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Green production-clean technology and eco-efficiency keys for sustainability

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ABSTRACT

Preserving their place on the agenda of international platforms in recent years, green (clean/eco efficiency) technologies are one of the basic components of the important concept of achieving sustainable development. Eco efficiency associates economic production with environmental factors in an internal union of economic development and protecting the ecosystem, in addition to revealing the importance of sustainable development and green economy in all stages of economic production. Green production controls the effects of process, product and services on human health and the ecosystem, while also being an approach to increase the sustainable efficiency of production. Changes to production and product development stages affect the whole value chain of products and steps taken within the scope of green technologies in this situation should be evaluated with the holistic approach of Life Cycle Analysis (LCA). LCA within this scope assesses the total environmental effect to prevent transfer of environmental load from one stage to another.

In this study, to leave a livable world for future generations, all aspects of the absolute relationships between green technologies and eco efficiency are dealt with and analysis of the current status in Turkey is performed.

Keywords: Green production, eco efficiency, clean technologies, life cycle analysis

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1. Introduction

In spite of significant difficulties in economic markets, interest in clean technologies including green energy (wind, solar, water, biomass, biofuel, hydrogen, geothermal, fuel cells), green transport, green chemistry, green production, information technology, eco-productivity and energy-saving devices has begun to increase further with every passing day [1]. The beginnings of demand for products causing less damage to the ecosystem has created a new area of competition for many industrial sectors. In current work processes, in addition to economic growth, the 'green work' concept including terms like clean technology, low carbon footprint, renewable resources, and recycling have gained importance [2]. Green production, clean technologies and eco-productivity are an ecosystem-sensitive waste management approach aiming to use less raw material and energy, increase reuse and recycling, create less waste and reduce amounts of dangerous waste [3].

The keys to the transition to sustainability are linked to progression in direct clean technologies, green production and eco-productivity fields. In sustainability, clean production represents prevention at the source before environmental effects occur, rather than being a 'pollution control' approach aiming to resolve environmental problems after they occur. It requires the inclusion of every parameter in planning processes in the design stage for all types of human efficacy like industrial, urban, agricultural etc. in terms of environmental topics. As a result, instead of pollution control approaches, green production approaches have begun to be used [4]. The differences between clean production approach and pollution control approach are given comparatively in Table 1.

Table 1. Differences between clean production approach and pollution control approach [5]

Pollution Control Approaches	Clean Production Approaches
Pollutants are controlled by filters and waste treatment techniques and technologies; in other words, attempts are made not to solve the problem itself, but to resolve negativities occurring as a result.	Pollutants are prevented from forming, at the source with integrated precautions.
Pollution control are applications coming to the agenda after processes and products are developed and pollution problems have occurred.	Prevention of pollution is an inseparable part of the process and product development process; as a result, it is more effective.
Environmental improvements with pollution control are seen as an additional cost factor for organizations.	Pollutants and waste are seen as potential resources that can be transformed into beneficial products or by-products by being rendered harmless.
Application of pollution control technologies is the duty of environmental experts like waste managers, etc.	Implementing environmental improvement and clean production requirements is the responsibility of all employees in an organization including design and process engineers.
Environmental improvements require application of a variety of techniques and technologies.	Environmental improvements include not just techniques but also non-technique approaches.
Environmental improvement precautions are taken to abide by a series of standards set by the authorities.	Clean production is a continuous process targeting achievement of better environmental standards.
Quality is defined as responses to the needs of customers.	Quality is defined as production of products responding to the needs of customers in addition to minimizing effects on human health and the environment.
There are continuous costs of technologies used for pollution control and these costs increase over time.	Clean production approaches to solve the same problem may have high initial costs; however, in the long term implemented operation and maintenance costs are lower in total because consumption of inputs like raw material, water and energy are reduced as a result of clean production applications.

In this review, all aspects of the absolute relationship between green technologies and eco-productivity will be dealt with and information will be given about the present situation in Turkey.

2. Important keys in the transition to Sustainability

Since the 20th century, rapid industrial development, increases in population, production and consumption have caused the depletion or pollution of unrenewable natural resources. This situation has made sustainability a global topic debated by governments, manufacturers and society in the last 50 years [6].

Sustainable development is encountered as significant target that can be achieved dealing with protection and sustainability of the environment along with sustainable economic growth and social sustainability dimensions. Protection of the ecologic balance is necessary for sustainability of society by assessing the complementary targets of both economic growth and environmental quality. In this context, the important focal points in the successful transition to sustainability are the concepts of **green production, clean technology, eco-efficiency** and **life cycle analysis**.

2.1. Green (Clean) Production

The term green has an uncertain definition in daily life [7]. Green production comprises redevelopment of production processes and environmentally-friendly processes in production areas. This involves use of less natural resources, reduced amount of waste and recycling, reuse and disposal of material [8]. The United National Environmental Program (UNEP) defines clean production as 'continuous application of an integrated

and preventive environmental strategy to increase total efficiency and minimize risks to humans and the environment in processes, products and services' [9].
Different methods in green production ensure the reuse of products to reduce raw material use and lower negative effects on living organisms to minimum levels. The 5 main principles of green (clean) production are given in Figure 1.

Figure 1. Five main principles of clean production [10]

The advantages of green (clean) production are as follows [8]:

- No release of waste that can cause air pollution
- May ensure economic benefit in some situations
- Production with fewer resources and as a result ensures an improvement in costs
- Renewable alternatives mean undepleted raw material resources.
- Reducing CO_2 greenhouse gas may slow the effects of global warming
- May ensure efficient energy use.

2.2. Clean Technologies

While clean technologies offer solutions for global sustainability, they are new technologies offering competitive feedback to investors/innovators and users and work models designed related to this. They include applications focusing on operational performance, productivity and efficiency, reducing costs, use of input resources, energy consumption, and waste amounts while improving information, intensive products and services, widespread market economy, sustainability and opportunities offered by these returns [11]. Clean technologies encompass 14 categories including energy production, water treatment and efficient production techniques (Figure 2).

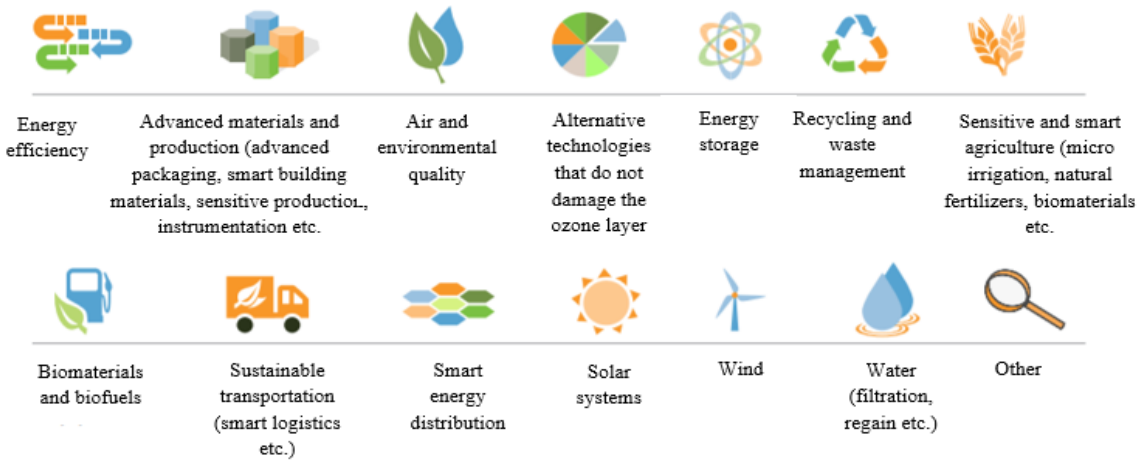

Figure 2. Categories included in clean technologies [11]

2.3. Eco-efficiency

Eco-efficiency includes innovative approaches and concepts mentioned in recent periods especially about industrial environmental management. Eco-efficiency related to product development targets improvement of the environmental performance of operations. Eco-efficiency is based on the principle of producing the same amount with less natural resources, renewable energy use and less waste production through the use of high efficiency production technology and methods. With this quality, it appeals to many areas, not just environmental concerns, like 'protecting natural resources', 'industrial efficiency' and 'economic development' (Figure 3). In short, eco-efficiency increases efficiency in production meaning both environmental and economic benefit is provided [12].

Figure 3. Eco-efficiency cycle

2.4. Life cycle analysis (LCA)

Life cycle analysis (LCA) is a method to assess the environmental effects caused during the life duration of the product and processes encompassing obtaining the raw material, production, use, final disposal and all intervening transport stages. All energy, water and material inputs in these stages and all waste and emissions are collected in a comprehensive inventory and assessed together and potential environmental impacts of products are calculated (Figure 4). Different to environmental impact analyses with narrow scope, the integrative method of LCA prevents transfer of environmental problems from one stage of a product's life to another with the 'cradle to the grave' approach [13].

Industrial symbiosis brings a system approach to businesses. Refers to symbiotic relationships between living things and industrial systems. The main application of industrial symbiosis is substance (waste, by-product, water), energy exchange and reuse among businesses close to each other. It is in elbow contact with cleaner production, eco-efficiency and many other concepts. It can focus on both pollutant and process, and the entire

life cycle (Figure 5). The integrity and hierarchy of cleaner production and industrial symbiosis should not be overlooked. First, waste should be minimized within the enterprise, and then symbiotic possibilities should be evaluated [14].

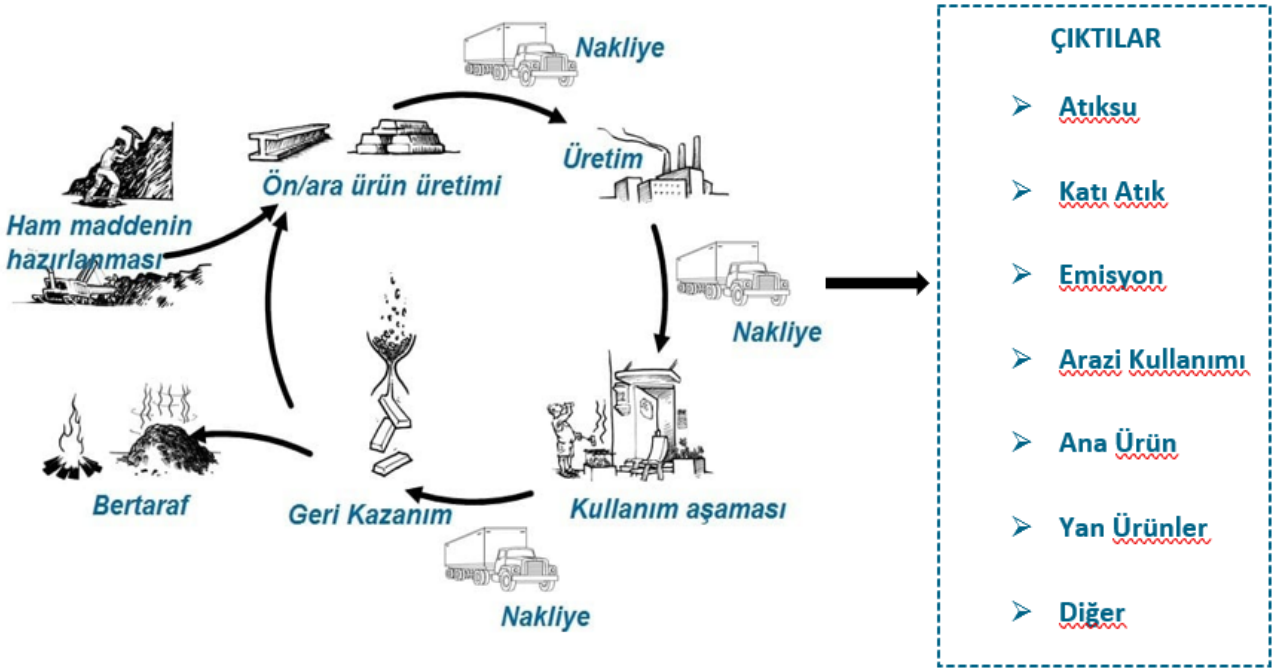

Figure 4. LCA stages [13-15]

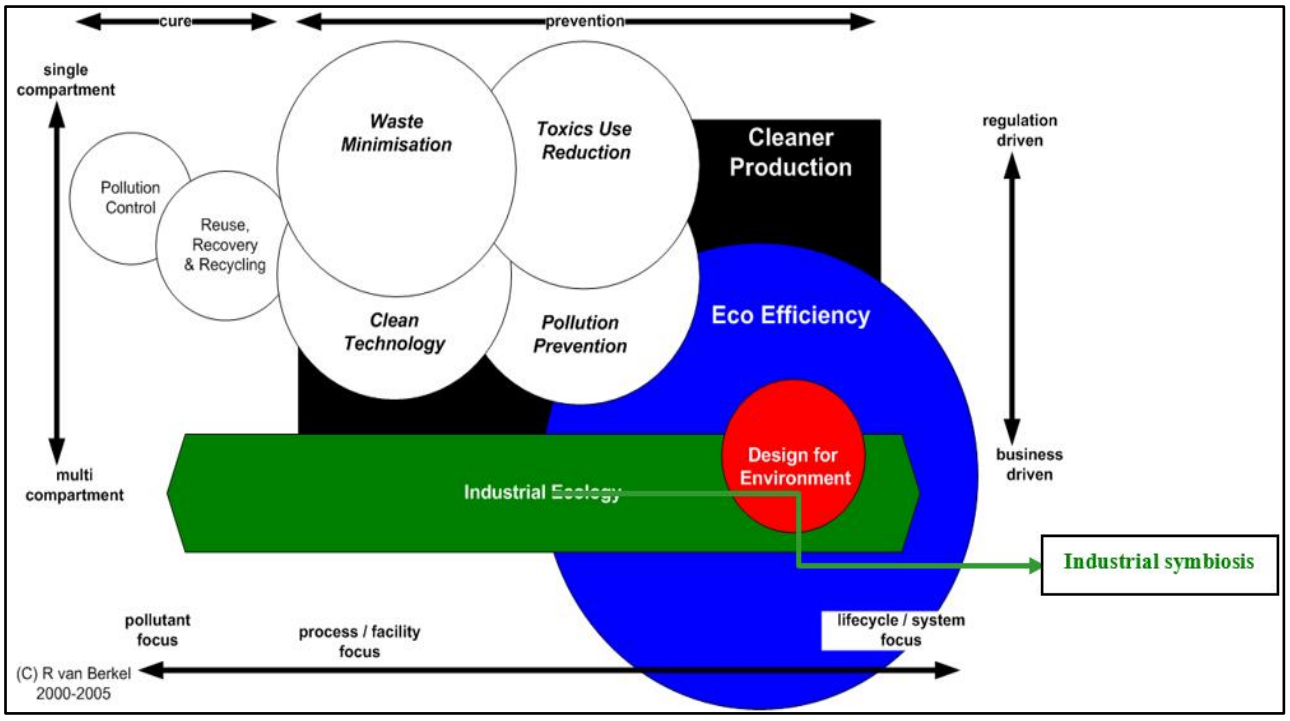

Figure 5. Industrial symbiosis [14]

2.4.1. Life cycle analysis methods and stages

The standard LCA method defined by ISO documents comprises four main stages; determination of purpose and scope; inventory analysis of life cycle; impact analysis; and interpretation of results and improvement. The relationships between the stages are stated in Figure 6.

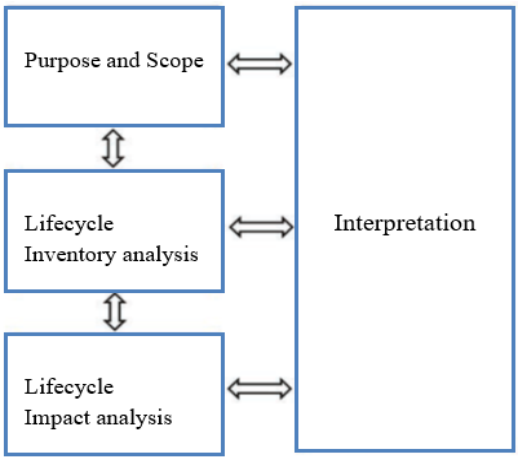

Figure 6. LCA methodology [16]

- **Determination of purpose and scope:** This stage determines the functional units of the product/service to be evaluated and draws the system boundaries. In other words, within the scope the system/s processes, functional units, system to be studied, system boundaries, sharing procedures, impact variety, impact assessment method, interpretation stage, data requirements, assumptions, limits, quality requirements for initial data, critical review, report type and format necessary for studies are considered and clearly stated [17].
- **Inventory analysis:** Energy, water and raw material use that will occur within system boundaries and linked emission levels, determination of water and soil requirements, and creation of a process flow diagram. Inventory analysis directly affects the accuracy of the other stages in LCA analyses, and the accuracy level and details of the collected data [18].
- **Impact analysis:** Grouping of resource use and emission impacts, division into certain impact groups and giving points according to degree of importance. Impact analysis is the most important stage in creating the connections between product/process and their possible environmental effects [18-19]. After these three stages of LCA comes the interpretation and improvement stage.
- **Interpretation and improvement:** This is the stage where subunits of the effective system with high impact share have materials or processes identified and scenarios developed to improve the environmental performance of the system. In addition to being consistent with the purposes and scope section, it is important that this be easy to understand, with nothing missing and be presented consistently [20].

2.4.2. Application areas for Life Cycle Analysis

LCA is one of the methods to assess environmental impact and has a broad area of application for a variety of products, services and systems in the private sector, public sector and academics. Allowing the possibility for integrated analysis of different performance criteria, LCA has important areas of use like strategic planning, developing public sector policies and performance markers, determination of priority products and processes in production, identification of possibilities for improvement, providing important inputs in product development or redesign stages, supporting a variety of sustainability statements and eco-labelling programs, and comparing different production alternatives.

Among these, environmental declarations with importance for sustainable consumption and production are summarized below.

2.4.2.1. Environmental Declarations and Life Cycle Analysis

To document and declare the environmental performance of a variety of product groups, LCA allows the possibility to obtain data in accordance with ISO standards based on scientific principles in advanced environmental labelling programs. An eco-labelling system is a certification program developed in line with sustainable environmental targets to encourage products/services with reduced environmental effects during the life cycle and to provide accurate and scientific information to consumers with a voluntary environmental labelling system [21]. Eco-labels are also one of the three labelling types defined by the International Standardization Organization (ISO) [22-23] (Table 2).

TYPE 1: Programs rewarding products with environmental selectivity for product categories abiding by life cycle principles which are voluntary, based on multiple criteria and by a third party.

TYPE 2: Programs documenting environmental claims declared by manufacturers and suppliers themselves and mostly used in promotions.
TYPE 3: Programs determining numerical criteria at the basis of life cycles or permitted by another third party which are voluntary with the scope of numerical criteria previously determined by a qualified third party.

Currently, the frequently-used **Eco-Label** concept enters the Type 1 label class. Inclusion of a second party in the labelling process in Type 1 and Type 3 labelling types have criteria and compliance determined by industry representatives or third parties. The inclusion of a third party in the labelling process in Type 1 labels occurs by an independent party/stakeholder outside the relevant industrial sector. The parties responsible for organizing labelling are responsible for determining the criteria. Due to being independent, the scenario where a third party is responsible for the labelling pattern is more reliable and more effective. The common feature of all label varieties is to create market demand for **environmentally-friendly products**. These types of labels have the quality of declaring sufficiency in relation to topics encompassing elements like environment, food quality and health and can be seen in Type 2 labels [15].

Table 2. Environment Labelling types [22-23]

Type	Explanation	Example
	Guidelines for all label types	ISO 14020
Type 1	Environmental labels which are voluntary, leading in terms of the environment, and represented by the emblem of the third party in most cases. Criteria are determined by a third party, and labels are given to products that abide by previously-determined requirements.	ISO 14024:ISO 1999a AB Eco-Label Turkey Environmental Label
Type 2	Self-declared environmental labels based on explanations given by manufacturers, importers and distributors. Generally, involve only one quality, sometimes like a company environmental emblem.	ISO 14021:ISO 1999b
Type 3	Labels given based on quantitative environmental information according to ISO life cycle analysis parameters related to products. Generally environmental declarations are in the form of a matrix containing detailed information.	ISO 14025:ISO 2006 ISO 14040

Most eco-labelling programs do not include only the use stage of products and services but criteria encompassing the whole value chain. In this context, the **LCA** method plays an important role in R&D studies about producing products and services in accordance with the requirements of the **Eco-Label** program or making current products appropriate [24].

3. Relationships between Keys

3.1. Relationship between Clean Production and Eco-efficiency

- Clean production concept was first used by the United Nations Environment Program (UNEP) Industry and Environment Department in 1989, while the eco-efficiency concept was used by the World Business Council for Sustainable Development (WBSCD) in 1992.
- Eco-efficiency concept means obtaining more products and services with less renewable energy and less natural resources. Clean production is a strategy targeting continuous development of processes, products and techniques to reduce waste at the source (waste minimization) while also increasing efficiency.
- Eco-efficiency targets increasing economic profits and efficiency while using resources more efficiently and minimizing damage to the environment. For an operation to ensure eco-efficiency, clean production techniques come into play to reduce the resources and energy amount used per unit product, to reduce waste amount per unit product, to increase recycling and reuse rates and reduce dissemination of dangerous material.
- Clean production firstly prevents or reduces waste formation, ensuring less consumption of the resource and energy used to protect environment and biological diversity; in short, the target is sustainable production. Clean production applies preventive environmental strategies to processes, products and services to increase eco-efficiency and thus ensure reduction of risks to humans and the ecosystem.

- Clean production like eco-productivity requires integration of sustainable development with economic and environmental development.
- The eco-efficiency concept firstly addresses work environments emphasizing efficiency, profitability, competition, etc.
- Considering the methods used and targets to be achieved (reduction of raw material and energy use), these two concepts appear to be in continuous compliance with each other [25].

3.2. Relationship between Clean Production and Life Cycle Analysis

Clean production is a preventive approach to reduce the impacts of processes, products and services on human health and the ecosystem and to increase efficiency in production. With this approach, changes are made to production systems to improve energy, water and resource efficiency in production, to reduce waste and emissions, and to obtain economic benefit by increasing the competitive power of products. Clean production applications include changes made to technology, equipment, process inputs-outputs, facility management and maintenance, waste management and product design. Changes made to the production and product development stages affect the whole value chain of the products and in this context, it is important to assess steps taken within the scope of clean production with the integrative approach of the LCA method. We can see this concept more clearly in the following examples.

- Transitioning to sustainable raw material in production, improving the 'raw material supply' stage
- Increasing the energy efficiency of electronic goods produced with R&D studies and lowering the carbon footprint 'during use'
- Changing product packaging, making 'product delivery' or logistic stages more efficient and linked to this lowering air emissions.
- Designing more easily recyclable products to reduce environmental impacts in the 'final disposal' stage.

LCA studies encompass all stages of the product value chain, assess the cumulative environmental impacts together and by considering cross-media effects, prevent transfer of environmental load from one stage to another [26].

3.3. Three-way relationship between Eco-efficiency, Clean Production and Life Cycle Analysis

The final target in combining eco-productivity, clean production and life cycle analysis is to minimize negative impacts of products and services on **human health, ecosystem pollution** and **country economy** and maximize efficiency in production. In this context, changes made in the product/production development stages with eco-productivity and clean production should be made in compliance with LCA stages (Figure 7).

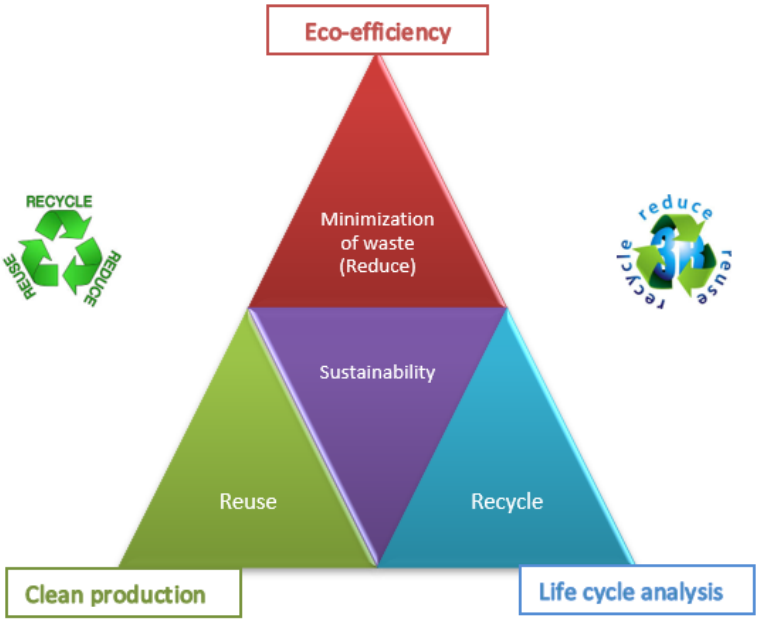

Figure 7. Relationship pyramid between three basic keys and 3R

4. Current status in Turkey

In Turkey, the first steps towards the clean production/eco-productivity concepts began to be taken at the end of the 1990s and a variety of organizations and institutions have completed studies about this topic in the intervening period. Item (f) in article 2 in the Decree Law (Law provision decree) numbered 635, dated 03/06/2011 states *'with the aim of development in accordance with the principles of efficiency in economy, to prepare efficiency policies and strategies, to increase and develop efficiency of industrial operations and to support clean production projects'* are included in the duties of the Republic of Turkey Ministry of Science, Industry and Technology. Decree Law number 649 dated 17 August 2011 added to KHK no. 635 abolished the National Productivity Center, a service unit in the Republic of Turkey Ministry of Science, Industry and Technology, and restructured it as the General Directorate of Productivity (GDP). Studies about clean production continue in the Republic of Turkey Ministry of Science, Industry and Technology and one of the duties of the General Directorate of Productivity was defined in KHK no. 635 with the statement '*to complete activities about preparation and applications of clean production programs and projects by businesses'* [2].

In Turkey, public organizations and institutions playing a key role in the determination, implementation and popularization of policies about clean production note the importance of small-medium enterprises and include the Ministry of Environment and Urbanization, Ministry of Health, Ministry of Industry and Commerce, State Planning Organization, Small and Medium Industry Development Organization (KOSGEB), National Productivity Center, Scientific and Technological Research Council of Turkey Marmara Research Center (TÜBİTAK-MAM) and municipalities [27].

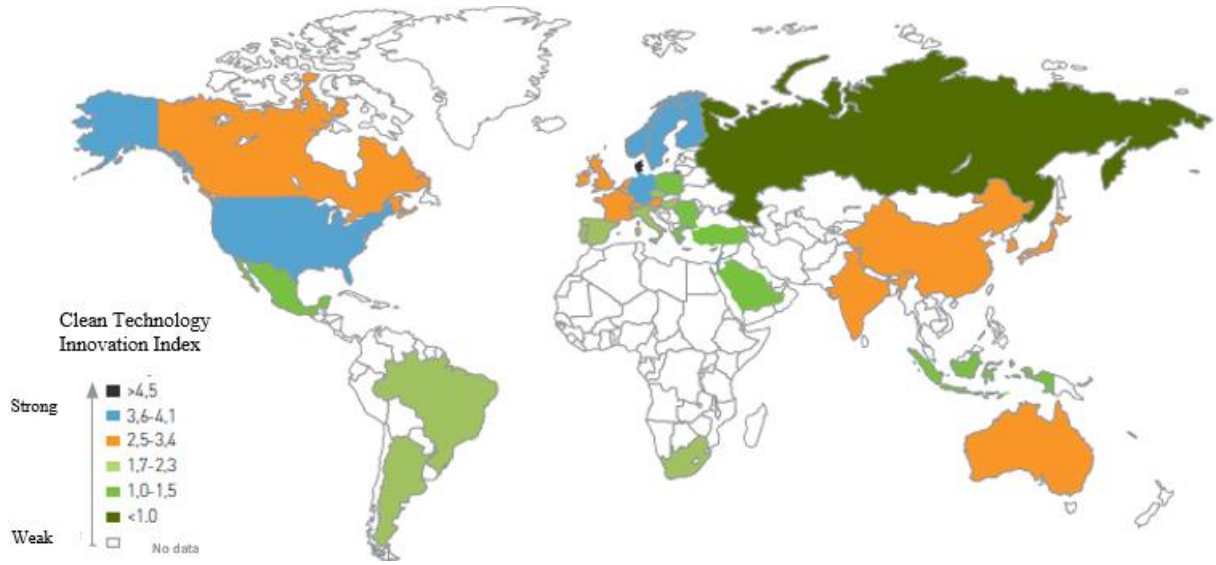

Figure 8. Clean Technology Innovation Index [28-29]

Global consumption and production cannot be reduced due to many reasons like rapid industrialization, population increase, urbanization and environmental degradation and external dependence on many industrial inputs. With the use of production technologies and methods with high efficiency, based on the principle of producing the same amount with less natural resources and energy use and lower waste production, sustainable consumption and production is known and applied at very limited levels, contrary to the great importance for our country. Turkey is behind many countries in the categories of 'evidence of innovation development' and 'innovation impacts' about clean technology. In developed countries, the clean technology innovation index is above 4.5, while the innovation index for Turkey is from 1.0-1.5 [28-29] (Figure 8).

Turkey's strategies for green jobs and renewable energy is given in Figure 9. The purpose of these strategies or action plans is as follows [30]:

Action plan between 1998-2018; Promoting the use of clean and renewable energy sources.
Action plan between 2005-2015; To encourage all investments to prevent environmental pollution, to determine environmentally friendly and efficient technologies, to create planning to reduce greenhouse gas emissions.
Action plan between 2008-2012; Dissemination of energy recovery activities from wastes within the structure of sustainable development principles.

Action plan between 2010-2020; Using clean production technologies, climate-friendly and innovative technologies, conducting R&D studies in this field and supporting the domestic industry
Action plan between 2010-2023; Improving the use of renewable energy sources in settlements
Action plan between 2011-2014; By 2020, with measures to be taken regarding energy efficiency; increasing the share of renewable energy resources in energy production, supporting the transition to low carbon economy and cleaner production processes in industry, introducing new business models, providing of new employment and green jobs opportunities.
Action plan between 2012-2023; Increasing the number of sustainable environmentally friendly buildings using renewable energy sources, increasing the number of original designs and products in the renewable energy sector.
Action plan 2023; Building green railway and green stations by establishing an environmental management system on railways, bringing all airports to green airport status, making arrangements on green ships, giving importance to green logistics, developing environmentally friendly vehicles, efficient energy use.
Action plan 2050; Emphasizing climate change, on the road map drawn for "living within the boundaries of the planet" ; including the costs of externalities, starting with carbon, water and ecosystems, Stoping deforestation and increase the efficiency of planted forests; to maximize low-carbon energy systems and demand-side energy efficiency, thus halving greenhouse gas emissions by 2050, which will peak in the 2020s (by 2005 level) worldwide; “To list objectives related to direct climate change, such as providing universal access to low-carbon mobility”, and “plays a key role in the development of business world, policy and innovations” to realize this roadmap.

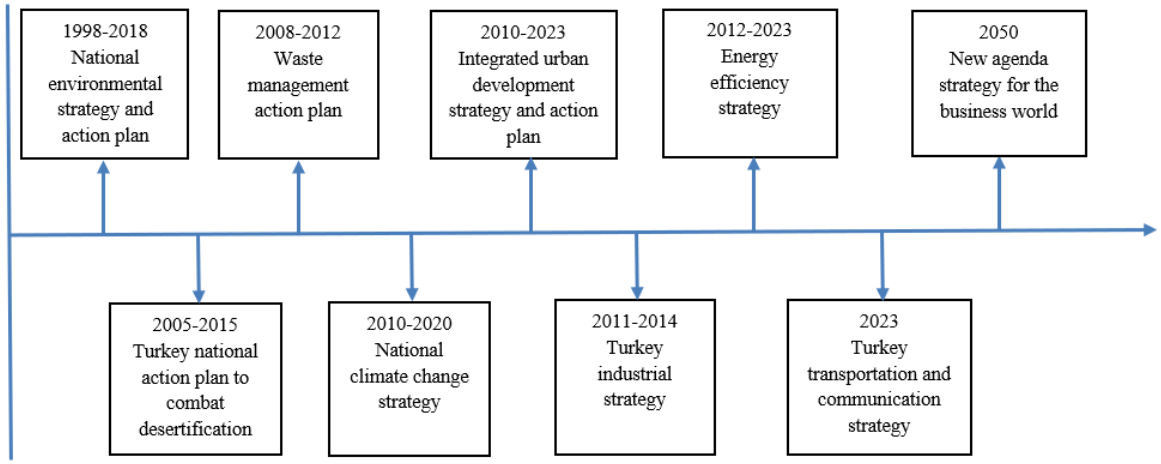

Figure 9. Turkey's strategies for green jobs and renewable energy [30]

5. Conclusions and recommendations

In the near future, it is unavoidable that studies related to concepts like clean production, eco-productivity and clean technologies in environmental management and efficiency will gain a more spiral structure. International projects, regulations, precautions taken on a country basis, incentives, and developments about this topic will reveal the importance of use of clean technologies and clean production processes for sustainable development. The development process of policies about sustainability over time is summarized in Figure 10.

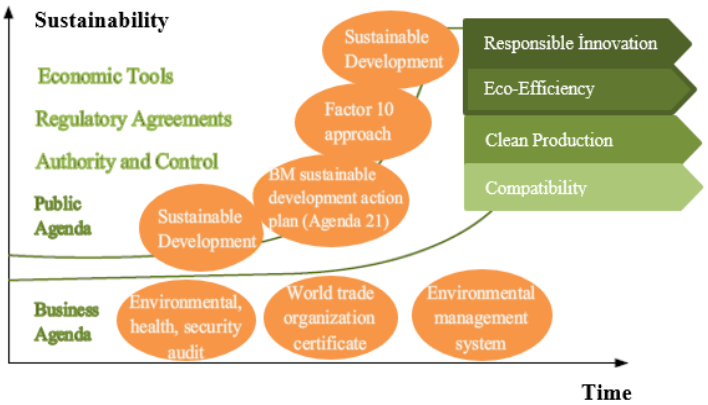

Figure 10. Development of policies about sustainability against time [31]

Factor 10 approach: an approach predictive lowering per person energy and material consumption of humanity by 10 times within 30-50 years and additionally increasing resource productivity and efficiency by 10 times [31]

We can summarize the elements recommended to popularize the concepts of clean production, eco-efficiency and clean technology as follows;

- Increase the determinative role of topics related to the environment in economic and social policies
- Ensure increases in the supply, recycling and efficiency of use of resources
- Encourage new work areas and increased employment in developing countries especially
- When developing approaches evaluating economic, social and environmental requirements together, sensitive observation of the topics of 'environment' and 'ecosystem' without ignoring the concepts of innovation, increased productivity, competitiveness and entrepreneurship.
- Pioneering incentives and regulation that will speed up the use of clean technologies in the market by public and private sector organizations
- Providing continuous training to necessary units in the area of green growth strategies
- Incentive packets developed and applied in many countries to enliven the economy should definitely include precautions about popularizing clean technologies.

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