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Environmental Technological Innovations and the Sustainability of their Development

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ABSTRACT

In this paper, we explore the crucial role of technological innovation in achieving sustainable development. Technology has the potential to promote sustainability by incorporating green practices into production methods. However, it's important to design technology that balances economic, environmental, and social considerations, benefiting all stakeholders while minimizing negative impacts on the planet and society. We provide a systematic overview of the challenges of development over time and according to the scope of societal interest. We identify the direction of progress towards a more holistic and sustainable approach to innovation, aligned with the requirements of Smart Industry 4.0 and 5.0. The paper also delves into the significance of advanced tools like Cleaner Production (CP), Environmental Accounting (EA), Pollution Prevention (PP), Recycling (R), Life Cycle Analysis (LCA), Eco-labelling (EL), and the Environmental Technologies Action Plan (ETAP) in promoting sustainable development in the transition towards Smart Industry. Moreover, we address the timing of innovation strategies through a backward decision-making system and the selection of innovation tools to meet the goals of Industry 4.0 and the Smart and Sustainable Industry Generation 5. We recognize that the economic viability of each technology is essential for sustainability and must be considered over a period of 20+ years.

Keywords: sustainable development, product and technology, innovation strategies, tools and methods, environmental engineering, green growth

INTRODUCTION

The functioning of the economy in a globalised environment is increasingly influenced by technological progress, the intensification of technological innovation, efficiency and productivity gains, with a significant link between the economy and the environmental and social aspects of business. Technical and product innovation is a key element and instrument for achieving the objectives of sustainable socio-economic development and the continuous improvement and sophistication of the quality of production in all sectors of economic activity.

However, technologies for sustainable development and environmental technologies do not fulfil the same functions. While environmental technologies, in terms of production, remediation and maintenance, primarily address the issue of minimising, eliminating and compensating for environmental pollution, sustainable technologies also pursue the broader objectives of not exceeding the ecological recovery capacity and consolidating growing inequalities in the achievement of economic, social and environmental development goals. Sustainable development technologies utilised today are also characterised as best available technologies (BAT) in terms of technical performance, economic availability and environmental excellence for the industries concerned (Feola 2015; Majerník et al. 2017).

To achieve the ambitious goals of global development strategies for sustainable development and the environmentalisation of technologies, a wide range of precautionary tools and methodologies are used. These tools are being coordinated globally, refined through research and standardised as ISO standards. From a technological point of view, the main methodological approaches today are the implementation of the 4th Generation Smart Industry Strategy and its intensification in the framework of the development of the Industry 5.0 concept in the greening of the economy.

CHARACTERISTICS OF SUSTAINABLE TECHNOLOGIES

Sustainable technologies have a broader scope than just minimising pollution and preventing environmental degradation through continuous improvement of production. Sustainable technologies are a means of meeting the needs of the population in a way that does not exceed the available capacity of the planet and, within that, the capacity of local ecosystems. Their aim is to bring global production into line with the principles of nature and not to exceed the carrying capacity of the Earth, in the context of meeting the global needs of humanity and with standardised economic and social indicators of sustainable socio-economic development. There are several key elements that sustainable technologies should include:

- Environmental responsibility: Sustainable technologies should minimize their impact on the environment and contribute to reducing greenhouse gas emissions and pollution.
- Resource efficiency: Sustainable technologies should use resources, such as energy and raw materials, efficiently, reducing waste and minimizing the depletion of natural resources.
- Longevity: Sustainable technologies should be designed to last for a long time, reducing the need for frequent replacements and reducing waste.
- Cost-effectiveness: Sustainable technologies should be economically viable, both in terms of initial investment and ongoing maintenance costs.
- Social impact: Sustainable technologies should contribute to social equity and inclusion, providing benefits to all members of society and avoiding negative impacts on marginalized communities.
- Innovation: Sustainable technologies should incorporate new and innovative approaches to solving environmental problems, encouraging ongoing research and development.
- Scalability: Sustainable technologies should be designed to be scalable, so that they can be widely adopted and have a significant impact on reducing environmental harm.

Sustainable technologies should be designed to balance economic, environmental, and social considerations, providing benefits to all stakeholders while minimizing negative impacts on the environment and society (Vacchi et al. 2021; Weaver et al. 2017). Table 1 lists the key aspects and challenges in addressing sustainable technology development and innovation. The concept of globalisation of innovation links two fundamental phenomena of modern economies: the increasing international integration of economic activities and the growing importance of knowledge in economic processes (Chaminade et al. 2018).

Today and in the future, the ability to innovate technologically is seen as the ultimate condition for maintaining competitiveness and managing the sustainable development of companies and the economy as a whole (Majerník & Drábik 2020). In a dynamically changing business environment, driven by increasingly demanding customer requirements, the growth of products and services and the consequent increase in market competition, technological development and the globalisation of business, innovation is an effective means of coping with change.

Figure 1 summarises the innovation challenges and key tools for sustainable technological development. In seeking and securing future gains, a globalised society today can focus on the broad perspectives over time embodied in globally coordinated development strategies. In relation to sustainability of development, the overarching challenge is the general improvement of the environmental behaviour of production facilities and the greening of their technologies.

The key instruments for improving environmental performance and greening technologies are: Clean production and environmental accounting;

- Integrated pollution prevention and control and recycling;

Table 1. Characteristics of sustainable technologies

KEY ASPECTS AND CHALLENGES OF TECHNOLOGY SUSTAINABILITY		
Meeting the development needs of a globalised society	**Global development thinking and responsible action**	**Finding timely deadlines to address potential problems**
• Analysing technology needs and ensuring their sustainability; • Uncovering specific and hidden needs for their legality; • Identifying new more sustainable ways of fulfilment; • Preferring and timing alternatives in terms of environmental, social and ethical aspects.	• More efficient and sustainable solutions are essential before further development, • Environmentally more efficient technologies: mitigate negative effects in different areas, have a longer-term effect and are so far used on a small scale.	• Environmental and safety aspects of operating obsolete technology; • Lack of innovation potential vs. competitiveness in markets; • Energy efficiency and material availability, integrated waste management.
SYSTEMIC INNOVATION IN TECHNOLOGY - DEVELOPMENT SUSTAINABILITY		
Changes in the primary energy base	**Replacement of the raw material base**	**Elimination of emissions production**
• Greater use of renewable energy sources; • Creating energy mixes; • Use of international standards for energy efficiency management (ISO); • Elimination of fossil fuels in energy generation; • Application of hydrogen technologies and electro mobility.	• Using waste as a source of valuable raw materials - circular economy; • Use of biodegradable packaging and materials; • Use of recyclable materials in construction; • Prioritising renewable sources of raw materials; • Use of biotechnology and nanotechnology.	• Wider use of environmentally sound products and technologies (ESP and ETAP - according to ISO standards); • Use of best available techniques and technologies (BAT/BATT according to BREFF); • Preventive assessment of environmental impacts of activities (EIA/SEA/HIA); • LCA/LCI Life Cycle Assessment; • Application of circular economy principles.

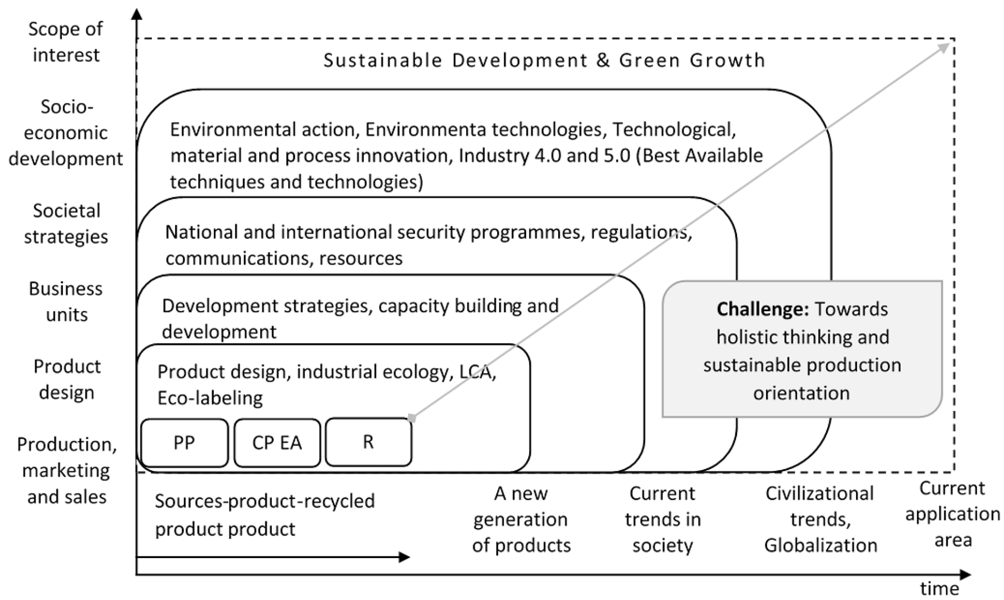

Fig. 1. Development challenges for technology innovation and sustainability of production: PP – pollution prevention, CP – cleaner production, EA – environmental accounting, R – recycling

- Any methods for comprehensive environmental optimization of products and greening of industry;
- Methods and tools that have been incorporated into business strategies;
- National security and its long-term perspective;
- Techno-economic development strategies Industry 4.0 and 5.0.

METHOD OF REVERSE SELECTION OF SUSTAINABLE TECHNOLOGICAL INNOVATIONS

Optimisation of current technologies is very important in relation to their sustainability, but the potential for improvement is often limited.

The backward selection of innovations (Figure 2) is a methodological approach and

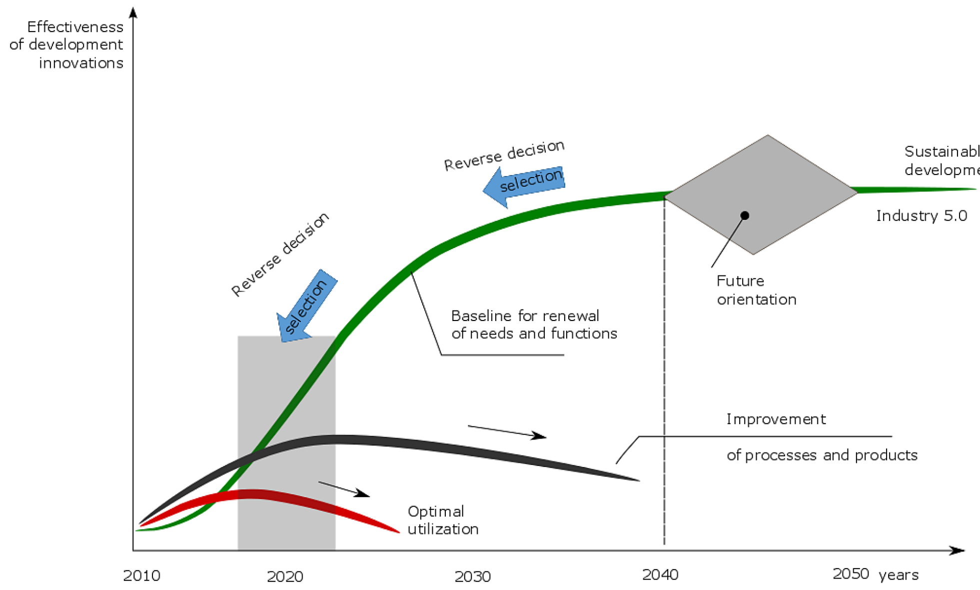

Fig. 2. Reverse decision-making on development innovations – technology selection

identification of sustainable technological innovations and is based on an analysis of current socio-economic needs at the time. Its purpose is to generate long-term optimization and innovation terms and to obtain stakeholder consensus regarding renewal and its optionality.

The decision-making and retrospective selection of innovations (Table 2) consists in:

- Analyzing and identifying socio-economic needs;
- Identifying the optimal time for technology improvement;
- Creating general visions for stakeholders for the future;
- Developing concepts of progression pathways that lead to the fulfilment of the visions;

Table 2 Technological innovation – reverse selection method

KEY ASPECTS OF THE REVERSE SELECTION OF TECHNOLOGICAL INNOVATION			
Needs analysis and identification with their choice	**Voluntary identification with the improvement and development of technology**	**Creating general visions for the future**	**Validating development paths towards the company's vision for the future**
Basic human needs: • food • housing • clean air • safety • clothes • water • human communication • health • self-respect • transportation, etc., which do not disappear in time To satisfy needs, the following are generally necessary at the very least: • energy • materials and technology • space • education and training, etc.	The general principles of leapfrog technology change include: • selection of a leading-edge system (BATT) for both product and process • minimizing and preventing pollution (CP) • closed loop life cycle assessment (LCA), refurbishment, • recycling (R) • organising production and consumption and improving performance through the use of renewable energy sources • use of low-cost materials with the possibility to change their design • minimising damage to the ecosystem (PP) • introducing flexible technological innovations adaptable to development pathways (Industry 4.0 and 5.0)	Accelerating technological progress: • Research on biotechnology, e.g. in food production, waste disposal, pharmaceutical production, soil revitalisation, GMOs in agriculture, food, medicine, etc. • development of nanotechnologies, creation of new substances with desired properties (e.g. extreme strength, electrical conductivity, etc.) for use in physics, chemistry, biology, production of materials and preparation of drugs Innovative technologies contribute to: • improving quality of life • rapid growth of new substances with unknown health and environmental effects, pollution of water and soil by pharmaceutical residues, etc.	Socio-technical map as a tool includes: • state in development and its technologies • dynamics of development and its technologies • different complications of stakeholders during these technologies • the stakeholders' perspectives and interests regarding these technologies Scenario analysis: • a general tool for decision-making – industrial strategies for sustainable socio-economic development

- Developing a consensus for an effective path forward to the visions of the future.

GREEN TECHNOLOGICAL GROWTH FOR SUSTAINABLE DEVELOPMENT

Green socio-economic growth (GE) is part of the UR. Green growth focuses on greening production and consumption (Gotschol et al. 2014; Luukkanen et al. 2019) through the invention of green technologies and the use of clean energy. Technological innovation thus addresses both production-based and demand-based emissions and is therefore considered a major driver of industrial development (Yao et al. 2018). The design, development and implementation of clean technologies enhance sustainability (Bhupendra & Sangle 2015).

Green growth and its scope is more narrowly focused, through an operational policy plan, on achieving concrete, measurable progress at the interface between the economy and the environment. Key to this is fostering the necessary conditions for innovation, investment and competitiveness to generate new sources of economic growth in line with resilient ecosystems. The strategies and action plans of the RoW must also address a number of specific social and equity concerns. These may arise as a direct consequence of the application of ecological principles in the economy, both at national and international level. Strategies should therefore be implemented in parallel with initiatives oriented towards the indicators of the social pillar of the UR.

World actors face traditional development issues (e.g. economic stagnation, crisis, persistent poverty, hunger and disease) as well as new challenges (e.g. globalisation, climate change, energy crisis). A key approach that has emerged in this field is the concept of sustainable development, i.e.”development that lasts” (Huttmanová & Valentiny 2019; Munasinghe 2009).

Sustainability can be interpreted and approached in different ways. The concept can either be left open to be addressed within the process or more closed and predefined. One early example is ‘transition management’, which largely leaves open the space for participants to develop an understanding of sustainability in any particular setting. “Planetary boundaries” is one example of the second option, which frames sustainability in the form of “boundary conditions” that function as biophysical limits that must not be crossed (Rockström et al. 2009). Sustainable development is the process of improving options that will enable individual people and communities to achieve their aspirations and full potential over long periods of time, while maintaining economic, social and environmental systems.

This approach has given rise to a more focused and practical approach to sustainable development as the continued improvement of the present quality of life at a lower level of resource intensity, thereby leaving for future generations a non-negligible increase in productive assets (i.e. productive, natural and social capital) that will be used to improve the quality of life.

The basic framework of sustainability rests on the following principles and methods:

- Making development more sustainable step by step (MDMS),
- The Sustainable Development Triangle and the balanced treatment of the three pillars (Economic-Social-Environmental),
- Crossing conventional boundaries for better integration,
- Full application of practical analytical tools and methods from data collection to policy, implementation and operational feedback-institutional pillar.

Current thinking on the concept has evolved to encompass three main aspects: economic, social and environmental, constituting the so-called Sustainable Development Triangle (Figure 3). These three dimensions of sustainable development are based on Brundtland’s definition and are widely used and internationally accepted. Each of the dimensions corresponds to a domain (and system) that has its own distinct drivers and goals. The economic domain focuses mainly on improving human well-being, primarily through increased consumption of goods and services. The environmental domain focuses on protecting the integrity and resilience of ecological systems. The social domain emphasizes the enrichment of human relationships and the achievement of individual and group aspirations.

Sustainability is a practical, transdisciplinary framework that seeks to create an overarching “holistic” model for analysis and policy guidance, while the components (principles, methods and tools from many other disciplines) are strictly “reductionist” building blocks and foundations (Majernik et al. 2019).

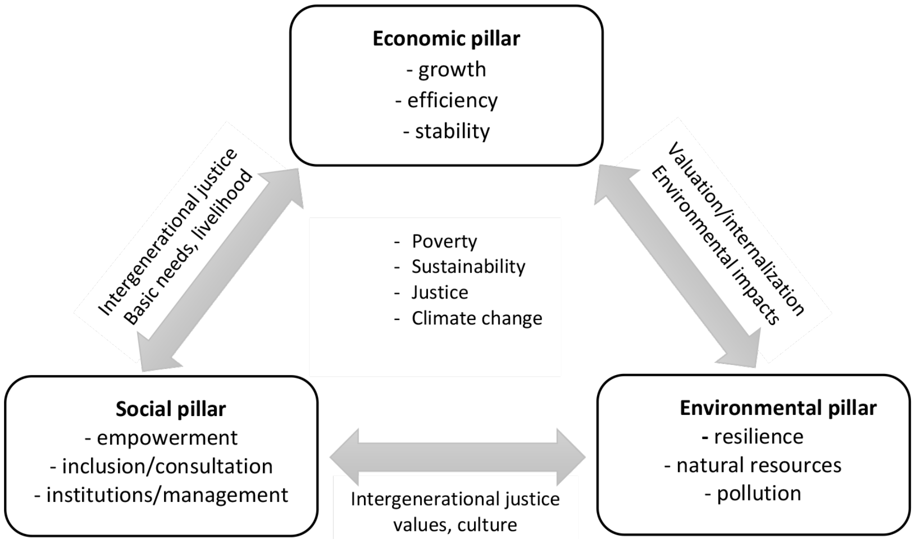

Figure 3. The Sustainable Development Triangle – key elements and linkages

The UN 2030 Agenda for Sustainable Development states that "bold and transformative actions are urgently needed ... to put the world on a sustainable and resilient path" (UN 2015).

Discussions of transformational change to achieve sustainability are at the heart of research on transformation towards sustainability (Markard et al. 2012). In this case, such change is understood as 'system innovations' or 'transitions' that involve fundamental processes of change at the level of systems in society, where unsustainable systems are progressively removed and more sustainable configurations emerge. Transitions are seen as long-term, open-ended, co-evolutionary, multifactorial processes that are inherently complex, uncertain and ambiguous (Chovancová et al. 2022; Markard et al. 2012).

In the context of managing transitions, visions of a sustainable future play an important role and the ability to create transformational momentum in the desired direction is an essential element of leading transitions towards sustainability.

The application of the principles and objectives of sustainable development in the field of technology innovation is nowadays implemented in corporate practice mainly in the form of implementation of formalised environmental management systems according to ISO 1400x or according to the European EMAS III scheme with subsequent registration of the developed system in the European register. They are among the best known and most effective tools for all types of organisations, enabling them to integrate environmental objectives into their activities. Business practice, especially in SMEs, still considers the implementation of these systems to be a rather complex process, demanding in terms of personnel and administration, and costly also in terms of consultancy services.

A wider range of active, less formalised and less demanding voluntary tools applicable in different areas and sectors have been developed to improve the environmental technological behaviour of the business sector. These are also useful as preparation for the transition to standardised tools. Table 3 characterises selected tools applicable to environmental and sustainable technological innovation.

CONCLUSIONS

Strategic decisions at both global and regional levels in the sphere of socio-economic policy and its development must always take into account a longer time horizon. Models of economic growth, the concept of sustainability and technological, material, environmental and energy innovations are closely related and build on each other. This creates a dependency in their development and a mutual technological, environmental and institutional interdependence.

The environmental impacts of consumption and production, technologies and activities are also cumulative and sometimes irreversible. This creates a strong link between today's strategic choices and society's future economic opportunities and quality of life.

Table 3. Progressive methods and tools for environmental technology innovation

Cleaner production – CP	It represents the practical implementation of the UR strategy, which is the principle of prevention. The key aspects of CP are: reducing the amount of pollution, limiting pollution at source, preventing pollution, introducing cleaner technologies and production processes. The EU's Environmental Technologies Action Plan (ETAP) targets the development of the economy by introducing state-of-the-art technologies and eco-innovations that are more environmentally friendly. This objective is to be achieved through 28 actions divided into 4 groups: the research-to-market pathway, improving market conditions, acting globally and moving forward continuously.
Life-cycle assessment – LCA	It is an information tool for environmental product policy. ISO 14040 defines it as the collection and evaluation of inputs, outputs and potential impacts in relation to the life cycle phases of a product or service. It helps professionals in ecodesign, in corporate marketing, in new product selection, in ecolabelling in setting regulations and criteria, and also in government administration and in further scientific and technological development.
Eco-labelling	The aim is to create a market for environmentally friendly products and thus influence both producers and consumers to reduce the negative impact of the product on the environment. According to the ISO 14020 series of standards, there are 3 types of eco-labelling: Type I is a voluntary labelling practiced by both public and private organisations. It can have a national, regional or international dimension (e.g. EU-European Flower Label). Type II is a self-declaration of the product in the form of inscriptions, symbols or graphic expressions on the product label, packaging. Type III in the form of written information with quantified data appearing on semi-finished products, raw materials and finished products, but not intended for the consumer. Technology is also part of the assessment. In terms of Best Available Technique (BAT). an ERA can only arise within an ETAP.
Assessing the environmental performance of the product system	It is a quantitative management tool that allows the stakeholder to study environ. ZC impacts of the product system simultaneously with the value of the product system. International Standard ISO 14045 defines the principles, requirements and guidelines for the assessment, which include: defining the objective or scope, environmental assessment of the value of the product system, quantification of the environmental performance including quality assurance, reporting and critical review of the assessment.
Environmental cost accounting	It deals with the identification, collection, estimation, analysis, reporting and communication of information on material and energy flows, environmental costs and benefits, and other information in terms of value, which are the basis for decision-making within a given organisation, technology, industry. It monitors and evaluates value-based information from financial and management accounting in monetary units and data on material and energy flows in correlation with the objectives of increasing the efficiency of materials and energy use, mitigating the impacts of business activities, products and services on the environment, reducing environmental risks and improving business performance.

The science of sustainability issues and challenges must propose ways to draw on conventional science, taking into account the complexity of these challenges and, crucially, maintaining a focus on innovation, action and implementation.

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