SUSTAINABILITY ASSESSMENT OF NANOTECHNOLOGICAL BUILDING MATERIALS

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ABSTRACT

Increase of natural resource consumption and environmental pollution due to population growth and industrial expansion causes considerable damage to the ecosystem. With the ecological crisis experienced in the 1970s, alternative ecological discourses have been expressed, measures have been taken to reduce the use of resources, and new technologies have been developed accordingly. Research has revealed that most of the natural resources are consumed in the construction sector. Therefore, sustainable technologies have started to be used and gain importance in this sector.

The term 'Nanotechnology' means the engineering of matter at the atomic molecular level and reveals its new properties. Research on nanotechnology has increased worldwide. However, the most important paradox encountered in the developmental stages of this technology is whether nanotechnological materials (nanomaterials) are harmful to nature during production, use and post-use stages.

In this study, it was aimed to

* contribute to improving the environmental aspects of nanomaterials with the findings of this study

* guide architects and other decision-makers in selecting nanomaterials considering sustainability

In this context, an assessment was made to determine the environmental advantages and disadvantages of nanomaterials used in the construction sector. In line with these purposes, nanomaterials were classified, and the types of these materials used in the building sector were investigated based on literature in the first part of the study. The environmental impacts of nanomaterials were evaluated in the context of energy, raw material, and water efficiency through the literature in the second part. The

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environmental advantages and disadvantages of nanomaterials used in the building sector were determined.

As a result of the study; reducing the consumption level of raw materials, production of durable materials, increasing energy efficiency and consequently reducing CO_2 emissions, low pollutant emitting materials, the feasibility of reuse of wastes are the environmental advantages of these materials, while the increasing environmental toxicity (air, water, soil and sediment) are the disadvantages of these materials, although scientific uncertainties still exist.

Keywords: Sustainable Building, Nanotechnological Materials, Environmental Assessment, Resource Efficiency

1. INTRODUCTION

Construction activities in the world are responsible for forty percent of materials and energy use, more than thirty percent of carbon emissions, twenty-five percent of tree cutting, and more than fifteen percent of clean water consumption (Say and Wood, 2008).

Sustainable architecture is defined as all activities that consume minimum energy and resources during the construction and usage phase, adapt to its environment, protect human health and comfort, and exhibit participatory structures in the ecosystem cycle. People spend ninety percent of their lives in buildings. Therefore, it is clear that buildings have a significant impact on human and environmental balance (Yılmaz and Vural 2015).

Nanotechnology is today seen as the fastest growing technology. Nanotechnological materials are developing in the construction sector as well as in many disciplines in terms of production and usage. Many positive developments in the field of architecture have emerged with nanotechnology (Niroumandet al. 2013).

In this context, it is aimed to present the nanotechnological materials used in the building sector firstly by classification, then to determine their environmental advantages and disadvantages by examining the environmental impact categories in this study.

2. NANOTECHNOLOGY AND NANOTECHNOLOGICAL MATERIALS

Nanotechnology aims to reveal the new properties of the material by engineering it at the atomic molecular dimension; It is a set of technologies that includes the development of functional materials, structures and systems for the understanding, control, and production of physical, chemical and biological phenomena at the nanometer scale.

The earliest example of nanotechnological materials is the cup of Lycurgus made by a Roman glass master in the 14th century. This work has the property of converting its color from green to dark red with the effect of sunlight due to the silver and gold nano-particles in its content. In 1959, at Richard Feynman's famous conference titled ''There is a lot of room at the bottom'', unnamed technology, in these years, emerged with the words as "If materials and devices can be made at the molecular level, this will be the source of discoveries " (Feynmann 1992). The term nanotechnology was first used by the Japanese scientist Norio Taniguchi in 1974 (Taniguchi 1974).

Nanotechnology is an exciting field of scientific development that promises more for less. It is a science that can create smarter, cheaper, lighter and faster devices that can do smarter jobs, use less raw materials and consume less energy (Elborombaly 2016).

Nano-scale particles naturally occurring spontaneously by environmental influences in nature are mineral oxide, iron oxide, silicate and carbon group. There are also particles such as metal oxides, carbon nanotubes produced in the laboratory environment. As a result of these studies, they have become the most important technological parts of today both industrially and scientifically with their atomic sequences that can be changed in order to meet the desired usage as well as having perfect properties (Ünşar 2013).

It is needed to use renewable energy resources very efficiently due to the need for less harmful, more flexible, more durable and long-lasting building materials during production and process. Nanotechnology, which is one of the most important technology fields of today, is expected to contribute significantly to the development of the building materials with these properties (Candemir et al. 2012).

Nanotechnology research has increased worldwide since 1980. However, an important challenge encountered in the developmental stages of this technology is that nanotechnological products are harmful to nature during production, use and post-use stages. Fear of any technology has led to the prevention of harmful effects on humans and the environment. This technology, which has the potential to create many new materials and devices with a wide range of applications, raises concerns about the toxicity and environmental impacts of the nanomaterials (Elborombaly 2016).

The effects of the developed nanotechnological materials on human and environment are complicated. These effects vary depending on particle properties and chemical toxicity (Science for Environment Policy 2017).

2.1. Classification of Nanotechnological Materials

In this study, nanotechnological materials (nanomaterials) used in buildings are classified according to their *formation, size, position in the product* and *ingredients.*

According to their formation, nanomaterials are classified as; organic and inorganic. Organic nanomaterials consist of biological, geological, atmospheric particles. Materials such as fullerene, carbon nanotube, aerogel etc. are examples of organic nanomaterials. Nanomaterials that do not contain carbon atoms are called inorganic such as nano-titanium dioxide (nano-TiO_2), nano-silica (nano-SiO_2), nano-aluminum oxide (nano-Al_2O_3) (Hansen 2009).

According to their size, nanomaterials are classified as zero-dimensional (nano pellets, nanoparticles etc.), one-dimensional (nanowires), two-dimensional (nano-films, nano-coatings) and three-dimensional nanomaterials (fullerenes, carbon nanotubes, aerogels) (Hansen 2009).

Considering the position of nanomaterials in the product, they are classified as nanomaterials in mass, nanomaterials applied to surface, and nanomaterials containing nanoparticles. For the materials in mass, it can be one or more different types of nanomaterials in the mass. Nanomaterials applied to surface can be grouped as the materials where the mass and surface are same, the materials coated with a nano thin patternless film on the underside of a different material, and the materials covered with a nano thin patterned film on the bottom surface. Nanomaterials containing nanoparticles can be grouped as the materials containing nanoparticles attached to the surface of a different solid form material, the materials containing nanoparticles suspended in a liquid or solid materials or the air (Hansen 2009).

Nanomaterials according to their ingredients, they are divided into three as carbon-based, metal-based and nanocomposites. Tubes (nanotube / nano rod), ellipsoids, and empty spheres (nanotop) are the types of carbon-based nanomaterials. Nano zinc oxide, nano silver, nano aluminum oxide, and nano titanium dioxide are the types of metal-based nanomaterials. And, polymer, ceramic, metal types are the example of nanomaterials (Hansen 2009).

2.2. Nanomaterials Used in Buildings

Nanotechnology controls substances at the nanoscale and changes their structures at the molecular level. In this way, it can improve the physical and chemical properties of traditional materials used in architecture. And new materials can be produced by changing the basic properties forming the structure of the materials such as strength, surface area, conductivity, and flexibility (Elvin 2013) (Tepe 2007).

In this study, the nanomaterials used in the buildings were classified as structural nanomaterials, nanocoatings, nanotechnology and insulation applications, nanotechnology and photovoltaic panels, nano adhesives, nano plastics, and nano lighting elements.

Nanomaterials according to their use in buildings they are classified. This classification and related materials were listed below.

- Structural nanomaterials

Nanoparticles are used in the structure of concrete, steel and wood bearing systems in structures.

- Nano coatings

Self-cleaning nanocoatings, lotus effect self-cleaning nanocaps, self-cleaning nanocaps with photocatalytic effect, easy to clean nanocoatings, air-clean nanoclays, anti-fog nanocaps, anti-bacterial nanocaps, fingerprint-free nanocoatings, uv-protected nanocoatings, non-scratch and abrasion resistant nanocovers.

- Nanotechnology and insulation applications
- Nanotechnology and photovoltaic panels
- Nano adhesives
- Nano plastics
- Nano lighting elements.

3. THE ENVIRONMENTAL ASSESSMENT OF NANOMATERIALS IN THE CONTEXT OF RESOURCE EFFICIENCY

Nanotechnology has significant potential in the field of construction and building materials. In the scope of this study, the environmental impacts of nanotechnological materials were assessed in the context of energy efficiency, raw material efficiency and recyclability, water efficiency through literature review.

Energy Efficiency;

According to researches, forty percent of all the energy produced in the world is consumed by buildings. Considering that thirty percent of carbon dioxide emissions are caused by the buildings that we live in, it is clear that the largest users of the resources in the world are the building construction sector and the man-made environment (Özdil 2007).

Approximately one-third of the total energy consumed in the world and Turkey is used in the construction, maintenance, operation, and demolition processes of buildings. Therefore, energy-efficient building design has recently become one of the important research areas in architecture (Tokuç 2014).

Figure 1 indicates that if the current trends continue, approximately one-third of the world's energy will be used by the building sector (URL 5).

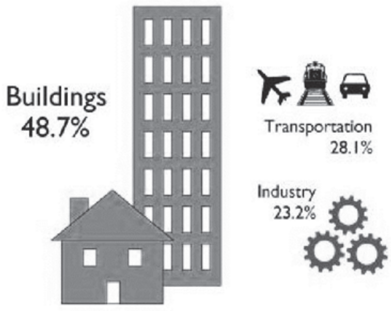

Figure 1: Distribution of world energy consumption and energy consumption by sectors [URL 5]

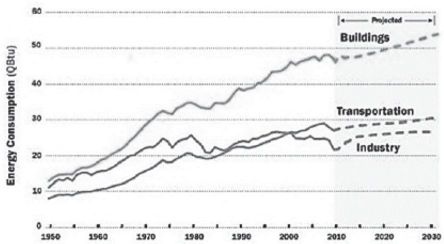

Figure 2: Energy consumption by sector (foreseen date) (URL 5)

High strength nanomaterials and nanocomposites can carry more weight per unit than conventional materials. Because of these properties, they consume less energy (Avcı 2009).

Ultra-fine carbon nanotubes can perform structure, structure and shell functions simultaneously, provide sustainable structures with higher strength, less maintenance, and lower energy consumption replacing traditional construction systems (Akyol and Örgülü 2014).

Raw Material Efficiency and Recyclability;

One of the major problems of the construction sector is the depletion of non-renewable raw material resources. In the world where natural resources are rapidly depleted, the use of alternative sustainable building materials that reduce raw material consumption will have a positive impact on the country and the world economy. It will also provide future generations with the opportunity to benefit from natural resources (Gürer et al. 2004).

Forty percent of the raw material extracted from the world is used in the construction sector, and forty percent of the man-made wastes are produced by this sector (Özdil, 2007). Therefore, recycling practices are important especially in the construction sector (Gürer et al. 2004). According to Keller et al. (2013), total nanomaterials wastes comprise 63-91% landfill waste, 8-28% soil emissions, %0,4- 7 water emissions, and air emissions are less than 1,5%.

The most important reason why nanomaterials have an environmental impact is that nanoparticles can easily bind to the porous environment, usually under the ground and in the water (Bradley 2010).

The nanomaterials are used for various purposes. Nano wastes are considered as normal waste in solid or liquid form and are therefore disposed of through existing waste management systems. Thus, a nano-waste can be mixed directly into the environment as waste. For all these reasons, the release of nano-waste the environment should be prevented through appropriate waste management practices (URL 4).

Water Efficiency;

The amount of water per capita in Turkey is 216 liters per day (TSI). In addition to direct consumption, the amount of water consumed indirectly through goods and services, the amount of virtual water is 5,416 liters (URL 1). According to the studies, Turkey will be among water-poor countries, and the amount of water per capita will be reduced by a quarter in 2030 (URL 2). Therefore, better management and sustainability of water resources is very important.

By using nanotechnology, significant gains in water efficiency are achieved and studies are carried out to reduce the energy requirements associated with the transport and use of water (Kim et al., 2013).

According to the researches, it is predicted that 100.000 liters of water will be saved during the service life of buildings used with self-cleaning glass with photocatalytic titanium dioxide coating. Besides, in terms of the actual construction and maintenance costs in the buildings where these glasses were used, the average return on investment was calculated to be six years (Orhan 2013).

The self-cleaning glasses look like standard glazing and require less frequent cleaning while staying clean longer. These glasses, which are easier to clean, are environmentally and economically advantageous by providing less water and detergent (URL 3).

However, since these materials are very small in size, they are easily regarded as toxic contaminants passing through existing treatment systems. The toxic effects of nanomaterials vary depending on their characteristics (chemical structure, size, etc.), dose and storage time. Filtration studies with the use of nano membranes in water purification systems are continuing (Arif 2012).

Environmental Advantages of Nanotechnological Materials;

It is expected that nanotechnology can reduce stress on energy demands by providing clean, alternative energy sources, such as photovoltaic and fuel cells, at a lower cost. Photocatalysts based on nanomaterials that can remove organic pollutants have been developed. Therefore, some estimates claim that nanotechnology will actually reduce the air and water pollution we have today (Kulkarn 2015).

Table 1. Environmental Assessment of Nano Building Materials (Sánchez and Sobolev 2010 and Leydecker 2008), (Krishnamoorthy and Iniewski 2016), (Lee et al. 2010), (URL 5 2016)

Nano-particles	***Field of Applications in Buildings***	***Environmental Impact Assessment***	***Environmental Advantages of Nanotechnological Material***		
			Energy Efficiency	***Water Efficiency***	***Raw Material Efficiency***
Nano Silica (SiO_2)	*Concrete*	Reinforcement in mechanical strength, energy efficiency use	✓		
Nano Silica (SiO_2)	*Ceramic*	Increased scratch resistance, increased fire resistance	✓	✓	
	Window	Fire resistance, increased scratch resistance	✓		✓
Titanium Dioxide (TiO_2)	*Cement*	Self cleaning, water efficiency use increased durability of structures and components, energy efficiency use	✓	✓	✓

Table 1 Continued. Environmental Assessment of Nano Building Materials (Sánchez and Sobolev 2010 and Leydecker 2008), (Krishnamoorthy and Iniewski 2016), (Lee et al. 2010), (URL 5 2016)

Nano-particles	***Field of Applications in Buildings***	***Environmental Impact Assessment***	***Environmental Advantages of Nanotechnological Material***		
			Energy Efficiency	***Water Efficiency***	***Raw Material Efficiency***
Titanium Dioxide (TiO_2)	*Concrete*	Mechanical durability rapid hydration, self cleaning		✓	✓
	Window	Increased fire resistance, self cleaning, energy efficiency use, water efficiency use	✓	✓	✓
	Photo -voltaic Panel	Increase in electricity generation efficiency	✓		
Carbon Nanotubes (CNT)	*Concrete*	Mechanical durability, crack prevention, increased lifetime, energy efficiency use	✓		✓
Carbon Nanotubes (CNT)	*Steel*	Mechanical durability, increased lifetime, energy efficiency use, anti-corrosion protection	✓		✓
Carbon Nanotubes (CNT)	*Ceramic*	Advanced mechanical and thermal properties, energy efficiency use	✓		
	Photo -voltaic Panel	Increase in electricity generation efficiency	✓		
Silver (Ag)	*Coating*	Removal of harmful components		✓	✓
	Paint	Anti-Bacteria Effect Improving air quality and providing indoor comfort, Prevent the formation of organic dirt, bacteria, germs and odors		✓	✓

Table 1 Continued. Environmental Assessment of Nano Building Materials (Sánchez and Sobolev 2010 and Leydecker 2008), (Krishnamoorthy and Iniewski 2016), (Lee et al. 2010), (URL 5 2016)

Nano-particles	***Field of Applications in Buildings***	***Environmental Impact Assessment***	***Environmental Advantages of Nanotechnological Material***		
			Energy Efficiency	***Water Efficiency***	***Raw Material Efficiency***
Magnesium (Mg)	*Coating*	Useful as protection for surfaces exposed to corrosion, moisture, oxidation increased durability and service life of structures and components	⎫		⎫
Zinc oxide (ZnO)	*Solar Cells*	Increase efficiency in electricity generation	⎫		
Copper (Cu)	*Steel*	Corrosion resistance			⎫
Lithium (Li))	*Photo -voltaic Panel*	Energy efficiency use	⎫		
Nano-alumina	*Water Filters*	Water efficiency use		⎫	
Aluminum Oxide (Al_2O_3)	*Concrete*	Improving the mechanical and physical properties of concrete	⎫		⎫
	Steel	Corrosion resistance	⎫		⎫
	Wood	Improving resistance to surface damage due to UV radiation	⎫		⎫
	Lighting	Energy-saving	⎫		
Iron Oxide (Fe_2O_3)	*Concrete*	Increased compressive strength, Abrasion resistance			⎫

According to the Tablo 4, it has been revealed that nanoparticles such as Nano Silica (SiO_2), Titanium Dioxide (TiO_2), Carbon Nanotubes (CNT), Magnesium (Mg), Zinc oxide (ZnO), Lithium (Li)), Aluminum Oxide (Al_2O_3), Aerogels, Nano structured thin films and Nano-Membranes provide energy efficiency to the materials they are used with. Nano Silica (SiO_2), Titanium Dioxide (TiO_2), Silver (Ag), Nano-alumina, Aerogels, Nano-Membranes, Nano-Catalysts provide water efficiency to the materials they are used with. Nano Silica (SiO2), Titanium Dioxide

(TiO_2), Carbon Nanotubes (CNT), Silver (Ag), Magnesium (Mg), Copper (Cu), Aluminum Oxide (Al_2O_3), Iron Oxide (Fe_2O_3), Aerogels, Nano-Membranes provide raw material efficiency to the materials they are used with.

Besides the many positive effects of nanotechnology, it also has negative effects. Researches show that nanoparticles used in structures can penetrate the skin, lungs and intestinal system (Helland A., 2004), (Kreyling et al., 2002). Also, nanoparticles can react with other substances and mix with organisms, soil and groundwater. This situation may cause other negative effects (Oberdorster et al., 2004), (Falkner and Jaspers, 2012). Besides, many studies indicate that nano-particles can pass to organs such as lungs and liver (Baalousha, 2016), (Karlsson et al., 2009).

4. CONCLUSION

Nanomaterials can provide solutions to important environmental problems with energy, raw material and water efficiency thanks to its many properties. In addition to these advantages, nanotechnology reduces the numbers of production processes and thus contributes to the environment by providing resource efficiency.

According to this study, it is determined that concrete, steel, cement, ceramic and glass based nanotechnological building materials provide energy and water efficiency structure. Besides, it was determined that photovoltaic panels produced by using nanotechnology are energy efficient by reducing heat loss due to their high performance in thermal insulation and coating applications.

In this study, it is highlighted that nanotechnological materials provide mechanical resistance, efficiency in energy use, fire resistance, corrosion protection, removal of harmful components, anti-bacterial effect, more efficient heat insulation to respond positively to many environmental effects. However, it is important to determine the negative environmental properties of nanomaterials during production, use, and recycling stages within the framework of the Life Cycle Assessment methodology in terms of obtaining more sustainable nanotech-nological materials.

5. REFERENCES

Say, C. and Wood, A. 2008. Sustainable Rating Systems Around the World, Council on Tall Buildings and Urban Habitat (CTBUH) Journal, P. 2, 18-29.

Feynman, R. 1960. There´ S Plenty of Room at The Bottom (Reprint from The Speech Given at The Annual Meeting of The West Coast Section of The American Physical Society. Eng Sci; 23:22–36.

Taniguchi, N. 1974. On the Basic Concept of Nanotechnology. In: Proceedings of International Conference on Production Engineering Tokyo, Part II, Vol. 2. Japan Society of Precision Engineering. P. 18–23.

Elborombaly, H. 2016. Green Nano Architectural Materials Use in Conservation the Heritage Buildings “As A Raw Material and Energy Saver for Sustainability

Kökdemir Ünşar, E. 2013. Nanopartiküllerin Evsel Arıtma Çamurlarının Anaerobik Parçalanabilirliği Üzerine Etkilerinin Belirlenmesi Yüksek Lisans Tezi

Candemir, B. Beyhan, B. Karaata, S. 2012. İnşaat Sektöründe Sürüdülebilirlik: Yeşil Binalar Ve Nanoteknoloji Stratejileri

Science for Environment Policy IN-DEPTH REPORT 14 2017. Assessing The Environmental Safety of Manufactured Nanomaterials

Elvin, G. 2013 Nanotechnology for Green Building. http://esonn.fr/esonn2010/xlectures/maangematin/Nano_Green_Building55ex. pdf

Tepe, A. 2007. Nanoteknolojide Nano ölçekteki Yapıların Yerel Olmayan Elastisite Çerçevesinde İncelenmesi, Doktora Tezi, İ.T.Ü., Fen Bilimleri Enstitüsü, İstanbul

Özdil, S. 2007. Çelikle sürdürülebilir yapılaşma. Yapı Dergisi Yapıda Ekoloji: Ekolojik Tasarım ve Sürdürülebilirlik Eki, (Kasım), 36-37.

Tokuç, A. 2014. Uyarlanabilir Yapi Kabuklari İle Enerji Etkin Bina Tasarimi

Avcı, G. 2009. İşlevsel Nanokaplamalar, Bilim ve Teknik Dergisi, 497 48-49

Akyol Altun, D., Örgülü, B. 2014. Towards a Different Architecture in Cooperation with Nanotechnology and Genetic Science: New Approaches for the Present and the Future, Architecture Research, 4(1B), 1-12.

Gürer, C., Akbulut, H., Kürklü, G. 2004. İnşaat Endüstrisinde Geri Dönüşüm ve Bir Hammadde Kaynağı Olarak Farklı Yapı Malzemelerinin Yeniden Değerlendirilmesi, 5. Endüstriyel Hammaddeler Sempozyumu, İzmir

Bradley et al. 2010 Nano Risk Analysis: Advancing the Science for Nanomaterials Risk Management

S. Kim et al. 2013. The study of heat transfer for nanofluid with carbon nano particle in an exhaust gas recirculation (EGR) cooler. Heat Mass Transf. 49, 1051–1055

Ibrahim Abdulwahid Arif, 2012. Toxic Effects of Nanomaterials

Sánchez Florence and Sobolev Konstantin. (2010). Nanotechnology in concrete – A review, Construction and Building Materials, 24 (2010), pp. 2060–2071. http://dx.doi.org/10.1016/j.conbuildmat.2010.03.014

Leydecker S. 2008. Nano Materials in Architecture, Interior Architecture and Design, Germany: BirkhauserVerlag AG.

Krishnamoorthy, Sivashankar and Iniewski, Krzysztof. (2016). Nanomaterials: a Guide to Fabrication and Applications, USA: Taylor & Francis Group, LLC.

Lee, J., Mahendra, S. ve Alvarez, P., J., J., Nanomaterials in the Construction Industry: A Review of Their Applications and Environmental Health and Safety Considerations, ACS Nano, 4, 7(2010) 3580-3590.

Niroumand, H., Zain, M.F.M. Jamil, M., 2013. "The Role of Nanotechnology in Architecture and Built Environment", Procedia - Social and Behavioral Sciences, Volume 89, 243-247.

Predicted releases of engineered nanomaterials: from global to regional to local, Arturo A. Keller* and Anastasiya Lazareva, 2013

Nanotechnology: Principles and Practices, Sulabha K. Kulkarn, 2015

Helland A (2004) Nanoparticles: a closer look at the risks to human health and the environment, perceptions and precautionary measures of industry and regulatory bodies in Europe, Master's thesis, IIIEE, Lund University

Kreyling WG, Semmler M, Erbe F, Mayer P, Takenaka S, Schulz H et al (2002) Translocation of ultrafine insoluble iridium particles from lung epithelium to extrapulmonary organs is size dependent but very low. J Toxicol Environ Health A 65(20):1513–1530

Oberdorster G, Sharp Z, Atudorei V, Elder A, Gelein R, Kreyling W et al (2004) Translocation of inhaled ultrafine particles to the brain. Inhalation Toxicol 16(6–7):437–445

Falkner R, Jaspers N (2012) Regulating nanotechnologies: risk, uncertainty and the global governance gap. Glob Environ Politics 12(1):30–55

Baalousha M (2016) Outdoor urban nanomaterials: the emergence of a new, integrated, and critical field of study. Sci Total Environ 557:740–75

Karlsson HL, Gustafsson J, Cronholm P, Möller L (2009) Size-dependent toxicity of metal oxide particles: a comparison between nano-and micrometer size. Toxicol Lett 188(2):112– 118

Reference from Internet

URL1: http://d2hawiim0tjbd8.cloudfront.net/downloads/su_ayak_izi_raporweb.pdf?2720

URL 2: https://www.wwf.org.tr/

URL 3: www.smsenerji.com

URL 4: https://www.nanopartikel.info/en/nanoinfo/cross-cutting/2518-nanomaterials-in-waste

URL 5: http://nano.elcosh.org/, 2016; Nanowerk, 2016