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NEUROSCIENCE FOR UNDERSTANDING AND DEVELOPING SUSTAINABILITY: NEUROSUSTAINABILITY

SÜRDÜRÜLEBİLİRLİĞİ ANLAMAK VE GELİŞTİRMEK İÇİN NÖROBİLİM: NÖROSÜRDÜRÜLEBİLİRLİK

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ABSTRACT

Sustainability is a complex and innovative concept that inherently requires the new ways of thinking constantly for basic biological decision-making processes such as adaptation and collaboration. Neuroscience is a scientific field that investigates the functions and responses of nervous systems and the brain, which are becoming more and more widely used with technological innovations in brain imaging. As an interdisciplinary field neuroscience is especially along with health, engineering, social sciences and art, has led to the emergence of new fields such as neuropsychology, neuroeconomics, neurosociology, neuroinformatics, neuropolitics, neuromarketing, etc. Although a vast majority of neural connections are operated for the continuity of an organism or an organization, unfortunately there have been no extensive studies in sustainability literature that use neuroscience findings, techniques, and approaches. In this context, this study fills this gap with the concept of neurosustainability as a new interdisciplinary field that demonstrates its relationship with neuroscience in the field of sustainability and reveal strategic elements and implications for future research.

Keywords: Sustainability, neuroscience, neurosustainability

JEL Codes: Q01, C63

ÖZET

Sürdürülebilirlik, doğası gereği adaptasyon ve işbirliği gibi temel biyolojik karar alma süreçleri için sürekli yeni düşünme yollarını gerektiren karmaşık ve inovatif bir kavramdır. Nörobilim ise; beyin görüntülemedeki teknolojik yenilikler ile birlikte gün geçtikçe kullanımı yaygınlaşan sinir sistemlerinin ve beynin işlevleri ile tepkilerini araştıran bilimsel bir alandır. Nörobilim özellikle sağlık, mühendislik, sosyal bilimler ve sanat ile birlikte inter disipliner bir alan olarak nöropsikoloji, nöroekonomi, nörososyoloji, nörobilişim, nöropolitika, nöropazarlama vb. yeni alanların ortaya çıkmasını sağlamıştır. Ancak, her ne kadar nöral bağlantıların büyük bir çoğunluğu organizmanın ya da organizasyonun devamlılığı için işletilse de maalesef sürdürülebilirlik literatüründe nörobilim bulgu, teknik ve yaklaşımlarını kullanan araştırmalara rastlanmamıştır. Bu bağlamda bu çalışma, sürdürülebilirlik alanında nörobilim ile karşılıklı ilişkiselliğini ortaya koyan interdisipliner yeni bir alan olarak nörosürdürülebilirlik kavramı ile bu boşluğu doldurmakta ve gelecekteki araştırmalar için stratejik unsurlar ve çıkarımlar ortaya koymaktadır.

Anahtar Kelimeler: Sürdürülebilirlik, sinir bilim, nörosürdürülebilirlik

JEL Kodları: Q01, C63

1. INTRODUCTION AND TERMINOLOGY

Since 1987, the world started to criticize the needs of today generations also with the needs of future generations by the Brundtland Report (WCED, 1987: 39) and sustainability has become a term that increases its importance day by day and takes even a definition, an effort, and importance in many different fields of science. At this point, how and where did awareness and consciousness of sustainability form at the point of thinking and protecting, also the rights of the external clusters of societies? What made people to think other beings instead of selfish todays' choices? What happened on minds then communities started to empathize for whole with ethics and justice?

Neuroscience is a field that analyzes the nervous system to understand the biological basis for behavior (Squire et al., 2008: 3), it is clear that neuroscience will be needed to measure the underlying causes of sustainability and sustainable behavior. At this point, this field starts to be more exciting while making investigations on questions about the location of sustainability awareness, decision-making mechanism and sustainable actions in brain, also the neurological processes they contain.

Basically, the main research question of this paper is; Can an interdisciplinary relationship be established between sustainability science and neuroscience as a new field "neurosustainability"?

In order to examine, understand and develop an interdisciplinary relationship between sustainability and neuroscience, first the definition and issues of sustainability were investigated to establish a framework of sustainable thinking, developing and engineering. Then, a general information about the scope, technologies, branches, and measurements of neuroscience was presented to understand which issues of sustainability can be studied by neuroscience and how these issues can be examined with neuroscience. As a new field a general framework of neurosustainability has been prepared by examining the research on sustainability issues that are studied with methods and technologies of neuroscience.

1.1.Sustainability and Sustainable Development

Although sustainability is the basic aim for a creature from the beginning of life, first definitions were made on first decade of 20th century after economic and ecological crisis and also by the consequences of I-II World War and industrial revolutions. When the terminology searched, in 18th century the word sustainability started to use for preserving nature while harvesting forests only on ecologically view in German word Nachhaltigkeit (Wilderer, 2007: 2). Until 1980s' the word sustainability is mostly used for preserving ecology and economics of ecology.

In 1987, the common and comprehensive definition of sustainability is provided by the World Commission on Environment and Development Report also known as Brundtland Report. By the view of economic development and sustainable economics, sustainability described as an economic and sociology-based activity that *"meets the needs of the present without compromising the ability of future generations to meet their own needs"* (WCED, 1987: 39). Brundtland Reports' sustainability definition indicates that environmental concerns are important, but the basic discussion is one of welfare, seen in a context of inter-generational equity (Kuhlman & Farrington, 2010: 3438) and people protect resources not for environment, for next generations. By the way, the social sustainability starts to take attention and scientist began to investigate the importance of providing 'equity' and 'welfare' in community.

After the first definitions of sustainability were indicated three major dimensions of sustainability, the term has taken its place as an interdisciplinary and complex field of science. European Commission called that a sustainable development triangle formed by 3P's: People, Planet, and Profit/Prosperity (European Commission, 2002). Some communities called the three dynamics of sustainable development as 3E's: Environment, Economy and Equity (Purvis et al., 2019: 690) that also Paehlke called sustainability in the same title of his book as *"Democracy's Dilemma*" (Paehlke, 2004).

At the same time without collecting terms only just one letter, scientist called all pillars or dimensions of sustainability as "environment", "social" and "economy" because social sustainability was not only about equity and economical sustainability did not just cover profits or prosperity as can be seen on Figure 1. Sustainability science contains lots of issues, tools and activities to develop most suitable conditions for all dimensions of sustainability. Sustainability needs to be studied along with all these dimensions.

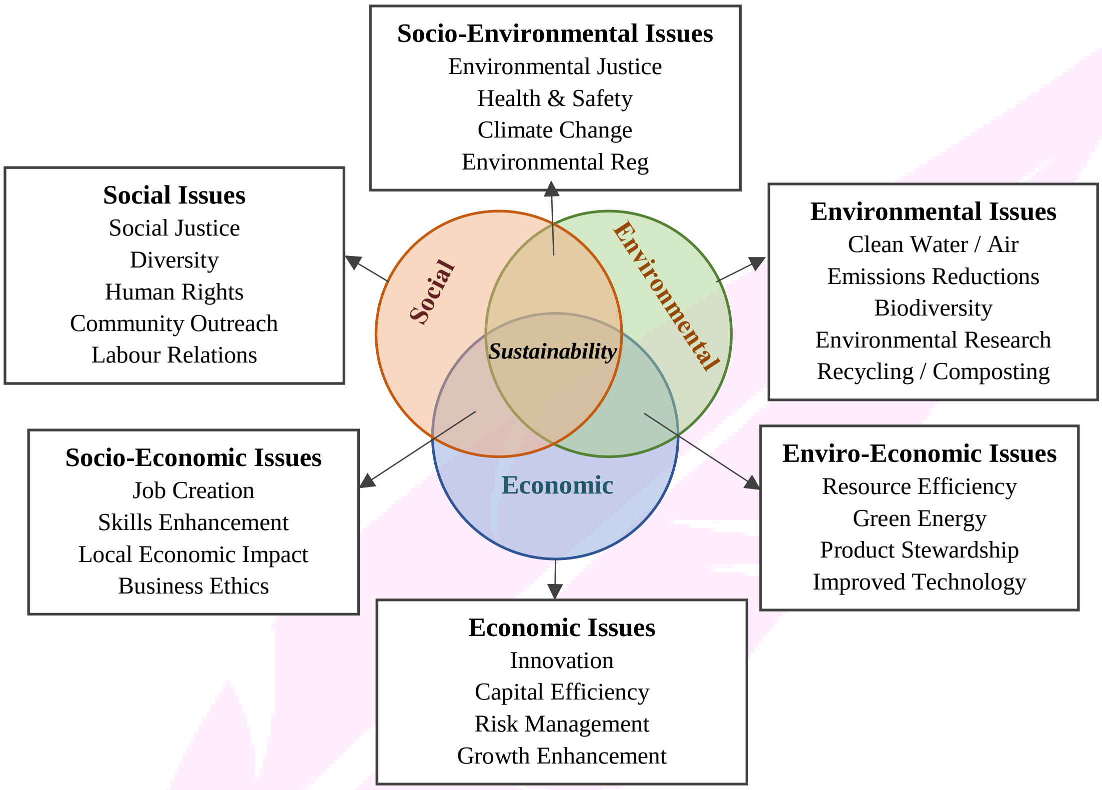

Figure 1. Issues, Tools and Activities of Sustainability (Nijenhuis, 2012: 14)

Awareness of sustainability offers people a good, quality, beautiful and sustained life and living space and it also tries to bring equality, justice, free thought, democracy, respect for differences, and ethics to an understandable and enforceable level in the whole society by preventing from audacity, dictatorship, lawlessness, arrogance, and immorality. Along with these, it aims for the fair distribution and continuity of income for everyone. The mechanisms of all these sustainable conditions listed in the paragraph must be calculated and operated fairly and accurately without putting the interests of one(s) before the interests of other individuals or ecosystems. Therefore, the establishment of a sustainability system and the continuity of its functionality throughout the life of our planet requires serious engineering and innovative thinking.

Indeed, as shown on Figure 1. and definitions indicates that continuing humanitarian activities and development without harming all dimensions of sustainability is a complex field that requires fairly calculated innovative engineering processes for sustainable development. For example, if a human action brings both economic and social benefits, but simultaneously causes long-term ecological harm, it is unfair to refer to this activity as a sustainable action in its long-term living life, which includes the environment and humanity.

Figure 1 shows the issues, tools and activities of all dimensions that needed for sustainable goals. The actual interaction between dimensions of sustainability is shown in Figure 2.

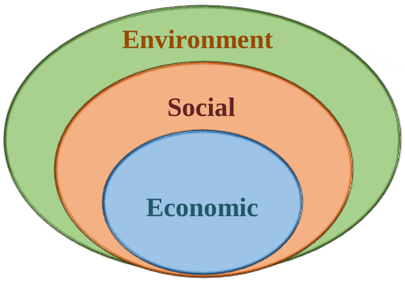

Figure 2. Interaction Between Dimensions of Sustainable Development (Scott Cato, 2009:

An environmental activist Edward Abbey's one of famous quote *"growth for the sake of growth is the ideology of the cancer cell."* is the best definition that emphasize the relationship and integrity between the three dimensions of sustainability that can be seen in Figure 2. The appropriate system is the co-development of each cell. The ecology cell feeds the cell of the social, and the social cell feeds the cell of the economy. Due to ecological crises, the depletion of social systems and subsequent economic collapse is inevitable. Conversely, if a subsystem is supported too much without supporting a parent system, the enlarged cell will break down a parent cell. For example, an economy overinflated by improper production and consumption policies can first break down its social cell and then its ecological cell, just like a cancer cell as Abbey indicated. Another example is that with technologies developed for increased well-being, the overinflated social cell can break down the ecology cell. Consumption of the economy should not be society; the consumption of society should not be ecology. Understanding and developing this dynamic requires a serious innovative thinking, training, and engineering.

"Sustainable development" defined as the practice of maintaining world processes of productivity by replacing resources used with resources of equal or greater value without degrading or endangering natural biotic systems (Kahle & Gürel-Atay, 2014: 50). As Lawn described in 2000, sustainable development is a desirable human goal (Lawn, 2000: 38). Towards 2015, 17 Sustainable Development Goals (SDGs) were adopted by all United Nations Member States, with 169 targets to reach by 2030. These goals and targets are universal, meaning they apply to all countries around the world, not just poor countries (IISD, 2021).

The 17 SDGs are: (1) No Poverty, (2) Zero Hunger, (3) Good Health and Well-being, (4) Quality Education, (5) Gender Equality, (6) Clean Water and Sanitation, (7) Affordable and Clean Energy, (8) Decent Work and Economic Growth, (9) Industry, Innovation and Infrastructure, (10) Reducing Inequality, (11) Sustainable Cities and Communities, (12) Responsible Consumption and Production, (13) Climate Action, (14) Life Below Water, (15) Life On Land, (16) Peace, Justice, and Strong Institutions, (17) Partnerships for the Goals (United Nations, 2021).

Figure 1 and Figure 3 indicates that SDGs are developed to support all the dimensions and aspects of sustainability that evolve sustainability science to an interdisciplinary field. Therefore, it must because each discipline as represented by a community of human practitioners focuses just on the study of a limited aspect of reality within the finite human lifespan. This immediately brings research to the need to coherently bring together the knowledge and unique insights from as many disciplines as possible and a complete study of sustainability must coherently address as many of the relevant aspects as possible (Cabezas, 2012: 3). Actually, sustainability problems can be seen as the one-sided dominance of one worldview at the cost of the others, and their resolution is requiring balance and synthesis (Vries, 2013: 177). *"If we are in harmony with nature, everyone wins"* (Rolsten, 1994: 218).

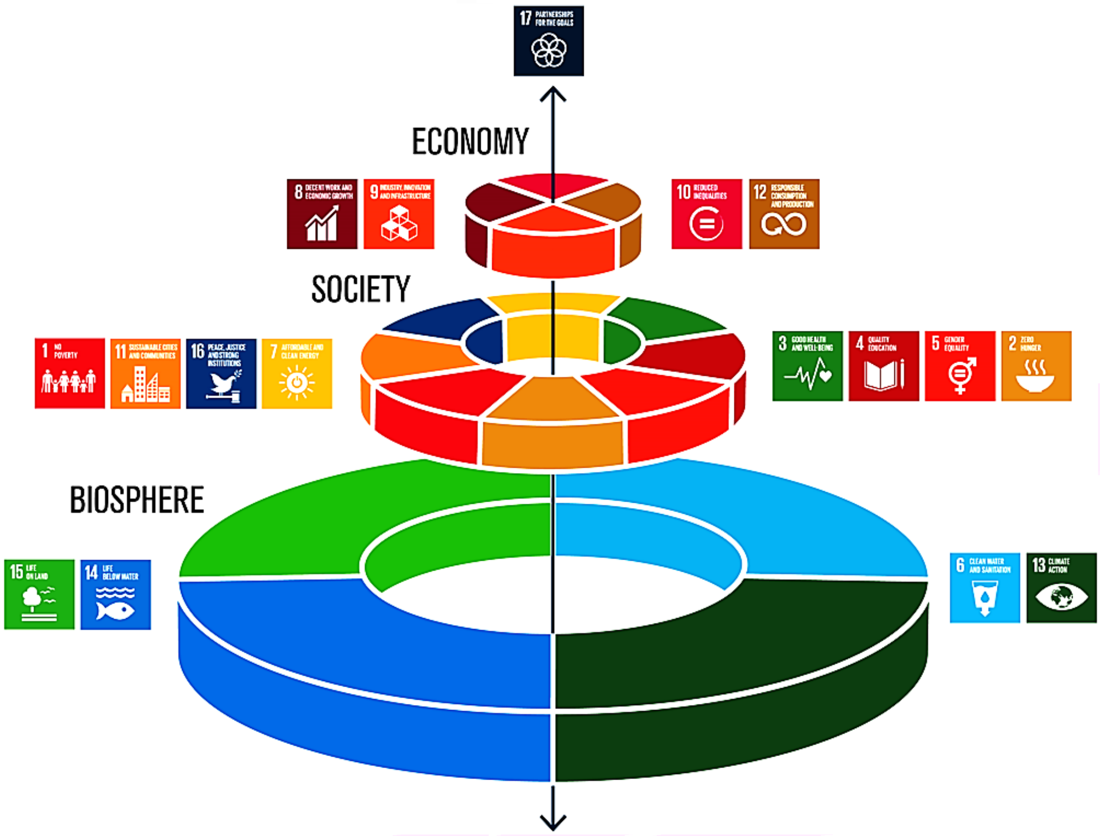

Figure 3. Sustainable Development Goals Pyramid (Institud Für Bildungsmanagement, 2021)

As a result, sustainable development could only happen by simultaneously ensuring ecological, social, and economic sustainability that is intertwined and balanced. The more precise meaning of sustainability, however, depends on contexts and intellectual fields such as ecology, energy, engineering, environment, agriculture, social dynamics and anthropology (Murhy & McDonagh, 2016: 2), population and demographics (Portney, 2015: 53), politics, culture (UNESCO, 2021), justice (Seghezzo, 2009: 549), public actions (Caradonna, 2014: 251), technology and economics as can be verified in Figure 1.

So, what decision-making mechanisms and neurological processes are linked with all these efforts (Figure 1), also SDGs (Figure 3)? How can neuroscience serve to the balance (Figure 2) of these efforts and SDGs?

1.2.Neuroscience and Brain

Neuroscience is multidisciplinary sciences; that analyze the nervous system to understand the biological basis for behavior since the middle of the nineteenth century (Squire et al., 2008: 3). Neuroscience is defined as *"a branch (such as neurophysiology) of the life sciences that deals with the anatomy, physiology, biochemistry, or molecular biology of nerves and nervous tissue and especially with their relation to behavior and learning"* (Merriam-Webster, 2021). Neuroscience studies "why do people do what they do, and how does the brain carry out these tasks?".

In the last three decades, scientist take lots of answers by the developing brain stimulation and brain imaging (neuroimaging) technologies in neuroscientific practice (Boer, et al., 2020: 503). Functional brain imaging offers the ability to examine a person's brain while that individual engages in a psychological activity of interest (Gonzalez & Berman, 2010: 111). Many brain imaging tools are available; including positron emission tomography (PET), near infrared spectroscopy (NIRS), magnetoencephalogram (MEG), electroencephalography (EEG), and functional magnetic resonance imaging (fMRI) for cognitive neuroscientists (Xue et al., 2010: 120), to understand the neurological processes such as decision-making, memory, flight or fight reaction and etc.

In decision making, a number of cognitive processes come into play, among them the processing of the stimuli present in the task, the memory of previous experiences and the estimating of the possible outcomes of each option (Martínez-Selva et al., 2006: 411). It is known that the decision-making process results from communication between the prefrontal cortex (working memory) and hippocampus (long-term memory) but there are other regions of the brain that play essential roles in making decisions, but their exact mechanisms of action still are unknown (Moghadam et al., 2019: 443). Also, decision-making processes for a sustainable choice cannot be understand.

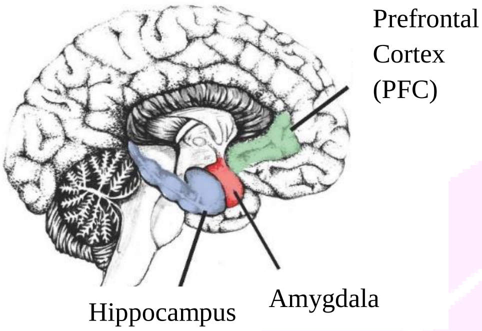

Figure 4. Human Brain Anatomy Correlate with Stress, Decision-Making, and Memory (Bell, 2021: 16)

Of particular relevance to enlightening the dynamics of sustainability in brain are recent findings within the realms of memory, perception and decision-making (Fleming et al. , 2012: 6123). That are correlated with the brain parts; prefrontal cortex (PFC), amygdala and hippocampus as can be seen on Figure 4. These decision-making processes often result in a new behavior or behavior change. Behavioral change processes are motives, self-regulation, resources, habits, and environmental/social influences especially for promoting voluntary behavior change in environmental psychology (Bamberg & Schulte, 2019: 330) also in all dimensions of sustainability.

Branch	*Description*
Affective neuroscience	*the study of the basic emotions, typically through experimentation on animal models; is about "feelings"*
Behavioral neuroscience	*the application of the principles of biology to the study of genetic, physiological, and developmental mechanisms of behavior in humans and non-human animals.*
Cellular neuroscience	*study of neurons at a cellular level including morphology and physiological properties.*
Clinical neuroscience	*examines the disorders within the nervous system*
Cognitive neuroscience	*the study of cognitive processes and their implementation in the brain*
Computational neuroscience	*theoretical study of the nervous system.*
Consumer Neuroscience	*also called* **neuromarketing;** *study of commercial marketing communication field that applies neuropsychology to market research, studying consumers' sensorimotor, cognitive, and affective response to marketing stimuli.*
Cultural neuroscience	*study of how cultural values, practices and beliefs shape and are shaped by the mind, brain and genes across multiple timescales.*

Developmental neuroscience	*studies the processes that generate, shape, and reshape the nervous system and seeks to describe the cellular basis of neural development*
Education Neuroscience	*primarily information about learning grounded in laboratory research; neuroscience informs education*
Evolutionary neuroscience	*studies the evolution of nervous systems.*
Molecular neuroscience	*studies the nervous system with molecular biology, molecular genetics, protein chemistry, and related methodologies.*
Neural engineering	*uses engineering techniques to interact with, understand, repair, replace, or enhance neural systems.*
Neurochemistry	*the study of how neurochemicals interact and influence the function of neurons.*
Neuroeconomics	*studies of the brain during "decision making".*
Neurogenetics	*the study of the genetical basis of the development and function of the nervous system.*
Neuroimaging	*the use of various techniques to either directly or indirectly image the structure and function of the brain.*
Neuroinformatics	*a discipline within bioinformatics that conducts the organization of neuroscience data; application of computational models and analytical tools and the study of neuroscience with information science/technology and deals with the creation of the data systems that will be required to achieve such integration.*
Neurolinguistics	*the study of the neural mechanisms in the human brain that control the comprehension, production, and acquisition of language.*
Neuroplasticity	*studies on the ability of neural networks in the brain to change through growth and reorganization; a fundamental mechanism of neuronal adaptation*
Neuropolitics	*the study which investigates the interplay between the brain and politics. It combines work from a variety of scientific fields which includes neuroscience, political science, psychology, behavioral genetics, primatology, and ethology.*
Neuropsychiatry	*psychiatry relating mental or emotional disturbance to disordered brain function.*
Neuropsychology	*is a discipline that resides under the umbrellas of both psychology and neuroscience, and is involved in activities in the arenas of both basic science and applied science*
Neurosurgery	*the study of the surgical treatment of neurological disease*
Paleoneurobiology	*a field which combines techniques used in paleontology and archeology to study brain evolution, especially that of the human brain.*
Social neuroscience	*also called as* ***"neurosociology"*** *is an interdisciplinary field devoted to understanding how biological systems implement social processes and behavior, and to using biological concepts and methods to inform and refine theories of social processes and behavior.*

Table 1. The Major Branches of Neuroscience (Wikipedia, 2021; Squire et al., 2008; Medical News, 2021; Akil, et al., 2016; Pittenger & Duman, 2008; Jaak, 1990; Bjaalie, 2018)

In brief, neuroscience; is a scientific field that investigates the functions and responses of nervous systems and the brain, which are becoming more and more widely used with technological innovations in brain imaging. There are several branches that study with neuroscience, these branches also can be seen on Table 1. These branches also have inter-relationship with each other while working on a specific field. As an interdisciplinary field neuroscience is especially along with health, engineering, social sciences and art, that it has led to the emergence of new fields such as neuropsychology, neuroeconomics, neurosociology, neuroinformatics, neuropolitics, neuromarketing, etc. described in Table 1.

But as told before in this study, there are very few studies in a very limited area of the sustainability studied with neuroscience. So how can neuroscience efforts contribute to the understanding and development of sustainability?

2. NEUROSCIENCE OF SUSTAINABILITY: NEUROSUSTAINABILITY

Sustainability is a complex and innovative concept that inherently requires the new ways of thinking constantly for basic biological decision-making processes such as adaptation and collaboration. Not just only for living species, these decision-making processes are nearly similar with continuity of an organization or a community at all. Also, Scoon and Cox emphasized the importance of adaptation, collaboration, and scale for environmental governance of sustainability (Schoon & Cox, 2018: 679). All organisms, organizations, also communities need the skills of adaptation on changing conditions, and the capability of collaboration to get and share of the information that ensure continuity of their existence for today and future lifetime.

Moreover, sustainability is an empathic level of consciousness that creates a holistic benefit to society together with the ecosystem, also cares about its needs in future generations, rather than a selfish or a personal interest. For a balance that can be seen on Figure 2, sustainability science needs to understand the perception and position of sustainable conditions and ethics in nervous system by neuroscience, along with the decision-making processes that empathizes the best for continuity of all system instead of a selfish choice.

The main research question of this paper "Can an interdisciplinary relationship be established between sustainability science and neuroscience as a new field?" calls new studies for the answers to several sub-questions of neurosustainability:

- Can biological processes, mental processes, neural networks and chemistry be studied that motivate people to choose and produce what is more ethical and sustainable instead of selfish one?

- Can scientists benefit from neuroscience, neuroplasticity and artificial intelligence to develop sustainability science, sustainable education, sustainable design, sustainable engineering and innovations without damaging the harmony of sustainability dimensions that shown in Figure 2?

- Can the interaction of sustainable environment, sustainable methods-practices (Figure 1) and SDGs (Figure 3) with the human brain; also, their contribution to human development, creativity and productivity be determined by neuroscience?

Although a vast majority of neural connections are operated for the continuity of an organism or an organization, unfortunately there have been no extensive studies in sustainability literature that use neuroscience findings, techniques, and approaches. In order to find answers to these questions and establishing a general framework, sustainability-related issues were examined separately by research that use neuroscience technologies.

There have been studies in the field of environmental neuroscience (Berman, et al., 2015; Zheng, et al., 2017; Wolfe & Lindeborg, 2018; Berman, et al., 2019; Berman, et al., 2019; Madan, et al., 2020; Keifer & Summers, 2021) that are mostly investigated by dear researcher Marc G. Berman but mostly indicate on the effects of environment, architecture, and urbanization.

Several studies have examined the effects of neuroscience in sustainable design in engineering science (Hu, 2017; Aoki, et al., 2020). Some studies examine sustainability management in organization with neuroscience (Shahand, et al., 2015; McDonald, 2018).

But most studies indicates the effects of sustainability oriented marketing (includes green advertisements) to purchase and perception of green products; named as "consumer neuroscience" or "neuromarketing" (De Oliveira, 2014; Walla, et al., 2014; Oliveira, et al., 2014; Vezich, et al., 2017; Pozharliev, et al., 2017; Magdalena, 2019; Balconi, et al., 2019; Constantinescu, et al., 2019; Romanelli & Ionescu, 2019; Folwarczny, et al., 2019; Zhao, 2019; Sánchez-Fernández & Casado-Aranda, 2020; Pagan, et al., 2020; Varlese, et al., 2020; Nilashi, et al., 2020; Quevedo, et al., 2020; Anuar, et al., 2021). These studies are trying to understand the customer behavior for sustainability and green marketing.

When the results of these studies are evaluated for the main question, it is clear that an interdisciplinary relationship can be established between all dimensions, issues and efforts of sustainability science (Figure 1) and neuroscience by using major branches as can be seen in Table 1, as a new field. As a result, thesis of this research reveals many strategic elements and inferences by making multidimensional assumptions on a new field that investigates neuroscience of sustainability, named in this study as "neurosustainability".

Neurosustainability is a new field that try to clarify the effects and perceptions of sustainable conditions on brain and try to examine the neurological processes for the action of sustainable oriented thinking, sustainable design, sustainable innovation, also sustainability education with the all dimensions - ecological, social and economic- of sustainability. Inspiringly, this paper expects studies from the field of neurosustainability that examine a three-way correlation between neuroscience and sustainability by research scopes and research questions listed below:

1. Understanding of the biological processes, neural networks and chemistry that are involved in the adoption of sustainable habits and thinking, acting, communicating, and educating on sustainability:

- Where the perception of sustainability and ethics locate in brain?
- What motivates people to choose sustainability and ethics?
- What makes people to choose unsustainable, unethical, unfair or a selfish choice?
- How are people motivated for sustainable innovation and green engineering?
- What makes people to choose peace and collaboration instead of war and disunity?

2. Contributes of neuroscience, artificial intelligence (AI)[1] and neuroplasticity[2] to develop sustainability by the knowledge of neural context:

- How neuroscience, AI, and neuroplasticity help people to gain sustainable habits, sustainable-oriented acting, developing, learning, and collaborating with each other?
- Can neuroscience, AI, and neuroplasticity help people to abandon the unsustainable ones?

[1] Artificial intelligence (AI) enables machines to learn from experiences, adapt to new inputs, and perform human-like tasks - from computers playing chess to self-driving cars – and rely heavily on deep learning and natural language processing. Also with these technologies, computers can be trained to perform specific tasks by processing large amounts of data and recognizing patterns in the data (SAS Insights, 2021).

[2] Neuroplasticity is a continuous process that optimizes the functioning of neural networks during phylogenesis, ontogeni and physiological learning and provides short-term, medium-term and long-term reshaping of neuronosinoptic organization after brain damage (Duffau, 2016: 225)

3. Effects of sustainable or unsustainable conditions on brain development, creativity, and productivity:

- How sustainable conditions including 17 SDGs (clean energy, gender equity, peace, urban sustainability, or welfare, etc.) effect human brain?
- How unsustainable conditions (environmental pollution, undemocratic management, income distribution inequality, war, etc.) effect human brain?
- What is the importance and role of sustainability on human development?

In this context, this research fills this gap with a new concept called "neurosustainability" as a new interdisciplinary field that demonstrates its relationship with neuroscience in the field of sustainability and reveal strategic elements and implications for future research.

3. RESEARCH MATERIALS AND METHODS

Research method of this study is literature review. In order to interrelate two field – neuroscience and sustainability – content analysis is used.

First, five scientific databases - PubMed, ScienceDirect, EBSCOhost, JSTOR and NCBI- were searched for peer-reviewed studies published in all years up to May 1, 2021.

Primarily key words "neuroscience and sustainability" related resources were scanned together. Due to the limited number of results, "sustainability" and "neuroscience" topics in the literature were examined and the correlation of sustainability with other major neuroscience branches has been studied separately.

Also, the major branches selected due to the considered relations of sustainability. These branches are environmental neuroscience, neuropolitics, neurosociology, neuromarketing. These studies cognitive processes of green thinking tried to determine. Since the research did not have enough data to examine, other online and printed resources have been scanned. All recommendations have been made for future studies by subtracting relationship between sustainability and neuroscience.

- Limitations of methodology in this research: Due to the fact that the research question has not been studied before, no meaningful number of studies and data required for meta-analysis have been found.

4. RESULTS

The literature on sustainability is examined but extensive research using neuroscience findings, techniques and approaches is not found. Then, the issues of sustainability searched separately to find the studies that used neuroscience, but still not extensive research has found.

The major branches are selected due to the relationship with sustainability and there are 7 studies found which investigates "environmental neuroscience"; 2 studies are determined that use neuroscience on sustainable or green engineering; 2 studies are found that investigates the organization of sustainability with neuroscience; and, 17 studies are examined sustainability with neuromarketing to find the effects and perception of sustainability oriented marketing (includes green advertisements) to purchase and perception of green products.

This study determined the neuroimaging technologies and scales that are applied on selected fields as can be seen on Table 2. Although all studies were examined until 2021 without entering the date range, it was determined that the studies started to be carried out from 2010. It has been observed that all studies that can be a framework for neurosustainability have emerged in the last 10 years. Environmental neuroscience field use mainly fMRI, EEG and MEG neuroimaging technologies. In neuromarketing publications, it is clear that these studies prefer EEG, MEG and eye tracking. The papers in which the sustainable engineering and organization are studied with fMRI commonly.

# of Studies	Field of Studies	Neuroimaging Technology	Content	Scale/Metrics
7	Environmental Neuroscience (2015-…)	fMRI functional magnetic resonance imaging; MEG magnetoencephalography; EEG electroencephalography; PET positron emission tomography; fMRS functional magnetic resonance spectroscopy; fNIRS functional near-infrared spectroscopy.	these studies indicate on the effects of environment, environmental education, architecture, and urbanization.	The spatial and temporal scales of environmental neuroscience (ENS). Inclusion of Nature in Self (INS) scale
2	Sustainable Engineering (2017-…)	fMRI functional magnetic resonance imaging; fNIRS functional near-infrared spectroscopy.	the effects of neuroscience in sustainable design in engineering science.	Systems Thinking Scale Revised (STRS) Analysis-Holism Scale (AHS)
2	Sustainable Organization (2015-…)	fMRI functional magnetic resonance imaging; DTI Diffusion tensor imaging	sustainability management in organization with cognitive neuroscience.	Business Model Canvas (BMC) AMC computational NeuroScience Gateway (AMC-NSG)
17	Consumer Neuroscience (2014-…)	fMRI functional magnetic resonance imaging; EEG electroencephalography; MEG magnetoencephalography; eye tracking; face coding; voice recognition; ECG electrocardiography; VR visual virtual reality	the effects of sustainability-oriented marketing (includes green advertisements) to purchase and perception of green products	Statistical Parametric Mapping (SPM8) Self-Assessment Manikin (SAM) Technology Acceptance Model (TAM) Osgood scale Area of interest (AOI) Event-related potential (ERP)

Table 2. Major Branches of Neuroscience

Although these studies used common neuroimaging techniques, this study determined that they use different methods and scales/metrics to analyze the results changing for the filed. These scales shown on the third column also can give an information to develop a scale for neurosustainability studies.

5. DISCUSSION AND FUTURE WORK

This paper frames the concept of sustainability as an adaptation and collaboration between past, today and future; with the stress capability and adaptation memory of *past*, requires the consciousness for understanding, calculating and empathize of expectations and needs of future generations by taking an innovative action from *today*, also motivate and educate them for sustaining all life on earth for *future*.

When the literature of neuroscience is examined, it is clearly understood that sustainability science can benefit from neuroscience. This study determined that each research can provide information including suggestions on how the metrics related to the cognitive processes of sustainability by neurosustainability can be. This research also determined that in these studies commonly used neuroimaging techniques are fMRI, EEG, MEG, and eye-tracking. These neuroimaging technologies will also utilize for neurosustainability research in future. Furthermore, these studies indicate basic parts of the brain such as the amygdala, hippocampus, and PFC. In sustainable thinking, the main processes are based on adaptation and collaboration, and these processes are based on the basic neurological processes, especially basic parts of the brain such as the amygdala, hippocampus, and PFC. Also, these brain parts are expected to interest the field of neurosustainability.

When the branches of neuroscience are examined to study neuroscience of sustainability these studies shows that the branches of cognitive neuroscience, behavioral neuroscience, computational neuroscience, cultural neuroscience, affective neuroscience, social neuroscience, neuroeconomics, neuropsychology are necessary in terms of meeting sustainability in all its ecological, social, and economic dimensions. Also, other neuroscience branches can be including by neuroscientists and research of sustainability science as an emerging field that “probes interactions between global, social, and human systems, the complex mechanisms that lead to degradation of these systems, and concomitant risks to human well-being” (Sustainability Science, 2021). By using neuroscience techniques, the concept of sustainability can be better understood and disseminated in all dimensions on field with new innovations. In addition, the effects of an ecologically, socially, and economically sustainable environment on neurological processes in human brain can be examined.

In conclusion, neurosustainability tries to fill the gap in sustainability science to understand sustainable thinking, sustainability action and sustainable learning in neurological process with neuroscience. Indeed, the field contains lots of new research area, summarized as:

- Define the effects of sustainable conditions (also the SDGs on Figure 2) on brain by neuroscience. For example:

  the effects of organizational gender equality/inequality on conscious brain development which points cerebral cortex and the productivity of an individual…
  the effects of sustainable/unsustainable cities and communities on brain health…
  the effects of equal opportunities in education on student motivation level…

- To define the PFC neural processes and networks relates with limbic system, hippocampus and amygdala in decision-making processes for the option, which is sustainable, ethic or humanistic one, instead of unsustainable or selfish one.

- Combine social and engineering sciences with sustainability by using artificial intelligence and neuroplasticity by using neuroscience technologies for sustainable oriented thinking, sustainable design, sustainable innovation, and sustainability education.

- To find the best way to communicate and collaborate for sustainability conditions.

- Understanding Society 5.0 (super smart society) dynamics that is related with social and sustainable innovations, with the approach of human development and anthropology by using neuroscience.

5.1. Avenues for future research

Studies from field of neuroscience indicate the sustainability learning and sustainable actions of community and organizations can be supported by neuroscience techniques, neuroplasticity, and artificial intelligence. But because of the need of developing an artificial neural network architecture, the neural processes of sustainability must be revealed. In order to understand the neural processes of sustainability, this research indicates that neuroscience is necessary.

- Consequences of this studies shows that the neuroimaging technologies fMRI, EEG, MEG and eye-tracking can also utilize in neurosustainability research.
- These studies also point out especially basic parts of the brain such as the amygdala, hippocampus, and PFC (Prefrontal Cortex).
- When the scales/metrics are determined for neurosustainability, the spatial and temporal scales of environmental neuroscience (ENS) and Inclusion of Nature in Self (INS) scale are important to put the effects of sustainability and human brain interaction but does not give the information of decision-making processes in sustainable thinking, acting, learning and engineering and also ethics.
- Furthermore, cognitive neuroscience, sustainability anthropology, sustainability biology, human development, brain development, neuroplasticity, decision-making processes, behavioral changes must be worked together with the field and major indicators of sustainability, also including SDGs.
- In addition, the effects of sustainability to neurological and biological development in humans should be revealed.

5.2. Limitations of field

The limits for further studies on neurosustainability are as follows:

- Identifying neural connections related to sustainability as a whole, is still difficult in today's neuroscience technologies. For example: the blockage of amygdala cannot be understood for smoke while the person knows the consequences of smoking. It cannot be understood that sometimes humans they sense that they are being forced to change their behavior, they build up strong resistance (Schwartz, et al., 2021).
- Since the decision-making mechanisms and behavioral changes on brain cannot be fully defined, it is difficult to explain the neural activity that drives the organism's orientation to what is sustainable.
- There is no research on neuroplasticity or artificial intelligence that promote PFC for sustainable thinking, acting and learning. Deep neural network[3] architectures that simulating the PFC, hippocampus and amygdala are still tried to be explained and developed. This study thinks artificial intelligence and deep learning is important for development of sustainability education on individuals, and also communities.
- The difference on individual and collective results in studies on cognitive neuroscience; findings and reality. People usually give different reactions and choose different choices in neuroscience laboratory (findings) and in public (reality).

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[3] For machine learning algorithms, artificial Intelligence (AI) needs for neural networks which is a technology that built to simulate the activity of the human brain of pattern recognition and the passage of input through various layers of simulated neural connections. A deep neural network is a neural network with a certain level of complexity with more than two layers and each layer contains sophisticated mathematical modeling of deep learning (Techopedia, 2018) that is used to mimic the human brain in processing data (Great Learning, 2021) and its architecture is applied to fields including medical image analysis, machine translation, bioinformatics, speech recognition, social network filtering, computer vision, audio recognition drug design, natural language processing, and etc. (Galphade, et al., 2021)

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