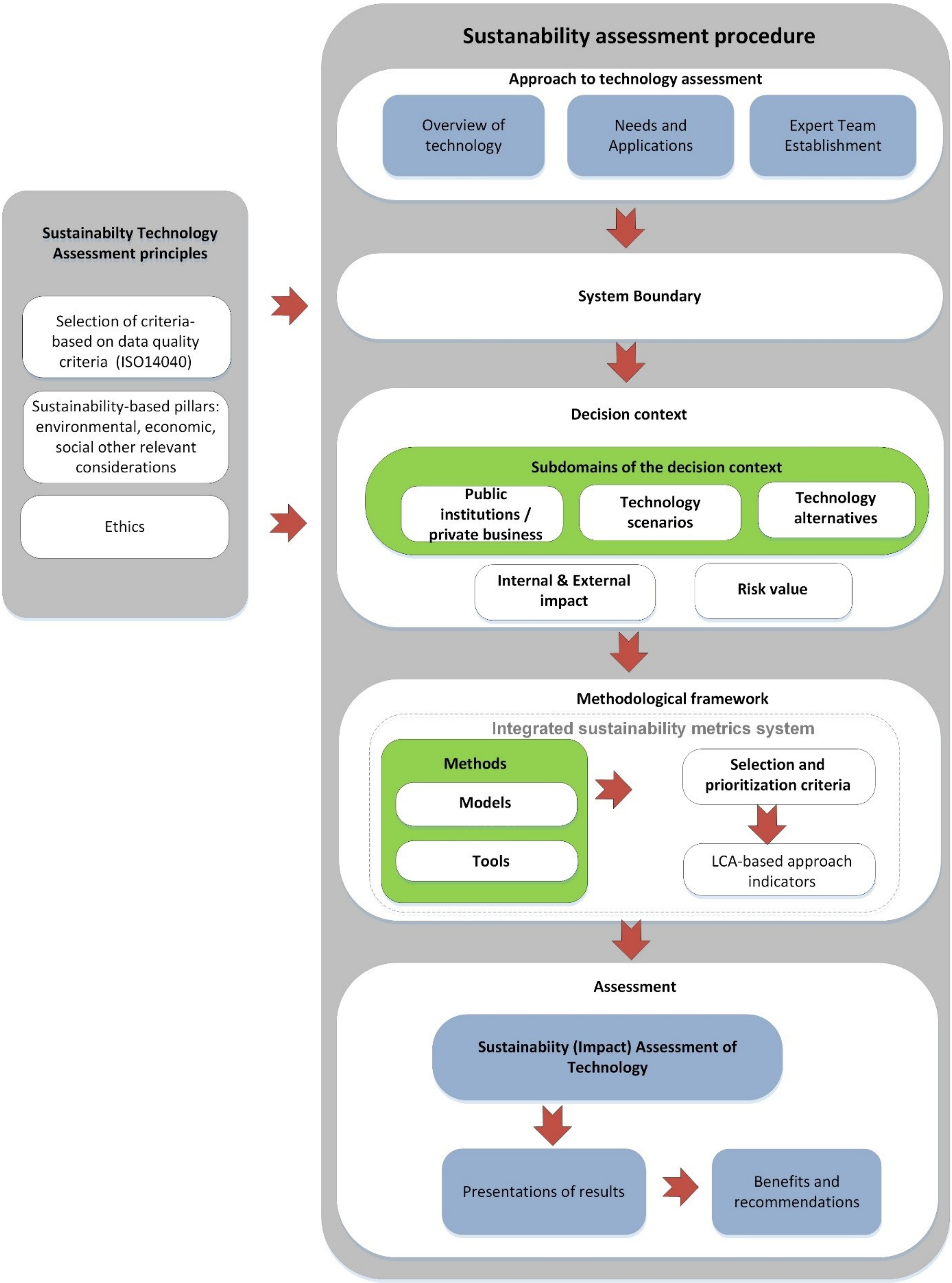

Fig. 1. Conceptual framework of sustainability assessment of technology (CFSAT)

3.2.1. Approach to Sustainability

The first domain within sustainability assessment procedure is characterized by: (1) overview of technology, (2) business need and application and (3) expert team establishment.

Business needs for sustainability technology assessment and application

The basic purpose of the technology sustainability assessment procedure is to accomplish the TA-principles and goals set by organizations, which declares has to perform as far as possible detailed and examination of the proposed idea-technology.

This subdomain sets out the main objectives for its assessment:

- Minimize expected environmental impacts.
- Maximize expected public support.
- Minimize expected cost.
- Maximize expected (financial, non-financial, engineering, pro-environmental) benefits.

The evaluation of a proposed technology must be very careful, considering and identifying all the factors that will affect the whole organization. These main factors are expected financial benefits, competitiveness with increased profitability, as the result of the introduction of a new technology, added value in its technology and the impact upon the business as a whole.

The goal of the stage is to scan "roughly" of technology in the stakeholder's perspectives and based on a simple-to-use questionnaire:

(1) Is there a need?

(2) Is the technology applicable?

(3) Which operational activities could be most improved by technology?

(4) Which of the list of operations, when improved, would improve the bottom line most?

(5) Is there operated potentially sustainable?

The three particular stakeholder's perspectives include:

- Users/Buyers.
- Producers/Providers of a specific technology.
- Regulators/Investors.

The set of indicators in terms of the sustainability categories: environmental, economic, social and ethical is ranked by the key stakeholders in the public and institutional sector (authority, governmental agency), have been identified within the methodological stage of CFSAT.

By introducing the three perspectives, the conceptual framework of sustainability assessment of technology (CFSAT) puts particular emphasis on roles of the users/buyers, the producer/provider, and the regulator/facilitator/supervisor in the detailed technology assessment. From among the remaining technologies which are potentially sustainability, there are considered those technologies, which represent the harmonization of several field expert`s answers and those which are the most consistent with the CFSAT principles.

Overview of technology

An overview of technology is very helpful to acquire information about technology that could provide innovative or improved product or processes in the technology business. As a part of the business perspectives, a description of the technology therein must be prepared. It should include aspects such as: maturity of technology (research stage; pilot stage or commercial stage), applicability opportunities (new markets, existing market, and mass market), its limitations, and its cost to bring market, customization.

In order to select and evaluate among different technologies the best fitted for the organization, some useful steps/phases are proposed that must be followed carefully and under potential review. HTA policymakers should keep three areas focusing on value and economic efficiency, incorporating real-world data, and developing better procedural rules around health technology assessment implementation[43].

Experts' team establishment

Expert team establishment with one or more managers will have the responsibility to lead and guide the team through a successful assessment process. Taking into account the above mentioned business perspective, the appointment of an experts experienced consultant can be achieved, depending on the complexities and difficulties of the technology and the financial situation and size of the organization.

3.2.2. The system boundary

The system boundary is the next step in the technology assessment procedure to be determined. The system boundary is governed by its spatial and temporal scales[44]. The spatial scale is the physical size of the system. The temporal scale is the period over which the impacts of business operations are considered. In general, the system boundary must be selected to include the necessary features of the business being assessed, but not drawn so widely that extraneous activities are included which could confuse subsequent analysis. The system reflects its nature and the purpose for which the analysis is being performed. It is essential that the system boundary is set to include all relevant effects.

The choice of system boundary is very important because it limits technologies to be included in the sustainability framework. However, it should be kept in mind that what lies outside the denned system boundary can still be of great importance. For example, the

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[43] Neumann P.J.: op.cit., Lessons for Health Technology Assessment: It Is Not Only about the Evidence. "International Society for Pharmacoeconomics and Outcomes Research (ISPOR)", Vol. 12, No. 2, 2009, p. 45-48.

[44] Tahir A.C., Darton R.C.: Sustainability indicators: using the Process Analysis Method to select indicators for assessing production operations. "Chemical Engineering Transactions", Vol. 21, 2010a.

organizations in charge of HTA processes may be on a local, regional, national and international level[45].

3.2.3. Decision context

One of the main implications for the conceptual framework of sustainability assessment is that it necessarily requires a clear vision of what sustainability means. Further, this vision needs to be translated into decision context specific sustainability criteria.

Decision context domain may be applied to assess the impact proposed technology on sustainability at the institutional level, private/business level, but, finally, it can also be used to assess comprehensively whether a technology is contributing to the sustainability (or unsustainability). The answer the main question (chapter Introduction) will be collected at government institutions and private levels in the field, which are from these key actors.

Scenarios analysis for the technology

Estimates and forecasts of the development of technologies, their (e.g. production) potential is in vital role in decision making both on governmental and business level. Possible technology scenarios could be evaluated on the basis of different criteria to the at least three pillars of sustainability. Both quantitative and qualitative research methods have been used. Quantitative forecasts are based on technology evolution and market diffusion models combined with forecasts and estimates on the availability. Qualitative analyses are typically based on specialist interviews, workshops, brain storming etc. For this reason, even with different approaches, in most cases, a single indicator is evaluated as a weighted combination of the criteria (e.g. multi-criteria assessment)[46].

Employing CFSAT principles quantitative and qualitative methods allow to consider two approaches, if appropriate, in the sustainability assessment: baseline approach and improvement approach (targeted-oriented scenario). It helps comparing these approaches in order to incorporate more objective assessment. Technologies are represented by various kinds of performance data, hence need to be based upon procedure for simplifying sustainability assessment in order to easy compare with the target scenario. Scenarios lead not directly to a selection of technologies, but it might give recommendations in order to build up the basis for an informed decision.

Technology alternatives

With multi-criteria analysis a number of technology alternatives ranked in the order of their scores emerge. The selection of technologies from an inventory relates to the

[45] Neumann P.J.: opt cit., p. 45-48.
[46] Sala S., Ciuffo B., Nijkamp P.: A systemic framework for sustainability assessment. "Ecological Economics", Vol. 119, 2015, p. 314-325.

stakeholder`s decision and is therefore subjective. Generally, these aspects can be overcome by collecting primary data, through expert interviews for example.

Technology options come to be eliminated and the alternatives with the best overall ratings are selected for further feasibility studies that assess sustainability in terms of environmental, social, economic, ethical and/or technical aspects. The remaining technologies are compared through the weighted average scores of their main characteristics. Then, the selected technology should be compared with the considered technology. Therefore, a new assessment is performed due to possible changes or improvements in technologies or available information based on which technology is weighted. Improvement potential could be evaluated rating scale from 1 to 3 (where 3 has the highest significance): from good and quick improvement (1) to little or no possibilities for improvement (3).

The criteria, weights and scores may differ enough ultimately to alter the technology system choice to be adopted by stakeholders. This is particularly important in energy projects, where there are many sustainability criteria and even more different and usually opposing of views of different stakeholders[47].

Risk assessment and value

Risk factors addresses risk and uncertainties such as legal, regulatory, political, market and stakeholders to the valuation.

Some technologies developed within a specific research field, such as ITC technology or nanotechnology offers "unknowns" about potential human, environmental and societal risks. Decision makers or stakeholders want to know which information is pivotal to assess whether technology (a nanomaterial or nanotech application) is safe. An interdisciplinary approach to carry out is required, with research that pushes boundaries, and maps out existing risk analyses of effects in the arena of health, safety and the environmental technologies. Consideration of political, social, and ethical goals, provide only a limited appraisal of the value of a technology. Hence, interdisciplinary approaches to risk assessment derived from this classification scheme are organized into four sections:

- Technical Risk Assessment, representing actual risks and calculated as the product of the probability and consequences of an adverse event[48]. From the perspective of the technical approach, risk can be evaluated independently of political, economic, or social conditions[49],

[47] Santoyo-Castelazo E., Azapagic A.: Sustainability assessment of energy systems: integrating environmental, economic and social aspects. "Journal of Cleaner Production", Vol. 80, 2014, p. 119-138.
[48] Klein J.H., Cork R.B.: An approach to technical risk assessment. "International Journal of Project Management", Vol. 16, No. 6, 1998, p. 345-351.
[49] Bradbury J.A.: The Policy Implications of Differing Concepts of Risk. "Science, Technology & Human Values", Vol. 14, p. 380-389.

- Economic Risk Assessment, focusing on calculating expected economic impacts,
- Psychosocial Risk Assessment, addressing how individuals and institutions evaluate and communicate to the public about technology risks.

The risk associated with various methods is that:

- focusing only on thresholds can give the misleading impression that "degradation below the threshold level is safe and improvements beyond it are of no value" [50],
- or concentrating on non-thresholds can consider with the level of confidence and may turn out to be worthwhile, especially during consideration of technology.

An attempt to develop and integrate a proactive risk assessment methodology with future-oriented technology analysis is examined in[51].

Internal & external impact

A thorough review of technology is made to identify the issues that have a significant internal and external impact[52]. This leads to select the indicator sets and appropriate metrics. Technologies that have impact on the tree types of capital are termed internal impact generators. These relate to activities within the system (internal) and are typically activities or the policies that cause the activities to occur. The owners of the capital impacted by the impact generator are termed external impact receivers (experienced by impact stakeholders). A group of stakeholders comprising local authorities, academics and researchers, community energy associations and consultancies will provide opinions on sustainability issues associated with considered technologies.

It could be a large number of internal impact generators identified for the aggregated dimensions: environmental, economic and social as shown in table 1. It is also selected to demonstrate how the sequence: Internal impact generator → External impact receivers → Object of studies/issues → Assessment method is developed in practice.

3.2.4. Methodological context

Within the methodological framework (Fig. 1), an assessment leads to selection of the methods, indicator sets and appropriate metrics. The integrated sustainability metrics system includes tools, methods, prioritization criteria and indicators which are developed based on scientific-value research and life cycle assessment based approach. Sustainability assessment of technology is done by measuring impacts on four pillars: environment, economic, social and ethical/technological. The impact on each of the four pillars is measured and then

[50] Polasky S., Carpenter S.R., Folke C., Keeler B.: Decision-making under great uncertainty: environmental management in an era of global change. "Trends in Ecology & Evolution", Vol. 26, No. 8, 2011, p. 398-404.

[51] Koivisto R., Wessberg N., Eerola A., Ahlqvist T., Kivisaari S., et al.: Integrating future-oriented technology analysis and risk assessment methodologies. "Technological Forecasting & Social Change", Vol. 76, 2009, p. 1163-1176.

[52] Tahir A.C., Darton R.C.: The Process Analysis Method of selecting indicators to quantify the sustainability performance of a business operation. "Journal of Cleaner Production", Vol. 18, No. 16, 2010b, p. 1598-1607.

aggregated into a single score. A report is provided to the decision makers justifying the recommended (one or a few) selected technology.

The terminology for description of methodological framework was adapted from Sala et al.[53]. In particular, the framework is the rationale and structure for the integration of methods and tools, indicators, such as:

a) The method is a set of models, tools and indicators that enable the calculation of the values of indicators for a certain impact category. Selection of the methods to be applied depends on decision makers or an expert experienced consultant depending on the difficulties of the technology considered, the financial situation of the organization in which a new technology will be implemented. Taking into account the previous considerations methodological frameworks and methods could involve LCA-based approaches or many others.
b) Most methods or tools are tailored for experts, and only few cater for non-specialists and SMEs[54]. The technology's contributions to sustainability could be are ranked on a simple 3-point scale, identifying positive impact (+), negative impact (-), and impact that may be mixed, or positive or negative depending on how it is undertaken (=). For a more advanced analysis, a 5-point scale could be used and care taken to avoid overlapping criteria[55]. The methods and tools to use indicators as a basis for decision-making in various sectors are under development. Several sustainability indicators have been developed so far[56], but none has emerged as a universal measure[57]. In addition there is no unanimity yet as to which criteria and indicators or which method is better to use in technology assessment. Multi-criterion rating systems focusing on environmental indicators have been proposed in different fields, industries[58]. As in previously mentioned paper, the assessment framework is extremely complex, comprising several separate analyses: an analytic hierarchy process with qualitative indicators.
c) The model is the mathematical description of the system and it is used to calculate a particular indicator of the impact of environmental/social/ economic interventions.
d) The tool is the software, application, database supporting the analysis done by adopting a specific method and the related models.

[53] Sala S., Farioli F., Zamagni A.: Progress in sustainability science: lessons learnt from current methodologies for sustainability assessment (part I). "International Journal of Life Cycle Assessment", Vol. 18, 2013, p. 1653-1672.

[54] Ibidem.

[55] Gaudreau K, Gibson R.: op.cit., p. 233-243.

[56] UN Commission on Sustainable Development (UNCSD): Indicators of sustainable development: framework and methodologies, 2001, http://www.un.org/esa/sustdev/publications/indisd-mg2001.pdf, 15.03.2017.

[57] Pope J., Annandale D., Morriosn-Saunders A.: op.cit., p. 595-616.

[58] Smeets E., Junginger M., Faaij A., Walter A., Dolzan P., Turkenburg W.: The sustainability of Brazilian ethanol - An assessment of the possibilities of certified production. "Biomass and Bioenergy", Vol. 32, No. 8, 2008, p. 781-813; Sahely H.R., Kennedy C.A., Adams B.J.: op.cit., p. 72-85.

e) Indicators, which characterize the different dimensions or aspects of technologies. Indicators can constructed as a ratio, with impact, either resource consumption or pollutant emissions, in the numerator and a representation of output, in physical or financial terms, in the denominator. To calculate the indicators, all impact numerators and output denominators are normalized to one functional unit. From a methodological standpoint, sustainability indicators are recognized as useful integration tools to evaluate a situation in several dimensions and to test sustainability. Sustainability assessment indicators should be divided into three categories to represent the "five pillars" of sustainability: environment, economic and social, health and ethical impacts. Identifying the set of indicators leads to directly to the metrics which quantify the impact. The metrics should be relevant and specific to the defined purposes.

The classification of indicators in relation to the main aspects depends on the hierarchy chosen as a basis. For this reason, the same indicator can be seen in different context in different methods. The selection of indicators can follow these principles described by Li et al.[59]: (1) Geographical and technological relevancy to characteristics or kind of technology; (2) Avoidance of double counting; (3) Indicators have to be quantifiable; (4) Value preference of each indicator shall be made clear and consistent; (5) Feasibility for model to be applied in real life according to resource availability; (6) Easiness to understand, so that the indicator is useful to decision makers and understandable to the public; (7) The indicators and analysis details must be transparent and accessible to all stakeholders.

Combining indicators and dimensions of the sustainability to provide technology assessment could be applied, if there is a good rationale for the combination. What else, interactions among these dimensions generate synergies and tradeoffs arising from the demands that each dimension poses over the others, and on the extent to which these demands are being satisfied, namely contributions.

Within this framework, the LCA studies analyzed the potential environmental impacts (impact categories), for assessing the environmental sustainability, life cycle costing for the economic and various social indicators for the social sustainability[60]. Typical LCA-related impact category indicators include resource depletion, global warming potential, smog production, acidification, eutrophication, toxic waste production and biodiversity impact. Impact is estimated using a simple numerical scale.

a) energy intensity,
b) water consumption,
c) toxic emissions,

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[59] Li T., Roskilly T., Wang Y.: A Life Cycle Approach to Sustainability Assessment on Community Energy Projects in the UK. 2016 ACEEE Summer Study on Energy Efficiency in Buildings, California 2016, http://aceee.org/files/proceedings/2016/data/papers/11_777.pdf, 20.09.2017.

[60] Santoyo-Castelazo E., Azapagic A.: op.cit., p. 119-138.

d) waste,
e) pollutant emissions.

Economic impact in terms of the Life Cycle Cost (LCC), the following indicators are considered: e.g. initial investment costs, operating costs, dynamic generation cost (DGC) or cost of protection of human health impairment

The LCA-based Life Cycle Sustainable Assessment (LCSA) has been used as the method to assess the social impact. Social impacts are analyzed through three impact categories, e.g.: employment provision, community impacts and reduction of poverty, work environment footprint or health and safety[61]. Possible indicators for environmental and social sustainability criteria in the manufacturing sector, which are still in a process of development are described by Labuschagne and Brent[62].

Selection and prioritization criteria & indicators

The defined criteria are used to assist consideration of their implications as a package, and to help identify ways by which technologies could make more consistently positive contributions to sustainability.

By adding ethical criteria as one of the principles and the sustainability could have been conceived for broad application to assessments of technologies of various kinds, scales and locations, and their options.

A number of studies emphasize the lack of transparency in technology selection and periodization processes, especially in health technology. Many health technology assessment organizations do not have clear priority-setting processes[63] that include selection methods and participation of stakeholders, most agencies have a panel to provide recommendations on the priorities[64]. In turn, Specchia et al.[65] reviewed the criteria for priority setting and indicators for health technology assessment taking into account medical and economic impact of their impact and the burden of the disease. Unfortunately, those criteria generally ignored the potential availability of new technologies in the near future, and their ethical, legal, or psychosocial implications.

A quantification criteria and indicators are proposed to facilitate objective decision-making. Depending on the complexity of the decision to be made, as well as the competence and the capability of stakeholder groups, a range of techniques or aggregation techniques can

[61] Li T., Roskilly T., Wang Y.: op.cit.

[62] Labuschagne C., Brent A.C.: Sustainable Project Life Cycle Management: the need to integrate life cycles in the manufacturing sector. "International Journal of Project Management", Vol. 23, 2005, p. 159-168.

[63] Noorani H.Z., Husereau D.R., Boudreau R., Skidmore B.: Priority setting for health technology assessments: a systematic review of current practical approaches. "International Journal of Technology Assessment in Health Care", Vol. 23, 2007, p. 310-315.

[64] Novaes H.M.D, de Soárez P.C.: Health technology assessment (HTA) organizations: dimensions of the institutional and political framework. "Cadernos de Saúde Pública", Vol. 32, No. 2, 2016.

[65] Specchia M.L., Favale M., Di Nardo F., Rotundi G., Favaretti C., et al.: How to choose health technologies to be assessed by HTA? A review of criteria for priority setting. "Epidemiology Preview", Vol. 39, No. 4, Suppl. 1, 2015, p. 39-44.

be applied. The aggregation method used in the assessment methodology should be easy to understand and flexible in order to meet the solution's requirements.

The suggested criteria at this stage demand much more detailed and quantitative information to facilitate decision making from a simple weighted sum method to more sophisticated approaches such as the Analytic Hierarchy Process (AHP)[66]. Numerous multicriterion decision making (MCDM) methods exist for supporting the evaluation and selection of indicators and alternatives technologies, processes and any of these could be used within this decision-support framework[67].

Each of the criteria (contributors) can be calculated in a quantifiable way, in order to avoid subjective judgements. Selected sustainability criteria in terms of sector or object of study considered for technology assessment are presented in table 1. Additionally, the suggested criteria at this stage demand indicators to facilitate decision making.

The conceptual framework of sustainability technology assessment is focused on three main criteria to avoid overlap, which ensures that each criteria has a unique set of indicators within the integrated sustainability metrics system.

3.2.5. Assessment

Once the decision to selects a particular methods and relative indicators to be technology assessed, has been made, it forms a foundation for further steps such as sustainability (impact) technology assessment.

The goal of this step is to comprehensively assess the applicability of a specific / selected technology in the stakeholder`s specific context to contribute to the sustainability. It is used to assess whether a technology is contributing to sustainable (or unsustainable) development. A decision can be made, which will take into account the sustainability dimensions and particular stakeholders` perspective.

3.2.6. Presentations results and recommendations

Through this presentation the results (scores) can easily be interpreted for each of the sustainability pillars and for the different key stakeholders. The outcomes should be reported to the stakeholders, especially government agencies, and other decision makers.

Benefits and recommendations

By means of applying integrated sustainability metrics system, within a technology assessment, the broad spectrum of benefits could be recognized, the appropriate assessment are carried out, and – if applicable – the best-possible course of action is recommended.

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[66] Saaty T.L.: How to make a decision: The analytic hierarchy process. "European Journal of Operational Research", Vol. 48, No.1, 1991, p. 9-26.

[67] Freitas A.A., Magrini A.: Multi-criteria decision-making to support sustainable water management in mining complex in Brazil. "Journal of Cleaner Production", Vol. 47, 2013, p. 118-128.

Through the involvement of all key stakeholders in the entire process of CFSAT application, their understanding causes that stakeholders think systemically about a technology assessment and provides a way to judge whether or not technology is truly more sustainable or not. It means a stakeholder`s awareness supports the acceptance of the results of the technology assessment.

Table 1

Selected sustainability criteria considered for technology assessment

Identified criteria/internal impact	External impact	Sector/Object of studies/ Project focus	Assessment Methods	Sources
Health benefits Evidence Timeliness Ethical, legal, and social implications	Capital providers Users/ Employees	Public/Health	A three-round Delphi study was conducted in the form of an electronic questionnaire distributed to a panel of national experts.	(Jankauskiene and Petronyte, 2015)
Number of construction enterprises Personnel costs per employee Labour productivity in construction Gross value added and gross domestic product in construction Energy intensity	Suppliers and contractors Capital providers	Public/Building construction	Multiple criteria decision making methods TOPSIS and SAW was applied	(Šaparauskas, 2007)
Technological suitability, Environmental considerations, (in terms of resources and emissions, risks etc.) Economic/ financial concerns Socio-cultural considerations		Private/Public	Sustainability Assessment of Technologies methodology (SAT) offers a set of generic criteria and indicators followed by Plan-Do-Check-Act cycle of continuous improvement as recommended by the systems like Quality/Environmental Management Systems.	(UNEP, 2012)
Alternatives Budget impact Clinical impact Controversial nature of proposed technology Disease burden Economic impact Ethical, legal or psychosocial implications Evidence Expected level of interest Timeliness of review Variations	Local communities Government agencies Capital providers	Health	Criteria related to HTA prioritization were identified and grouped through a systematic review and consultation with a selection committee. Criteria were scored through a pair-wise comparison approach. Criteria were pruned based on the average weights obtained from consistent (consistency index < 0.2) responders and consensus.	(Husereau et al., 2010)

cont. table 1

Health outcomes Disease and target population Technology alternatives Economic aspects Evidence	Government agencies Capital providers	Health	Medical databases (the Cochrane Library, Pub Med and Scopus; Multi-Criteria Decision analysis (MCDA)	(Mobinizadeh et al., 2016)
Socio-ecological system integrity and resilience Livelihood sufficiency and opportunity Intergenerational equity Intergenerational equity Resource maintenance and efficiency Social-ecological civility and democratic governance	Government agencies Local communities	Public/Energy Projects	Application of a sustainability–resilience Framework based on the generic sustainability assessment criteria for an existing small-scale biodiesel plant	(Gaudreau and Gibson; 2010), (Gibson et al., 2005)
Environmental, Economic Social Functional	Capital providers Local communities Employees Suppliers and contractors	Construction		
Environmental Economic	Capital providers	Energy	Assessment of electricity generation options from biomass using life cycle approach	(Dorini et al., 2010)
Environmental: raw material consumption, material recycling, renewable energy, water recycling, NOx, SOx, hazardous waste, energy savings, reduction in GHG emission, environmental investment *Social:* social expenditure, attrition rate, benefits for employee, no. of reported injures, no. of employees; *Economic:* net profit, retained EVA, contribution to tax; payment to employee	Government agencies Consumers, Employees	Energy	Corporate sustainability performance assessment using the weighting method (analytical hierarchy process)	(Goyal and Rahman, 2014)
Economic viability Environmental performance Social acceptability	Government agencies Consumers, Employees	Energy	The approach uses multi-criteria decision analysis (MCDA) and decision-conferencing to develop	(Elighali et al., 2007)
Qualitative Assessment Quantitative Assessment	Government agencies	Aerospace	Generic method for integrated sustainability and value assessment	(Bertoni et al., 2015)

4. LCA-based methodology applied to painting technology

4.1. Approach to Sustainability Technology Assessment

Due to limited data driven from a plant, a reasonable criteria set can be established based on adapted technological changes in an existing state of manufacturing technologies in the considered plant if the principles taken into consideration.

Business needs

Of all the boiler manufacturing processes, it contributes the most in terms of environmental emissions. Environmental concerns along with economic considerations for cleaner technologies led to the transition from solvent-borne to water-borne to powder paint coatings over the past decade for the objective of reducing VOC emissions and the need for abatement equipment. Therefore, the painting process is an area where technical change or improvements should be welcomed to reduce VOC and dust emissions. Pollutants such as NOx, SO, CO~, CH~, and N~O, contribute to the greenhouse effect when released into the atmosphere, during the painting process. These pollutants and particulate emissions can contribute to health problems that may affect employees, residents, and the community. Studies on VOC emissions have typically focused on the limitations of emission of harmful substances into the atmosphere from manufacturing processes. For the painting and finishing processes, this generally means satisfying a prescribed emission rate limit or using an accepted application technique.

The scan of technology was performed in perspectives of users/investors.

Table 2

Questionnaire

Questions	Users/Investors
Is there a need?	Yes due to safety and EU environmental regulations.
Is the technology applicable?	Yes
Which operational activities could be most improved by technology?	Implement a new painting booth with air circulation. Potential harm to the environment will also be reduced.
Which of operations, when improved, would improve the bottom line most?	Not applicable
Is there operated potentially sustainable?	Paint shop should have a positive effect on the sustainability of the painting process. VOC emissions are removed by the ventilation system and absorbed by the fiberglass mat filtration system.

Technology overview

The painting process used solvent-based paints applied pneumatically (air-operated method). The process consumes 2500 kg/year of solvent-based acrylic resins, using 502 kg/year of thinner. Preparing the surface of the sheet steel in advance of painting enhances the corrosion resistance of the boiler shells. The paints are durable and allow for permanent corrosion protection of the boilers throughout their effective life cycles spraying.

Painting is preceded by a thorough cleaning of the steel surface, by sanding, and sometimes degreasing. Paint dries on a surface through the evaporation of the solvent, leaving a film comprised pigment and binder. The sources of emission to the ambient air are solvent vapors released from the paint booth exhaust vent, the dry-off area, the baking oven exhaust vent, as well as solvent and dust from the paint preparation and spray gun cleaning areas, and the surface preparation area from unenclosed sanding and sand blasting.

Expert's team establishment

There is no unanimity yet as to which criteria and indicators or which method is better to use in green evaluation. In addition, the available assessment tools to select relevant criteria require high-level expert competence. There are three experts to evaluate environmental improvement options based on eight indicators for baseline scenarios and improvement scenarios.

The three improvements options have to be compared to each other (see table 3). Therefore they must be assessed for environmental performance aspects separately.

The evaluation outcome helps in choosing a more suitable environmental improvement alternative for a specific set of considered environmental criteria. It also shows how the environmental criteria can be accommodated.

The system boundary

In assessment of painting technology, the ISO standard states that boundaries between the technological system and its nature are determinated within the integrated method: AHP + TOPSIS and the LCA-based criteria. This means that criteria used establish the system boundary as well as the context of the assessment. Criteria (inputs and outputs) as a result of technological changes. Criteria which do not change technology or should be omitted.

4.2. Decision and methodological context

In order to identify the business needs of painting technology, a methodology should be proposed for meeting the business goals:

1. identification of painting technology that causes the painting process will operate at full capacity and in accordance with environment protection rules. AHP is applied for evaluating the importance of environmental requirements for the painting process. Secondly, the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) is used for ranking the alternatives.
2. assessment of the selected technology based on LCA approach.

Risk analysis and its value is not presented in the paper. This point is a subject of further analysis.

Alternative scenarios and their evaluation of environmental improvement options

Table 3 presents evaluated alternative improvements for the painting process, that were namely paint shops:

- alternative 1: equipped with fully heated enclosed spray painting and curing booth, electronically controlled with recuperation system, fitted with filter mats to capture solid pollutant,
- alternative 2: equipped with a professional paint spraying and drying booth with its own air supply and exhaust fans, and with its own heating system,
- alternative 3: paint shop in a separate room from curing with air supply and exhaust fans.

The weighting for the eight identified criteria are evaluated by three experts as presented in table 3. For assessing the relative importance of criteria, Saaty suggested a quantified on the linguistic "one – to – nine" measurement scale in which $a_{ij} = 1$ signifies that criteria i and j are equally important, 2 – *i* weakly or slightly more important than *j*, 3 – moderately, 4 – moderately plus, 5 – strongly, 6 – strongly plus, 7 – very strongly or demonstrated, 8 – very, very strongly, 9 – extremely[68]. A value of $a_{ij} = 1/5$ indicates that criterion j is strongly more important than *i* and $a_{ij} = 1/9$ indicates that criterion *j* is extremely more important than *i*. The pair-wise comparison matrix is checked for its consistency. The consistency matrices for the experts are less than acceptable standard of 0.10, therefore are valid and consistent.

To evaluate the three environmental improvement alternatives, TOPSIS method is applied. The TOPSIS considers how far each alternative is from the ideal and negative ideal solutions, and selecting the closest, relative to the ideal solution as the best alternative[69]. The ideal positive solution is a hypothetical alternative that has the best values for all considered criteria, whereas the negative ideal solution is a hypothetical alternative that has the worst values for all criteria. Methodological approach to select the painting technology was presented in by Kluczek and Gładysz[70].

Table 4 depicts calculations for expert 1 from the decision matrix to distances to both positive and negative ideal solutions. Similarly calculations were conducted for expert 2 and expert 3 (here results are given in table 4).

[68] Saaty T.L.: Analytic Hierarchy Process. McGraw-Hill, New York 1980.
[69] Hwang C.L., Yoon K.: Multiple Attribute Decision Making: Method and Applications. Springer Verlag, New York 1981.
[70] Kluczek A.: Gładysz, B.: Analytical Hierarchy Process/Technique for Order Preference by Similarity to Ideal Solution-based approach to the generation of environmental improvement options for painting process. Results from an industrial case study. "Journal of Cleaner Production", Vol. 101, 2015, p. 360-367.

Table 4

TOPSIS calculations

D = $[x_{ij}]_{mxn}$										Exp.2	Exp.3
	C1	**C2**	**C3**	**C4**	**C5**	**C6**	**C7**	**C8**			
Al.1	5	7	7	4	7	5	3	4			
Al.2	4	7	9	4	7	6	3	4			
Al.3	3	7	6	9	9	3	4	8			
w = $[w_j]$											
	0.13	0.11	0.22	0.16	0.13	0.07	0.14	0.05			
N = $[n_{ij}]_{mxn}$											
Al.1	0.71	0.58	0.54	0.38	0.52	0.60	0.51	0.41			
Al.2	0.57	0.58	0.70	0.38	0.52	0.72	0.51	0.41			
Al.3	0.42	0.58	0.47	0.85	0.67	0.36	0.69	0.82			
V = $[v_{ij}]_{mxn}$											
Al.1	0.09	0.06	0.12	0.06	0.07	0.04	0.07	0.02			
Al.2	0.07	0.06	0.15	0.06	0.07	0.05	0.07	0.02			
Al.3	0.05	0.06	0.10	0.13	0.09	0.02	0.10	0.04			
v_j^+											
	v_{1+}	v_{2+}	v_{3+}	v_{4+}	v_{5+}	v_{6+}	v_{7+}	v_{8+}			
	0.05	0.06	0.10	0.06	0.09	0.02	0.10	0.04			
v_j^-											
	v_{1-}	v_{2-}	v_{3-}	v_{4-}	v_{5-}	v_{6-}	v_{7-}	v_{8-}			
	0.09	0.06	0.15	0.13	0.07	0.05	0.07	0.02			
$d(v_{ij}^k;v_j^+)$									**d_i^{k+}**		
Al.1	0.001	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.057	0.072	0.069
Al.2	0.000	0.000	0.003	0.000	0.000	0.001	0.001	0.000	0.070	0.084	0.085
Al.3	0.000	0.000	0.000	0.005	0.000	0.000	0.000	0.000	0.074	0.074	0.074
$d(v_{ij}^k;v_{j-})$									**d_i^{k-}**		
Al.1	0.000	0.000	0.001	0.005	0.000	0.000	0.000	0.000	0.081	0.077	0.084
Al.2	0.000	0.000	0.000	0.005	0.000	0.000	0.000	0.000	0.076	0.076	0.076
Al.3	0.001	0.000	0.003	0.000	0.000	0.001	0.001	0.000	0.076	0.089	0.091

The relative closeness (RC_i) and total distances of each alternative from ideal ($di-^+$) and negative ($di-^-$) solution are 0.551, 0.488, 0.538 respectively, ranking the alternatives from most preferable to the least is Al.1, Al.3, Al.2. The most appropriate improvement option to be implemented for company is paint shop equipped with its own air supply, exhaust fans and heating system (Alternative 1).

The selection of technology to be implemented in the improvement scenario is also significant in reducing the environmental load, e.g., using materials with a high recoverability rate, which are safe, reliable and environmentally friendly.

4.3. Methodological context

Setting LCA-based approach indicators for sustainability assessment of the technology

Possible indicators selected and overall impact of manufacturing processes on a whole company should be considered and described as shown in table 5. A single impact LCA-based indicator in each impact category in terms of environmental and socioeconomic is applied:

The four environmental indicators are analyzed:

- Global warming potential (in terms of CO_2) (GWP),
- Photochemical Ozone Creation Potential (POCP),
- Air acidification potential (AP),
- Energy resources consumption (ER).

The three socioeconomic indicators encompass:

- Dynamic generation cost (DGC),
- Cost of protection of human health (CfHH),
- Work environment footprint (WEF).

Table 5

Evaluation criteria

		Characteristics of alternatives *			**Weights**		
Criterion	**Description**	**Alterna-tive 1 (Al.1)**	**Alterna-tive 2 (Al.2)**	**Alterna-tive 3 (Al.3)**	**Ex-pert 1**	**Ex-pert 2**	**Ex-pert 3**
C1. Investment cost	Amount to be expended to implement the alternative (infrastructure, equipment etc.)	$180 402	$166 000	$74 500	0.17	0.15	0.04
C2. Raw material	Amount and sort of materials used in the production process	2,500 kg/yr (solid paint) and 502 kg/yr (solvent)			0.17	0.03	0.11
C3. Energy consumption	Amount of commercial energy that is required directly and indirectly by the process of making a good or service	177 420 MJ/yr (electricity)		160 270 MJ/yr (electri-city)	0.18	0.14	0.35
		1 021 200 MJ/yr (LPG)	1 327 560 MJ/yr (LPG)				
C4. Waste generation	Amount of all waste, that enters a waste stream before composting, incinerating, landfilling, both hazardous and non-hazardous, generated by the process of making a good or service	Waste of paint: 350 kg/yr			0.21	0.11	0.13
		Emitted and absorbed: 1465 kg/yr		Emitted and not absorbed : 1465 kg/yr			
C5. Health and safety	Regulations, procedures, means put in place to prevent accident or injury in workplaces	General mechanical ventilation system required			0.09	0.23	0.08
		Grounding, protection against electric shocks and overvoltage protection, explosive detector					
		VOC emissions captured by carbon mat filters					
C6. Operational cost	Related to the amount to be expended during alternative operation, in materials, electricity, maintenance, labour, and to financial costs	$141 240	$153 240	$97 240	0.05	0.09	0.07

cont. table 3

C7. Reliability	Characterization of technology, machines, by the probability it will perform the desired function for a given time	Robust construction		0.07	0.21	0.16
		Long life over 20 years	Long life over 15 years			
		Permanently-lubricated and sealed bearings				
C8. Operating time	Period during which a system is working	Depending on filters used		0.05	0.04	0.07
		Filters changed every 5 years	Paper filters changed every 3 years			

* estimated for 150 000 kg of steel and 800 h of operation time

Table 6

LCA-based indicators used in the technology assessment

Environmental impact indicators	**Description**
GWP	The contributors to global warming were found to be CO_2, where GWP is calculated using Simple Carbon Calculator*. Carbon dioxide (CO_2), methane (CH4), and nitrous oxide (N_2O) emissions are all produced during LPG combustion. Nearly all of the fuel carbon (99.5 percent) in LPG is converted to CO_2 during the combustion process. The majority of the 0.5 percent of fuel carbon not converted to CO_2 is due to incomplete combustion in the fuel stream. Although the formation of CO acts to reduce CO_2 emissions, the amount of CO produced is insignificant compared to the amount of CO_2 produced.
POCP	The creation of ozone happens when volatile organic compounds (VOCs) react to sunlight (photo-oxidation). The speed at which low level ozone creation happens is affected by the presence of nitrogen oxides (NOx). This leads to aggravating asthma and other respiratory conditions. Photochemical Ozone Creation Potential (also known as summer smog) for emission of substances to air is calculated with the United Nations Economic Commission for Europe (UNECE) trajectory model (including fate), and expressed using the reference unit, kg ethane (C2H4) equivalents/kg emission[71].
ER	Total energy consumption [MJh/year]; Energy from different sources is considered: electricity, LPG. Liquefied petroleum gas (LPG) for transport is not included. Energy takes into account the energy demand per functional unit for the processes undergoing comparison.
AP	Acidification is caused by releases of protons in the terrestrial. In this study, the contributors to acidification were NO_2, NO_x, where acidification potential was calculated in SO_2 equivalents based on the appropriate conversion factors between different substances. SO_2 equivalence factors is 0.70kgeq SO_2. Transportation of air emissions has not been included.

[71] Mundy J.: The Green Guide Explained. BRE Centre for Sustainable Products, 2015, http://www.bre.co.uk/filelibrary/greenguide/PDF/The-Green-Guide-Explained_March2015.pdf, 23.09.2017.

cont. table 6

DGC	DGC shows what is the technical cost of obtaining an environmental effect unit (product), expressed in United States Dollars (USD) per unit of environmental effects. It is a ratio between discounted costs and discounted benefits. It is a dynamic index used widely in German banks and applied in Poland[72]. Additionally, the DGC indicator employs the Net Present Value (NPV) and Life Cycle Costing (LCC) expressed as all costs associated with the life cycle of painting technology to be used by the company to manufacture heating boilers[73]. Based on the data available in table 6, DGC may be calculated using (1): $$DGC=\frac{\sum_{t=0}^{t=n}\frac{KI_t+KE_t}{(1+i)^t}}{\sum_{t=0}^{t=n}\frac{EE_t}{(1+i)^t}}. \quad (1)$$ Where: KI_t - investment expenditures in year t, KE_t - operational costs in year t, EE_t - an economical effect in year t [assuming 4000 boilers through 20 year], i - a discount rate based on inflation rate, deposit interest rates and risk (18%), n - a lifetime of an investment (20 year). The value of DGC reflects technical costs of achieving one unit of effect in terms of the painting. Future costs and benefits (recurrent or one-time) are discounted to present values using (2) **: $$NPV = \sum_{t=0}^{n} NFV\,(1+r)^{-t} \quad (2)$$ where NPV is the present value of net economic cost, NFV is the net future costs, r is the real interest rate, and n is the total number of periods. Calculation of the NPV involves summing all the net cash flows associated with the proposed technologies throughout the economic life cycle, discounted before aggregation, in order to unify their monetary value[74]
CfHH	Cost of protection of human health is expressed as the cost of avoiding air emissions (CO, NO_x, VOC, CO_2, dust) and waste disposed in the context of handling emissions within a particular quantity center using (3) CfHH = annual cost of protection [USD/yearly] / production volume (3)
WEF	Absence from work due to accidents or work conditions; calculated as absence from work per worker in a given year divided by number of employees in an industrial plant where the considered technology will be installed (90 persons).

* http://www.carbon-calculator.org.uk,

** Elements of DGC calculation included in sustainability assessment of the painting technology assuming a production volume of 1 000 tons and manufacturing time of 800 h.

4.4. Assessment

The environmental end socioeconomic impacts and benefits of the painting technology are presented in this section. Based on the LCA-based indicators for painting technology assessment placed in table 5 and LCI data used, economic and socioeconomic impact

[72] Rączka J.: The cost-effectiveness analysis – a superior alternative to the cost-benefit analysis of environmental infrastructure investments. Proceedings of the Fifth European Conference on Evaluation of the Structural Funds "Challenges for Evaluation in an Enlarged Europe", Budapest 2003.

[73] Pons O., de al Fluente A., Aguado A.: The Use of MIVES as a Sustainability Assessment MCDM Method for Architecture and Civil Engineering Applications. "Sustainability", No. 8, 2016, p. 460.

[74] Rogowski W.: Account of Investment Efficiency. Kluwer, Cracow 2008 (in polish).

assessment are quantified and normalized. The results are the effect scores as presented in table 7.

Table 7

Life Cycle Inventory data

Existing technology	**Amount**	**Material cost [$]****	**Improved technology**	**Amount`**	**Material cost [$]****
Input			***Input***		
Electricity [kWh/year]	1 080	205.20	Electricity [kWh/year]	47 520	9 028
Electricity [MJ/year]	3 888	0	Electricity [MJ/year]	171 072	
Fuel [MJ/year]	0	0	Fuel [MJ/year]	1 021 200	29 391.14
Total material		93 962.60	*Total material*		93 962.60
Paints [kg/year]	2 500		Paints [kg/year]	2 500	
Solvent [kg/year]	502		Solvent [kg/year]	502	
Output			***Output***		
Total Emission		2 779.54	*Total Emission*		2 776.86
CO [kg/year]	7.2		CO [kg/year]	7.2	
NO2 [kg/year]	0		NO2 [kg/year]	0	
Dust [kg/year]	0		Dust [kg/year]	0	
VOC [kg/year]	1 465		VOC [kg/year]	1 465	
NOx [kg/year]	54		NOx	54	
Total waste		29	*Total waste*		29
Waste paint and varnish [kg/year]	350		Waste paint and varnish [kg/year]	350	
Degreasing wastes [kg/year]	0		Degreasing wastes [kg/year]	0	
Total production cost [KE_t]		106 029.52	Total production cost [KE_t]		141 240.60

** including labor cost: baseline scenario [$6053], improvement scenario [$6053].

Table 8

Environmental and socioeconomical impact assessment and energy use

	LCA				**LCC + social LCA**		
	Environmental impact category				*Socio-economic impact category*		
	Global warming potential [kgCO2 eq/kWh]*	Photochemical oxidation [$kgC_2H_4eq.$]	Air acidification [$kgeq.SO_2$]	Energy use [MJ/year]	Dynamic generation cost (DGC) [USD/year]	Cost of protection of human health (CfHH) [$/tons]	Work environment footprint (WEF)
	Baseline scenario						
B	836	303.8	37.8	3 880	556.66	2.77954	0.06
	Target-oriented scenario						
I	96 981*	303.8	37.8	1 192 272	785.87	2.77686	0

* sum of $kgCO_2eq.$ emissions for electricity [19 581] and LPG [60 201 $kgCO_2eq.$ assuming 99.5% conversion of fuel carbon to CO_2].

4.5. Results

Normalizing the results allows the impacts for each environmental category to be compared directly for baseline scenario with each the same for improvement one as shown in the graph below (Fig. 2). These results indicate that the overall levels of normalized impact are virtually the same or similar (POC and AP) in almost all cases, unlike increased emissions of CO_2 in GWP.

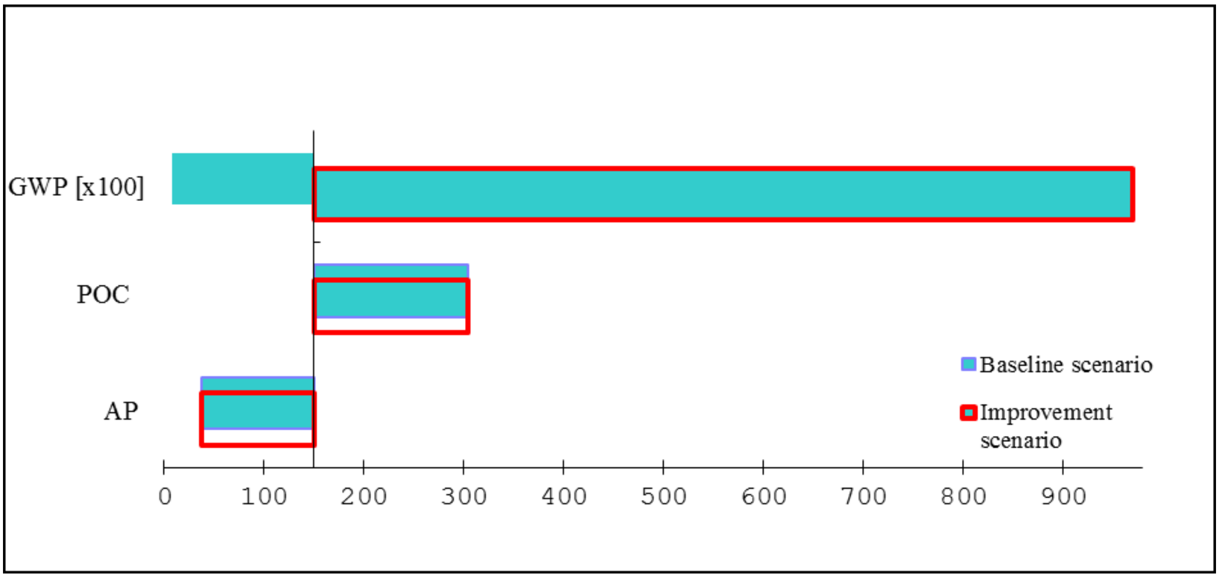

Fig. 2. Graphical representation of results for the environmental impact assessment of technologies

Changing from conventional to environmental-friendly painting technology, however, will increase energy consumption, thus increasing GWP over 115 times than of the conventional one.

The impact on CO_2 equivalent relates to improvement scenario, where 60 201 kgCO_2 per 1 liter of LPG and 36 780 kgCO_2 per 1 kg of electricity are released in the atmosphere. The greatest impact is due to the additional need for 40 000 liters per year of LPG for the curing process.

The installation of paint spraying and drying booth will absorb the amount of paint and solvent released into the air. Since NOx and CO concentrations are not reduced by the installation of paint booth, but the values for these parameters are the same for baseline and target-oriented scenarios.

Improved production, therefore can achieve a lower VOC emission only by capturing up to 1465 kg/year of these VOC rich emissions by installation of ventilation systems. This ensures that amounts emitted are low (less than 5 tons per year) as specified in Annex No. 8 in the Regulation of the Minister of Environment of April 22, 2011 (JL, 2011).

The same impact value in terms of photochemical oxidation (303.8 kg C_2H_4eq) and air acidification potential (37.8 SO_2 per kg of production) have the painting technology in both scenarios.

From economical point of view more energy about 99,6 % (1 192 272 MJ/yr) leads to more cost (see table 6), which is required to operate the painting. From table 7, it can be computed that cost of protection of human health from using the environmental-friendly is a little bit lower than for the conventional technology. The reduction in work environment footprint is due to expected decrease in numbers of injuries in the workplace.

The results demonstrate that the conventional painting is the most cost-efficient measured in terms of DCG than that of baseline scenario. Application of LCA- based assessment of technology, however, requires in-depth research to understand manufacturing processes in which technology will be operated, and to predict, or measure, variation in emissions.

Conclusions regarding potential environmental and socioeconomic impact of conventional and improvement technology are based on comparison of target-oriented technology, which do not necessarily represent reality if applied in production systems.

As a result, by looking at the evaluation of the painting technology (both scenarios), it is shown that the considered technology is going to reach the sustainability. Moreover, the presented framework methodology could be tailored to specific needs dependent on the technology used. Incorporation of specific assessment criteria and indicators in technology being analyzed might have significant influence in achieving sustainability performance.

Benefits for the selected technology

The expected benefits resulting from the assessment of the are as follows:

- The quantity of VOC content is reduced to 1465 kg/yr, where the expected amount of paint and solvent to be used is 302 kg/yr, (below the regulated 5000/yr).
- During the curing process, VOC emissions are removed by the ventilation system and absorbed by the fiberglass mat filtration system.
- Floor treatments, fluid management systems and material handling methods keep paints and solvents from leaking into the soil and groundwater.

Based on the performed asessment and determined benefits the painting technology could be reccomment to be applied at the business level. The comparative analysis between the original state and environmental-friendly technology demonstrates the overall environmental advantage of using the new technological solution. It is therefore important to consider the technology that is capable of capturing emissions, but negatively increase in energy use.

5. Conclusions and discussion

The article presents and discusses the methodological concept of technology assessment which could be applied in public and private sectors. Because technology assessment is time- and resource-consuming process, and therefore required a proper assessment methodology. Hence, the conceptual framework provided a methodology and a set of structured actions, which enables the expert teams to “walk through” all key steps as minimum requirements to assess technology comprehensively and take into mind all the factors related to the assessment of the proposed technologies. Implementing the technology assessment methodology the organization will be able to identify improvement opportunities and comparison it with target-oriented scenario.

Despite differences related to methodological propositions and relevant criteria the conceptual framework provides the challenges in setting the priorities of the technologies to be assessed and recommendations for various technologies at various levels. Assessment procedure/priority setting, as a best way to organize effective and explicit activities/aspects allocation, may be applied in various fields.

One major shortfall of current developments in the area of sustainability technology assessment is the relative lack of a real implementation of developed science-based methods. As demonstrated in this review, much progress has been made in the implementation of sustainability assessment methodologies in industrial sectors. However, a wide gap still exists between assessment theories and assessment practices. Encouraging activities and programs related to the stimulation of public awareness of, and interest in, assessment issues and the education and development of professional groups with broadened perspectives to staff future technology – assessment activities in government. This makes the need for a flexible approach mandatory. A suggestion is thus made for major assessment methods developed to be tailor-made to fit each study as well as used in assessing sustainability technologies in public sector across the various issues, spatial and time scales so as to allow for method comparison.

Technology assessment for sustainability requires a clear concept of sustainability with the more ambitious aim of seeking to determine whether or not technology is actually sustainable. Thus, the conceptual framework could be treated as an instrument for change in technology developing sustainable technology assessment procedures integrating methods and tools for broadening and better targeting stakeholder`s involvement through the procedure. An application of the exiting methodology for sustainability will accelerate technology providing information that could help the decision makers involved in developing new methods and that might define subjects for further technology evaluation analysis. In every application, the indicators database could be extended and focus on the social dimension for the private sectors. The social dimension pursues social inclusion by enhancing human, cultural and social capital. "The need for a more democratic participation of patients and representatives of society in technology selection and priority-setting criteria definition has been broadly discussed and encouraged in the international scenario" (Novaes and Soares, 2016). The public or institutional dimension could refer to those more formal and organizational aspects (e.g. knowledge about the system, legislation) concerning to human-human and human-nature interactions conveying to the functioning of the socio-ecological system.

Application of the different methodologies within the framework could lead to the development of definition of several criteria, and enhancing more traditional assessment methods. Nevertheless, although a standardization of criteria and methods has been developed for the application of technology assessments, the same is not completely true for various sector or industries.

The framework strives to support decisions concerning new and existing technologies, and for conducting prospective assessments. This provides a structure for selecting assessment methods and integrating results of the use of selected methods into a coherent overall assessment which assist with decision-making process by keeping stakeholders well informed of the sustainability of the assessed technology.

Even with theoretical and practical insights provided by this study, there are still many limitations. One major limitation is a risk assessment method to be applied. Usually, in method such as FMEA, risk value is compared with threshold value and therefore so that relying only on some fixed values and may not turn out to be worthwhile. For this reason, any threshold should be considered together with the level of confidence that has been assumed in its definition. Second, in fuzzy – based methods thresholds can hide considerable levels of uncertainty that, in turn is difficult to quantify. That is why two approaches are demonstrated to compare values within scenarios. Third, some criteria used within method in combination can reinforce each other or work against each other.

The presented conceptual framework might define subjects for further technology assessment analysis.

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