Research & Design

Volume 2 Issue 2
December 2025

ISSN: 3062-1798

MIM Research & Publishing

Research & Design (REDE) is a multidisciplinary, peer-reviewed, open-access journal committed to bridging the gap between research and design. Inspired by the fundamental problem-solving mechanisms of science, REDE fosters innovation by publishing studies that connect theoretical exploration with practical applications. Our mission is to advance knowledge and provide a platform where research-driven solutions meet real-world challenges.

Supported by the MIM Research Group, **REDE offers a free and open-access publication model**, ensuring that all published articles are freely available to the global research community. Authors are not required to pay any fees, reflecting the journal's dedication to inclusivity and equitable knowledge dissemination.

The journal welcomes contributions from diverse disciplines, emphasizing the interconnectedness of research and design across various fields. Original research articles, reviews, technical notes, and short communications that address complex societal issues are encouraged. Each submission undergoes a rigorous peer-review process to ensure academic excellence and impact.

REDE covers a wide array of fields, reflecting its commitment to multidisciplinary collaboration. From traditional engineering disciplines to contemporary topics like gamification and data science, the journal provides a home for innovative studies that address modern challenges.

We invite you to explore our diverse content and contribute to advancing research and design in your field.

The topics covered in REDE include:

- Aesthetics
- Built Environment
- Economics and Finance
- Social Sciences
- Engineering Sciences
- Data Science
- Game & Gamification
- Industrial Design
- Interface Design

Abstracting and Indexing
Please visit http://www.jrede.org/ for more information.

The journal of

RESEARCH & DESIGN

Volume 2 Issue 2

Research Group

Research Group
Research & Design
www.jrede.org

Editorial Board

Research & Design
www.jrede.org

Editorial Board Members

2025 Advisory Board Members

Research & Design
www.jrede.org

In This Issue

Research & Design
MIM Research Group Publications

http://www.jrede.org/

Research & Design
www.jrede.org

Research Article

Concrete paradox: Economic importance, environmental impacts, and the sustainability of concrete material

Hayri Baytan Ozmen*[a], Barış Tanrıverdi[b]

Department of Civil Engineering, Faculty of Engineering and Natural Sciences, Uşak University, Uşak, Türkiye

Article Info

Article History:

Received:

1 Aug 2025

Accepted:

10 Sept 2025

Keywords:

Alternative materials,
Carbon emissions,
Cement,
Concrete sustainability,
Infrastructure economics,
Life-cycle assessment

Abstract

Concrete is the most consumed man-made material on Earth, with global production exceeding 30 billion metric tons annually. This article critically examines the economic significance, functional advantages, environmental costs, and sustainability strategies surrounding concrete. While the concrete industry generates over USD 500 billion in annual revenue and supports 13+ million jobs, it is also responsible for approximately 7–8% of global CO_2 emissions, largely due to the cement production process. The paper evaluates the historical trajectory of concrete, assesses technological innovations such as supplementary cementitious materials, carbon capture, and geopolymer binders, and reviews the feasibility of alternative materials like engineered timber, rammed earth, and bamboo. a life-cycle and function-based comparative assessment is presented to determine when concrete use is economically and structurally justified and when substitution or reduction is environmentally preferable. The article concludes with policy recommendations to align concrete use with global climate targets, emphasizing a function-driven, lifecycle-conscious approach to material selection. The article also concludes that concrete is not inherently unsustainable, but it must be used strategically and responsibly, as the sustainability of future generations will be affected by the material choices we make today.

1. Introduction: The Concrete Paradox

Concrete stands as one of the most transformative materials in the history of human civilization. Its invention and widespread adoption have fundamentally reshaped the built environment, facilitating the construction of infrastructure, housing, and industrial facilities on an unprecedented scale. As of today, concrete is the second most consumed substance on Earth after water, with an estimated 30 billion metric tons produced globally each year [1]. Its universality is unmatched—concrete forms the foundation of urbanization, supports national economies, and sustains vital public services. Yet, this very necessity conceals a deep paradox: while concrete has become a cornerstone of modern development, it concurrently poses one of the most significant threats to environmental sustainability.

The dual nature of concrete's global presence—its economic necessity and its environmental burden—constitutes what may be termed the "concrete paradox." On one hand, it provides economic value by creating jobs, enabling mobility through roads and bridges, and facilitating social welfare through hospitals, schools, and housing. On the other, its production is highly carbon-intensive, accounting for approximately 7-8% of global CO_2 emissions, primarily due to the calcination process involved in cement

*Corresponding author: baytan.ozmen@usak.edu.tr
[a]orcid.org/0000-0001-6750-8632, [b]orcid.org/0000-0003-0557-0099
DOI: http://dx.doi.org/10.17515/rede2025-008en0801rs

manufacturing [2, 3]. The extraction of raw materials such as limestone, sand, and aggregates leads to ecosystem degradation, while the energy demands of production further intensify environmental pressure.

This paper seeks to interrogate this paradox by evaluating concrete not merely as a material, but as a socio-economic and ecological phenomenon. The analysis explores the historical trajectory of concrete's adoption, trace the economic logic underpinning its dominance, assess its functional strengths and technical limitations, and examine its environmental impacts. The article studies whether the continued large-scale production and use of concrete remains justifiable in an era defined by climate change and resource shortage. It considers emerging technologies, alternative materials, and policy interventions that might reconcile concrete's economic benefits with the constraints of sustainability.

Concrete's widespread use is not a product of inertia alone; it is driven by performance, availability, and cost-effectiveness. Yet, the sustainability crisis demands that we re-evaluate this legacy material's role in shaping the future. The goal of this paper is not to dismiss concrete outright, but to inspect the conditions under which its use remains viable and responsible. As such, the central research question: Is concrete still worth producing and using at the current global scale, given its economic utility and environmental costs? Addressing this question requires a multi-dimensional exploration that considers not just the material properties of concrete, but also its entanglement with economic systems, technological trajectories, and environmental thresholds.

2. Historical Evolution and Global Trends

The history of concrete is closely tied to the progression of human civilization, from ancient construction techniques to modern industrialized economies. While basic forms of concrete—mixtures of lime, volcanic ash, and aggregates—were used by the Egyptians, Greeks, and Romans, it was the development of Portland cement in the early 19th century that marked a turning point in the material's technological evolution and global spread. Patented by Joseph Aspdin in 1824, Portland cement became the cornerstone of modern concrete, offering improved strength, durability, and stability. This invention laid the groundwork for what would become the most widely used construction material in the world [4].

The 20th century witnessed a rapid acceleration in concrete usage, particularly after World War II, when the reconstruction of war-torn Europe and the expansion of suburban infrastructure in North America drove massive demand. The post-war economic boom saw concrete as a facilitator of rapid urbanization, industrial expansion, and infrastructural connectivity. In the 1970s and 1980s, concrete continued to be the material of choice for large-scale public works, including highways, dams, airports, and housing estates. During this period, industrialized nations dominated both the production and consumption of concrete.

However, the past two decades have marked a geographic and economic transformation in global concrete trends. With industrialization shifting toward the Global South, particularly Asia, concrete production and consumption have surged in developing economies. China, in particular, has dramatically altered the global concrete landscape. In 2020 and 2021 alone, China consumed more cement than the United States did in the entire 20th century [5]. This explosion in demand has been driven by aggressive urbanization policies, mega infrastructure projects, and an expanding real estate market. Other emerging economies such as India, Indonesia, Brazil, and Nigeria have followed suit, further reinforcing the centrality of concrete to modern economic development.

Global cement production—the primary binder in concrete—has followed this trend, rising from approximately 1.5 billion tons in 2000 to over 4.3 billion tons in 2021 [6]. This increase reflects not only population growth and urban expansion but also the material's cost-effectiveness and adaptability. At present, over 60% of cement production occurs in Asia, with China alone accounting for more than half of the total output [7].

In parallel to this growth, several new trends have emerged. First, the shift from manual to mechanized and automated production has improved output efficiency but raised questions about energy consumption and emissions. Second, precast and modular concrete technologies have gained prominence, particularly in high-density urban developments. Third, the emergence of "green" concrete and low-carbon cement technologies reflects the mounting pressure to reconcile concrete's economic benefits with climate necessities. Despite these innovations, global demand continues to climb. Forecasts estimate that total concrete production could reach 20 billion cubic meters annually by 2050, especially as emerging economies pursue infrastructure-driven growth strategies [1].

Importantly, this rising demand has been accompanied by growing criticisms. While concrete remains central to development agendas, its high environmental cost has fueled debates around sustainable alternatives and lifecycle emissions. In response, regulatory frameworks—particularly in the European Union, Japan, and parts of North America—have started to incorporate environmental performance metrics into building codes and procurement policies. Simultaneously, multilateral organizations such as the United Nations Environment Programme (UNEP) and the Global Cement and Concrete Association (GCCA) have begun issuing decarbonization roadmaps for the industry[8].

The historical trajectory of concrete is one of technological ingenuity, global expansion, and profound economic impact. Yet, as this trajectory converges with the realities of climate change and finite natural resources, it becomes crucial to contextualize concrete within a broader socio-environmental framework. Understanding how and why concrete became the material of choice globally provides the necessary background for evaluating its contemporary challenges and future viability.

3. Economic Value of Concrete

Concrete plays a pivotal role in the global economy, both as a direct contributor to gross domestic product (GDP) and as an enabler of broader economic development. Its significance extends across multiple sectors, including construction, transportation, energy, and manufacturing. The concrete industry—comprising cement production, concrete mixing, transportation, and construction services—generates an estimated USD 500 billion in annual revenue worldwide [9, 10]. Its economic value is not merely derived from volume, but from its foundational role in facilitating the physical infrastructure that underpins modern economies.

3.1 Direct and Indirect Employment

The concrete sector is a major source of employment. It is estimated that over 13 million people globally are directly employed in cement and concrete manufacturing, with tens of millions more in ancillary services such as logistics, construction, mining, and machinery [11]. In regions with growing infrastructure demands—particularly South Asia, Sub-Saharan Africa, and Southeast Asia—the labor-intensive nature of construction offers essential employment opportunities, especially for low-skilled and semi-skilled workers. Furthermore, the presence of concrete production facilities often stimulates local economies through demand for aggregate materials, transportation, and engineering services.

3.2 Enabler of Infrastructure and Economic Development

Concrete is essential to public and private infrastructure. Roads, highways, ports, airports, water systems, schools, hospitals, and energy plants are overwhelmingly built using concrete due to its structural strength, cost-efficiency, and durability. This makes concrete a keystone input in national development plans and international aid programs. The World Bank and regional development banks often link infrastructure investment directly to economic growth, where concrete is the material of choice due to its availability and affordability [12, 13].

For example, studies have shown that every dollar invested in infrastructure yields approximately $1.30 to $1.60 in GDP growth in developing countries, and concrete is a critical enabler of that return [14]. Mega-projects such as China’s Belt and Road Initiative, India’s Smart Cities Mission, and Africa’s Programme for Infrastructure Development all rely extensively on concrete-based construction, highlighting its centrality in large-scale economic planning.

3.3 Local Production, Supply Chain, and Economic Resilience

One of concrete's underappreciated economic strengths is its local production model. Unlike steel or polymers that often rely on globally distributed raw materials and centralized manufacturing, concrete is produced close to where it is used. Cement plants and batching facilities are typically located within a 100 km radius of major construction zones, reducing transport costs and fostering regional self-sufficiency [2]. This decentralization supports local quarries, small businesses, and municipal economies.

Moreover, this localized model enhances economic resilience by insulating construction industries from global supply chain disruptions. During the COVID-19 pandemic, while international shipping of manufactured goods was severely constrained, many concrete supply chains remained relatively stable due to their local sourcing and distribution networks [15].

3.4 Economic Multiplier Effect

The economic influence of concrete extends through multiplier effects. Concrete-intensive construction projects often generate upward and downstream economic activities, from equipment manufacturing and building services to real estate and finance. In high-income countries, infrastructure renewal—including the maintenance of bridges, tunnels, and buildings—continues to be a significant economic stimulus tool. In low- and middle-income economies, new construction creates demand-side momentum, catalyzing urban growth and real estate development.

Additionally, the financialization of concrete-related sectors—such as infrastructure investment funds, public-private partnerships (PPPs), and real estate investment trusts (REITs)—reflects how integral concrete is not only to physical development but also to financial systems. Concrete-based projects often underpin debt instruments, sovereign infrastructure bonds, and macroeconomic forecasting models [16, 17].

3.5 Costs and Trade-offs

Despite these economic benefits, it is essential to acknowledge the economic externalities associated with concrete. These include environmental remediation costs, health impacts from air pollution, and infrastructure maintenance burdens. For instance, aging concrete bridges and buildings in North America and Europe require billions in rehabilitation spending annually [18, 19]. Moreover, the lack of circularity in most concrete lifecycles implies future costs related to demolition waste and landfill management.

Nevertheless, from an economic standpoint, concrete remains a highly rational choice, especially in contexts where durability, availability, and affordability are paramount. The economic argument for concrete is thus not merely historical or structural—it is active, dynamic, and, for now, largely indispensable.

4. Functional and Structural Advantages of Concrete

The continued global reliance on concrete is not merely a consequence of economic convenience but is also rooted in its exceptional functional performance and structural characteristics. Concrete combines material versatility, local availability, and durability in a way that few construction materials can rival. Its technological maturity, adaptability to various design requirements, and compatibility with diverse climatic and geological conditions have rooted it as a default material for public, residential, and industrial infrastructure worldwide.

Table 1 consolidates the main advantages and disadvantages of concrete, providing a quick reference to the technical, economic, and environmental factors that influence its selection in construction projects.

4.1 Mechanical Strength and Structural Reliability

One of the most prominent functional advantages of concrete is its high compressive strength, which makes it particularly suitable for load-bearing structures such as foundations, columns, dams, and retaining walls. Although concrete is weak in tension and requires reinforcement, typically with steel bars or meshes (reinforced concrete), this composite system delivers superior structural performance. When properly designed and constructed, reinforced concrete can achieve lifespans exceeding 100 years, offering long-term reliability [20]. In addition to compressive strength, concrete exhibits excellent fire resistance and can maintain structural integrity during high-temperature events, making it ideal for fire-prone environments and critical infrastructure.

4.2 Durability and Low Maintenance

Concrete's resistance to weathering, corrosion (when properly treated), and environmental wear underpins its widespread use in exposed applications such as bridges, marine structures, and highways. Compared to materials like timber or steel, concrete requires relatively low maintenance over its service life, particularly in arid or temperate climates. Innovations such as high-performance concrete (HPC) and self-healing concrete have further enhanced its longevity by improving resistance to cracking, sulfate attack, and freeze–thaw cycles [21, 22].

The capacity of concrete to withstand time and environment not only reduces life-cycle costs but also aligns with the principles of sustainable construction, especially when evaluated using life-cycle assessment (LCA) methodologies. Long-lasting infrastructure reduces the frequency of reconstruction and the embedded emissions associated with repeated material usage.

4.3 Moldability and Design Flexibility

Concrete's plasticity in its fresh state allows it to be poured into a virtually infinite variety of forms. This makes it highly adaptable for both standardized and architecturally complex structures, from monolithic bridge piers to expressive facades in modern architecture. The material can be precast or cast in situ, enabling both mass production and custom, on-site fabrication.

Furthermore, advances in formwork technology and 3D concrete printing have expanded the material's design potential. Free-form architecture and digital fabrication techniques are increasingly leveraging concrete's moldability, reducing construction time and labor costs while offering new aesthetic possibilities [23, 24]. This functional advantage also contributes to modular construction approaches, which promote efficiency and minimize site disruption.

Table 1. Comparative advantages and disadvantages of concrete in relation to other common construction materials

Category	Advantages	Disadvantages
Structural	• High compressive strength (superior to timber, comparable to masonry). • Excellent fire resistance (better than timber; steel loses strength at high temperatures). • Dimensional stability—does not warp like timber.	• Low tensile strength—requires steel reinforcement. • Heavier than steel or timber, increasing foundation needs and seismic loads.
Economic	• Lower initial cost than structural steel in most regions. • Local raw materials reduce transport costs (less true for steel). • Long service life with proper maintenance.	• Maintenance for aging concrete (spalling, cracking) is less costly than steel corrosion repairs but higher than low-maintenance timber systems in some climates. • Slow on-site curing increases project time compared to prefabricated steel or timber modules.
Practical	• Versatile—can form complex shapes and massive monolithic structures unlike steel or timber. • Thermal mass benefits energy efficiency in buildings (better than steel, lower than masonry in some cases).	• Long curing time delays load-bearing readiness compared to prefabricated steel/timber. • Difficult to modify after curing (less adaptable than timber or steel frames).
Environment	• Long service life reduces replacement frequency compared to untreated timber. • Some incorporation of recycled aggregates and supplementary cementitious materials possible (steel also recyclable, timber renewable).	• High CO_2 footprint from cement production—greater than steel per mass for equivalent compressive strength. • Recycling potential limited to downcycling as aggregate, unlike steel's closed-loop recycling or timber's biodegradability. • High water and aggregate demand compared to steel and timber.

4.4 Local Material Availability and Economic Efficiency

Concrete's primary components—cement, aggregates (sand and gravel), and water—are generally abundant and locally sourced, reducing the need for long-distance transportation and enabling cost-effective production. This availability makes concrete uniquely scalable and suitable for use in both high-income and resource-constrained settings. Unlike steel or polymers, which often depend on imported raw materials and complex supply chains, concrete supports localized construction economies.

In disaster-prone or remote regions, this local availability is critical. Concrete allows for rapid deployment in emergency shelters, water infrastructure, and transport networks. Its favorable strength-to-cost ratio further contributes to its dominance in both large-scale infrastructure and small-scale residential construction.

4.5 Thermal Mass and Energy Performance

Concrete also offers advantages in energy efficiency through its thermal mass properties, which help regulate indoor temperatures by absorbing, storing, and gradually releasing heat. In temperate and hot climates, this can lead to significant reductions in energy demand for heating and cooling, particularly when combined with passive solar design principles [25]. While concrete is often criticized for its energy-intensive production phase, its operational energy performance over the building's lifespan can partially offset these impacts.

Moreover, innovations in insulating concrete forms (ICFs) and composite wall systems have expanded the role of concrete in achieving high-performance building envelopes. These systems contribute to building energy codes and green certification standards such as LEED and BREEAM.

5. Limitations and Economic Drawbacks

Despite its widespread adoption and manifold advantages, concrete presents significant technical, economic, and functional limitations that complicate its uncritical use in contemporary construction. These drawbacks are particularly noticeable in light of growing environmental, economic, and urban sustainability challenges. Understanding the limitations of concrete is essential not only for balanced material selection but also for guiding innovations that can mitigate its downsides.

5.1 Structural Limitations and Material Vulnerability

One of the primary structural disadvantages of concrete is its inherent brittleness and low tensile strength, which necessitate the use of reinforcing materials such as steel [20]. While reinforcement improves overall performance, it introduces complexity in design, increases cost, and creates long-term risks associated with corrosion of steel reinforcements. Chloride ingress, carbonation, and freeze-thaw cycles can lead to degradation of reinforced concrete structures, particularly in marine and humid environments, significantly reducing their service life and raising maintenance demands [26].

Moreover, shrinkage, creep, and cracking are common concerns that compromise both structural integrity and aesthetic appeal. These issues often lead to increased costs related to crack repair, waterproofing, and durability enhancements, particularly in high-performance or exposed structures.

5.2 High Embodied Energy and Resource Intensity

Economically, while concrete may appear cost-effective at the point of construction, it carries externalized environmental costs due to its high embodied energy and resource extraction footprint. The production of Portland cement, which constitutes 10–15% of concrete by weight, is extremely energy-intensive and emits significant levels of CO_2. Each ton of cement emits approximately 0.9 tons of CO_2, making it one of the most carbon-intensive materials in use today [3]. Additionally, the extraction of aggregates contributes to landscape degradation, water pollution, and ecosystem disruption, especially in regions with unregulated mining operations [27].

These environmental externalities have economic implications, especially in jurisdictions where carbon pricing, environmental impact assessments, or ecological restoration obligations are imposed. As regulatory frameworks tighten globally, the true cost of concrete may increase, thereby diminishing its appeal relative to emerging, more sustainable alternatives.

5.3 Maintenance and Infrastructure Lifespan Challenges

In aging urban centers across North America, Europe, and parts of Asia, concrete infrastructure built during the mid-20th century is reaching or has exceeded its design life. Bridges, tunnels, overpasses, and public housing blocks are increasingly requiring expensive retrofitting, reinforcement, or demolition. For instance, the American Society of Civil Engineers (ASCE) estimates that deferred maintenance on aging concrete infrastructure in the U.S. alone will require over $2.5 trillion in investments by 2025 [19]. These escalating lifecycle costs challenge the perception of concrete as a low-maintenance material and raise questions about long-term sustainability and public sector budgeting.

In addition, structures built with poor quality control, substandard mixes, or inadequate reinforcement are prone to early deterioration, especially in rapidly urbanizing regions where regulatory oversight is weak. The 2008 Sichuan earthquake, for example, exposed widespread failures in concrete school buildings, attributed in part to substandard materials and poor construction practices [28, 29].

5.4 Limitations in Design and Adaptability

While concrete excels in compressive applications, it is less suited for flexible, modular, or rapidly deployable construction. Its weight, rigidity, and need for curing time limit its usefulness in situations where speed, lightness, and reconfigurability are critical. For instance, in temporary shelters, mobile architecture, or lightweight vertical extensions, materials like engineered wood or steel often outperform concrete in terms of logistics and design adaptability.

Furthermore, concrete construction is labor- and time-intensive, requiring skilled labor, quality control, and extensive site preparation. These constraints can become cost-prohibitive in contexts where labor shortages, site access issues, or tight project timelines are prevalent.

5.5 Lifecycle and End-of-Life Challenges

Concrete's end-of-life scenario poses significant environmental and economic concerns. Unlike metals or plastics, concrete cannot be reprocessed into the same material without significant downcycling. While recycled concrete aggregate (RCA) is used in sub-base applications, it typically exhibits lower strength, higher porosity, and reduced durability, limiting its utility in structural applications [30, 31]. The demolition and landfilling of concrete structures contribute to construction and demolition (C&D) waste, which now constitutes 25–30% of total solid waste in many developed countries [32].

Moreover, deconstruction and recycling costs are often not factored into initial economic evaluations, creating a distorted view of concrete’s cost-effectiveness. As circular economy principles gain traction in the construction industry, these end-of-life limitations may become increasingly problematic.

6. Environmental Impacts of Concrete Production

Concrete, while indispensable in contemporary infrastructure, exerts a profound and multifaceted burden on the environment. The environmental costs arise not only from the energy- and emission-intensive production of cement—the primary binder in concrete—but also from aggregate extraction, water consumption, urban heat island effects, and end-of-life waste management. As the scale of concrete production has expanded, these impacts have reached global proportions, contributing significantly to anthropogenic climate change, resource depletion, and ecological degradation.

6.1 Cement Production and CO_2 Emissions

The most critical environmental issue associated with concrete is the carbon dioxide emissions from cement manufacturing, which accounts for approximately 7–8% of global CO_2 emissions [3, 6]. The emissions result from two main sources: (depending on energy sources and kiln efficiency) the calcination of limestone ($CaCO_3$) to produce clinker (the key component of cement), which alone releases about 60% of the CO_2, and the combustion of fossil fuels to reach the high kiln temperatures required, which contributes the remaining 40% [2]. Given the anticipated rise in global infrastructure demand, especially in developing nations, cement emissions are projected to remain a major barrier to achieving global carbon neutrality targets.

While technological interventions such as carbon capture and storage (CCS) and alternative fuels are being explored, widespread deployment remains limited by cost, technical feasibility, and regulatory inertia. Moreover, attempts to lower clinker content through the use of supplementary cementitious materials (SCMs)—such as fly ash, ground granulated blast furnace slag (GGBFS), and calcined clay—are constrained by regional availability and inconsistent performance metrics [1].

6.2 Resource Depletion and Aggregate Mining

Concrete's demand for natural resources is immense. Producing one cubic meter of concrete typically requires over 2,400 kg of raw materials, including cement, sand, gravel, and water. The extraction of sand and gravel—key aggregate components—has become one of the most ecologically destructive activities globally. According to recent estimates, humans extract more than 50 billion tons of sand and gravel annually, a figure that far exceeds natural replenishment rates and has led to severe riverbed degradation, coastal erosion, and biodiversity loss in numerous regions [27].

Unregulated or illegal sand mining, particularly in Southeast Asia, India, and parts of Africa, has resulted in not only ecological collapse in some freshwater ecosystems but also social conflicts, often involving corruption, violence, and displacement. The depletion of high-quality natural aggregates has also pushed extraction into increasingly remote or ecologically sensitive areas, thereby compounding environmental risks [33–36].

6.3 Water Use and Pollution

Concrete production is also water-intensive, especially during the curing phase and in ready-mix concrete operations. The World Business Council for Sustainable Development (WBCSD) estimates that cement production alone consumes approximately 1.7 billion cubic meters of water annually. In water-stressed regions, this demand competes directly with agricultural and domestic needs, worsening local water scarcity [37–39]. Additionally, cement and concrete plants contribute to surface and groundwater contamination through wastewater discharge and runoff containing high alkalinity and particulate matter. Improper handling of slurry waste and washing effluents can pollute aquatic habitats and soil systems, raising both environmental and public health concerns.

6.4 Urban Heat Islands and Land Use

Another indirect environmental impact of widespread concrete usage is its contribution to the urban heat island (UHI) effect. Concrete surfaces have low albedo (reflectivity) and high thermal mass, causing urban areas to retain heat during the day and release it at night, thus increasing average temperatures in densely built environments [40]. UHIs elevate energy consumption for cooling, intensify air pollution, and deteriorate public health, particularly during heatwaves.

In addition, the conversion of permeable land into impermeable concrete surfaces disrupts natural hydrological cycles, reducing groundwater recharge and increasing stormwater runoff, which can lead to urban flooding and water pollution. The ecological consequences of large-scale land sealing by concrete infrastructure—such as habitat fragmentation and loss of soil carbon—are often overlooked in life-cycle assessments but remain ecologically significant.

6.5 End-of-Life and Waste Generation

Concrete's end-of-life phase also carries a significant environmental burden. Demolition waste from concrete structures constitutes a major share of global construction and demolition waste, estimated at over 2.5 billion tons per year globally [32]. Although a portion of this waste is downcycled into road base material or fill, true recycling into new structural concrete remains limited due to technical and quality challenges.

The lack of circularity in the concrete lifecycle implies a linear consumption model—extraction, use, disposal—that runs counter to the principles of a sustainable, circular economy. This model not only exacerbates landfilling and environmental degradation but also necessitates continuous input of virgin raw materials, thereby perpetuating the cycle of environmental harm.

7. Innovations and Sustainability Strategies

In response to the mounting environmental challenges posed by conventional concrete production and use, significant technological, material, and policy-driven innovations have emerged over the past two decades. These strategies aim to reduce concrete's carbon footprint, conserve resources, and promote lifecycle efficiency without compromising its structural integrity and economic viability. The transition toward more sustainable concrete practices is being driven by a combination of industry innovation, academic research, regulatory mandates, and market pressures aligned with global climate goals such as the Paris Agreement and United Nations Sustainable Development Goals (SDGs) [41].

Table 2 presents info regarding emerging low-carbon technologies in the cement and concrete sector. SCM substitution is already widely adopted, while carbon capture and geopolymer technologies hold higher long-term promise but face cost and scalability barriers [6, 42–45].

Table 2. Low-carbon concrete innovations

Technology	Emission Reduction Potential	Cost Impact	Example Use Case
SCM substitution (fly ash, slag)	20–40%	Neutral to lower	Ready-mix concrete in EU & US
Geopolymer binders	40–80%	10–20% higher	Precast elements in Australia
Carbon capture in kilns	60–90%	30–50% higher	Pilot plants in Norway, Canada
Recycled aggregates	10–20%	Slightly higher	Japan & EU road bases

7.1 Supplementary Cementitious Materials (SCMs)

One of the most widely adopted strategies to reduce emissions in concrete production is the substitution of Portland cement clinker with supplementary cementitious materials (SCMs). Common SCMs include fly ash (a byproduct of coal combustion), ground granulated blast furnace slag (GGBFS) (from steel manufacturing), silica fume, and calcined clay. These materials not only reduce clinker demand—which accounts for the bulk of cement-related CO_2 emissions—but can also improve durability, workability, and chemical resistance [1].

Blended cements incorporating SCMs have demonstrated up to 30–50% reduction in embodied CO_2 emissions, depending on the blend and application [2]. The growing interest in limestone calcined clay cement (LC^3) is especially notable, as it uses abundant and low-cost materials to achieve performance comparable to ordinary Portland cement with significantly lower emissions [46].

However, the adoption of SCMs is not without challenges. The availability of industrial by-products like fly ash and slag is regionally variable and declining in some cases due to the global energy transition away from coal and blast furnaces. Moreover, performance variability and lack of standardized specifications in some regions hinder large-scale implementation.

7.2 Carbon Capture and Utilization Technologies

A promising frontier in decarbonizing cement production is the integration of carbon capture, utilization, and storage (CCUS) technologies. These approaches seek to either sequester CO_2 emitted during the calcination process or incorporate it directly into concrete products. For instance, carbonation curing, used in precast concrete, involves injecting CO_2 into fresh concrete to accelerate strength gain while permanently sequestering carbon in the form of calcium carbonate [47, 48].

Companies such as CarbonCure and Solidia Technologies have begun commercializing such systems, reporting 5–15% reductions in net CO_2 emissions per cubic meter of concrete. Nonetheless, widespread adoption of CCUS is hindered by cost, scalability, and infrastructure requirements, such as proximity to CO_2 sources and transportation logistics [49–51].

7.3 Alternative Binders and Geopolymer Concrete

Beyond partial replacement strategies, research is expanding into alternative binder systems that do not rely on traditional clinker. Geopolymer concrete, made from aluminosilicate-rich industrial waste (e.g., fly ash or metakaolin) and activated with alkaline solutions, offers substantial environmental advantages. Life-cycle assessments claimed to shown that geopolymer concrete can reduce CO_2 emissions by up to 80% compared to conventional Portland cement [52]. However, long-term performance and standardization may be barriers to achieve this goal.

However, technical barriers such as alkaline handling safety, long-term durability validation, and standardization issues limit current market uptake. Despite these hurdles, geopolymer technology holds long-term promise for zero-clinker concrete systems, particularly in specialized applications like precast elements and fire-resistant structures.

7.4 Recycled Aggregates and Circular Economy Models

Efforts to promote material circularity have led to increased interest in the use of recycled concrete aggregate (RCA) and construction and demolition (C&D) waste in new concrete formulations. While RCA typically results in slightly reduced mechanical properties, recent innovations in pre-treatment methods (e.g., acid washing, carbonation, and thermal processing) have improved its performance, making it viable for use in non-structural and, increasingly, structural applications [30].

Adopting recycled aggregates contributes to reduced lower extraction pressures on natural resources and shorter transportation distances. These benefits align with broader goals of transitioning to a circular economy, as encouraged by the European Green Deal and emerging national strategies in countries like the Netherlands and Japan.

7.5 Digital Technologies and Smart Construction

Technological innovation is also transforming how concrete is produced and applied. Digital fabrication techniques, such as 3D concrete printing, enable precise material usage, minimized waste, and complex architectural forms with fewer resources. Additionally, building information modeling (BIM) and digital twin technologies are optimizing concrete mix design, structural performance predictions, and maintenance planning, contributing to more efficient lifecycle management [23].

Smart sensors embedded in concrete can also monitor structural health, humidity, and carbonation depth, enabling predictive maintenance and extending infrastructure life, thereby lowering overall environmental and economic costs.

7.6 Policy Instruments and Green Certifications

Policy mechanisms are essential for accelerating sustainable practices in concrete production and use. Carbon pricing, green public procurement, and building energy codes are increasingly incorporating low-carbon concrete criteria. Certifications such as LEED (Leadership in Energy and Environmental Design), BREEAM (Building Research Establishment Environmental Assessment Method), and Envision incentivize the use of eco-efficient materials and lifecycle assessment in construction.

Furthermore, the Global Cement and Concrete Association (GCCA) and the Cement Sustainability Initiative (CSI) have developed roadmaps for carbon neutrality, setting benchmarks and timelines for reducing emissions. These initiatives reflect growing alignment between industry leadership and climate policy objectives.

8. Alternatives to Conventional Concrete

As the sustainability challenges of conventional concrete become increasingly urgent, researchers, engineers, and policymakers are exploring alternative construction materials that can reduce environmental burdens while fulfilling similar structural and functional roles. These alternatives vary widely in terms of their mechanical performance, resource intensity, and regional applicability. While no single material currently matches concrete in terms of global scalability and versatility, various low-carbon or renewable substitutes show promise in targeted applications, particularly in low- to mid-rise construction, modular systems, and climate-specific designs.

8.1 Engineered Timber and Mass Timber Products

Among the most widely discussed alternatives is engineered timber, especially in the form of cross-laminated timber (CLT), glulam, and laminated veneer lumber (LVL). These materials offer significant advantages in terms of embodied carbon. Timber acts as a carbon sink, storing atmospheric CO_2 absorbed during tree growth, and engineered forms of wood have improved strength, dimensional stability, and fire performance compared to traditional lumber [53].

Engineered timber structures have been successfully implemented in mid-rise and even high-rise projects, such as the Mjøstårnet in Norway (85.4 meters). These developments illustrate timber's potential to replace concrete in specific sectors. Moreover, prefabrication and modular construction with timber enables faster assembly, less site disturbance, and lower construction waste.

However, engineered timber also has limitations. It is less suitable for long-span or highly loaded structures, is susceptible to moisture degradation if not properly treated, and often faces code restrictions or lack of familiarity among contractors in many regions. Additionally, large-scale timber use must be matched by sustainable forestry practices to avoid unintended deforestation or biodiversity loss.

8.2 Rammed Earth and Stabilized Soil Construction

Rammed earth, an ancient building technique, is experiencing renewed interest due to its extremely low embodied energy and minimal processing requirements. It involves compacting layers of moistened subsoil into formwork to create solid walls. When stabilized with cement or lime, rammed earth offers improved mechanical strength, making it suitable for structural and load-bearing elements [54].

This method is particularly relevant in arid and semi-arid climates, where thermal mass is beneficial and local soil resources are readily available. Rammed earth buildings have high durability, excellent fire resistance, and low maintenance demands. However, limitations include labor intensity, long construction times, and variable performance based on soil composition and compaction quality. As such, its use is best suited for context-specific, low-rise, and residential applications.

8.3 Bamboo and Bio-Based Composites

In tropical and subtropical regions, bamboo is gaining attention as a renewable and high-strength construction material. Engineered bamboo products, such as laminated bamboo panels and bamboo-reinforced composites, demonstrate excellent tensile strength, rapid renewability (with growth cycles of 3–5 years), and biodegradability [55].

However, bamboo construction remains niche, constrained by limited standardization, vulnerability to biological decay, and poor fire performance without treatment. Despite these drawbacks, bamboo presents strong potential for temporary structures, low-income housing, and lightweight modular components, especially in Asia, Latin America, and parts of Africa.

Similarly, hempcrete, made from the woody core of the hemp plant mixed with a lime-based binder, provides high thermal insulation and carbon sequestration potential. Though not structurally load-bearing, it is increasingly used for non-load-bearing walls and insulation, particularly in green building contexts [56].

8.4 Steel and Hybrid Structural Systems

Structural steel offers an established alternative to concrete in high-rise, long-span, and industrial structures due to its high strength-to-weight ratio, tensile capacity, and prefabrication potential. Steel allows for lighter foundations, quicker erection times, and adaptability in seismic zones. Moreover, steel is recyclable at high rates—often over 90% in construction contexts—supporting circular economy models [57].

However, steel's production is energy- and emissions-intensive, and it typically carries higher upfront costs. Additionally, thermal and acoustic insulation requirements often necessitate complementary materials, making steel more suitable in composite systems rather than as a sole substitute for concrete.

Hybrid systems, combining steel frames with timber floors or precast concrete panels, aim to capitalize on the advantages of each material while mitigating their drawbacks. Such configurations offer design flexibility, performance optimization, and potential reductions in both emissions and costs.

8.5 Material Selection Based on Context

It is crucial to recognize that material substitution must be context-sensitive. Climatic conditions, resource availability, labor skill levels, building codes, and project scale all influence the suitability of alternative materials. For example, while CLT may be ideal for a mid-rise commercial building in Canada, rammed earth may be more appropriate for rural housing in Sub-Saharan Africa. Similarly, in high-density urban areas, steel-concrete hybrid systems may offer the best trade-off between performance and sustainability.

A critical challenge in evaluating alternatives to conventional concrete lies in the scarcity of region-specific life-cycle assessment (LCA) data. While global studies often highlight the potential of engineered timber, rammed earth, or geopolymer concretes, their actual environmental performance depends heavily on local resource availability, transportation distances, and energy mixes. For instance, engineered timber may yield substantial carbon savings in regions with sustainable forestry practices, but its benefits diminish in areas requiring long transport chains. The lack of comprehensive regional LCA datasets therefore limits the reliability of substitution assessments, underscoring a significant research gap in sustainable construction studies [1, 58].

No single material currently offers a universal replacement for concrete, but a diversified approach, leveraging regionally appropriate alternatives and hybrid designs, can significantly reduce reliance on traditional concrete and align with sustainable development goals.

9. Is It Still Worth It? Economic Validation vs. Environmental Costs

The dual identity of concrete—as both an essential engine of development and a significant contributor to environmental degradation—poses one of the most profound sustainability dilemmas in modern construction. As climate concerns escalate and resource constraints intensify, the question of whether concrete remains a justifiable material of choice demands critical re-examination. This section synthesizes the economic and environmental arguments developed thus far, assessing under what circumstances concrete's continued large-scale use is rational, and where its reduction or replacement may be warranted.

9.1 Contexts Where Concrete Remains Indispensable

There are several infrastructure domains where concrete's economic utility and technical performance remain unmatched. In large-scale infrastructure projects—such as highways, bridges, tunnels, ports, dams, and high-rise foundations—the compressive strength, durability, and local availability of concrete make it the most practical material. Alternatives, while promising in low-rise or specialized applications, often fall short in load-bearing capacity, scalability, or cost efficiency at such scales.

Moreover, the economic multiplier effects associated with concrete infrastructure continue to be vital in developing economies, where physical infrastructure directly correlates with productivity, connectivity, and poverty alleviation [14]. Concrete enables job creation, local industrialization, and regional self-sufficiency, particularly where imported or technologically advanced materials are prohibitively expensive or inaccessible.

Even in high-income countries, concrete remains a key material in urban renewal, transport modernization, and climate adaptation projects such as sea walls and flood defenses, where structural integrity under extreme conditions is paramount.

9.2 Cases for Reduction, Substitution, or Optimization

Conversely, many applications currently relying on conventional concrete could transition toward low-carbon or alternative materials without sacrificing performance. In low-rise residential construction, for instance, engineered timber, earth-based materials, or modular steel systems can achieve similar outcomes with significantly lower environmental costs. The overuse of concrete in contexts that do not require its full structural capacity represents a form of material inefficiency and, increasingly, environmental irresponsibility.

Moreover, in non-structural elements—such as pavements, partition walls, and urban furniture—there is growing scope to use recycled materials, SCM-rich blends, or even geopolymers, thereby reducing clinker dependency. Smart design, material efficiency, and performance-based specifications, rather than prescriptive norms, can guide architects and engineers toward optimal material use and functional sufficiency, avoiding the over-engineering of concrete elements.

The principle of sufficiency—using "enough concrete but no more than necessary"—is a powerful paradigm shift in sustainable design, encouraging not only material reduction but also a broader cultural change in construction ethics [59].

9.3 Economic Rationality vs. Environmental Responsibility

From an economic perspective, concrete remains appealing due to short-term affordability, established supply chains, and low volatility in cost. However, this economic logic often externalizes environmental costs—greenhouse gas emissions, land degradation, biodiversity loss, and waste generation—that are borne collectively and over time. Traditional cost-benefit analyses, which emphasize upfront expenditure and immediate returns, fail to account for life-cycle emissions, maintenance liabilities, and ecological impacts, thereby distorting the real "price" of concrete.

As climate regulations tighten, these externalities are likely to be internalized through carbon pricing, green taxes, and extended producer responsibility (EPR) frameworks. In this evolving policy landscape, continuing to rely on conventional concrete without innovation will become economically irrational. On the other hand, eco-efficient concrete technologies, material substitution, and digital optimization tools offer a path to align economic and environmental objectives.

9.4 A Conditional Justification

Concrete is not inherently unsustainable; rather, its sustainability hinges on how it is produced, where it is used, and for what purpose. In critical infrastructure and structural roles, its benefits may outweigh its environmental drawbacks—especially if enhanced through clinker substitution, low-carbon cement, carbon capture, and recycling. In marginal or non-critical applications, however, continued use of traditional concrete is increasingly hard to justify.

The future of concrete lies in selectivity: using it where truly necessary, optimizing it through technological innovation, and complementing it with alternative materials elsewhere. This nuanced approach, balancing performance, cost, and ecological responsibility, represents the most rational path forward in the era of climate constraint.

10. Conclusion and Policy Implications

Concrete has underpinned the structural and economic foundation of modern civilization. From transportation networks and housing developments to industrial facilities and coastal defenses, its widespread application has enabled unprecedented urbanization, connectivity, and socio-economic development. However, this material's extensive use comes at a steep environmental cost, particularly through its contribution to global carbon emissions, resource extraction, and ecological degradation. As the climate crisis intensifies and sustainability becomes a central policy priority, the continued use of conventional concrete must be critically reevaluated.

This article has demonstrated that while concrete remains functionally indispensable in certain applications—particularly large-scale and load-bearing infrastructure—it is increasingly difficult to justify its universal, default use, especially in non-critical or low-rise settings where more sustainable alternatives exist. The economic rationale for concrete, long centered on affordability, durability, and local availability, must now be balanced against the hidden environmental costs that are becoming harder to ignore or externalize.

The emergence of eco-efficient technologies, such as blended cements, supplementary cementitious materials, carbon capture and utilization, and digital design optimization, offers promising pathways to reduce concrete's environmental footprint. Likewise, the rise of alternative construction materials—including engineered timber, geopolymer concrete, recycled aggregates, and earth-based systems—illustrates a growing diversification in sustainable building practices. However, these innovations must be supported by robust regulatory frameworks, public procurement standards, and industry incentives to overcome technological inertia and market resistance.

Policy intervention is essential to accelerating this transition. Governments must establish clear targets for decarbonization in the construction sector, integrate life-cycle assessment metrics into building codes, and implement carbon pricing mechanisms that internalize the environmental costs of cement and concrete production. Public-sector infrastructure projects should prioritize low-carbon material use through green procurement strategies, while urban planning policies should support adaptive reuse, modular construction, and material circularity. At the same time, educational and professional institutions must equip architects, engineers, and developers with the knowledge and tools to design for material efficiency and sustainability.

Furthermore, the construction industry must move toward a function-driven approach—evaluating materials not solely based on tradition or habit, but on performance relative to need, environmental impact, and long-term resilience. This paradigm shift calls for interdisciplinary collaboration, involving materials scientists, environmental economists, urban planners, and policy makers. Only through such a coordinated effort can the industry transition toward a future in which concrete remains a part of the solution—rather than a persistent contributor to the problem.

In conclusion, concrete is not inherently unsustainable, but its future use must be strategic, optimized, and environmentally accountable. The challenge lies not in discarding concrete entirely, but in reforming its production, rethinking its applications, and reframing its role in the built environment. Achieving this balance is not only a technical and economic imperative but also a moral one, as the sustainability of future generations will, in part, depend on the material choices we make today.

References

[1] Habert G, Miller SA, John VM, Provis JL, Favier A, Horvath A, et al. Environmental impacts and decarbonization strategies in the cement and concrete industries. Nat Rev Earth Environ. 2020; 1(11):559–73.

[2] Scrivener KL, John VM, Gartner EM. Eco-efficient cements: Potential economically viable solutions for a low-CO2 cement-based materials industry. Cem Concr Res. 2018; 114:2–26.

[3] Andrew RM. Global CO 2 emissions from cement production, 1928–2018. Earth Syst Sci Data. 2019; 11(4):1675–710.

[4] Courland R. *Concrete planet: the strange and fascinating story of the world's most common man-made material*. Rowman \& Littlefield; 2022.

[5] Ritchie H. China uses as much cement in two years as the US did over the entire 20th century. 2023. Available from: https://www.sustainabilitybynumbers.com/p/china-us-cement

[6] IEA. International Energy Agency - Cement. 2023. Available from: https://www.iea.org/reports/cement

[7] van Oss HG. USGS Mineral Commodity Summaries: Cement 2021. 2021 Url: https://pubs.usgs.gov/periodicals/mcs2021/mcs2021-cement.pdf.

[8] Antoniou N. GCCA Global Definitions for Low Carbon and Near Zero Concrete. 2025. Available from: https://gccaepd.org/blog/gcca-launches-low-carbon-cement-and-concrete-definitions

[9] The Business Research Company. Cement And Concrete Products Global Market Report 2025. 2025 Url: https://www.thebusinessresearchcompany.com/report/cement-and-concrete-products-global-market-report.

[10] Allwood JM, Cullen JM, Milford RL. Options for Achieving a 50% Cut in Industrial Carbon Emissions by 2050. Environ Sci Technol. 2010; 44(6):1888–94.

[11] International Labour Organization. Green jobs in the construction sector. Geneva; 2020.

[12] Rozenberg J, Fay M. *Beyond the gap: How countries can afford the infrastructure they need while protecting the planet*. World Bank Publications; 2019.

[13] Timilsina G, Hochman G, Song Z. Infrastructure, economic growth, and poverty. World Bank Gr. 2020;

[14] Calderon C, Serven L. *Infrastructure, Growth, and Inequality: An Overview*. World Bank Group, Washington, DC; 2014.

[15] Agyekum K, Kukah AS, Amudjie J. The impact of COVID-19 on the construction industry in Ghana: the case of some selected firms. J Eng Des Technol. 2022; 20(1):222–44.

[16] Griffith-Jones S, Kollatz M. Infrastructure Finance in the Developing World. Multilater Lend Instruments Infrastruct Financ Glob Green Inst Intergov Gr Twenty Four. 2015;

[17] Hutchison N, Squires G, Adair A, Berry J, Lo D, McGreal S, et al. Financing infrastructure development: time to unshackle the bonds? J Prop Invest Financ. 2016; 34(3):208–24.

[18] Kopiika N, Robery P, Ninic J, Mitoulis S-A. Remaining Life of Ageing RC Infrastructure for Sustainable development—Deterioration Under Climate Change. Case Stud Constr Mater. 2025; 22:e04757.

[19] ASCE. 2021 Report Card for America's Infrastructure. 2021 Url: http://www.infrastructurereportcard.org/.

[20] Surahyo A. Physical properties of concrete. In: Concrete Construction: Practical Problems and Solutions. Springer; 2019. p. 61–88.

[21] Yilmaz S, Ozmen HB. *High Performance Concrete Technology and Applications*. Yilmaz S, Ozmen HB, editors. InTech; 2016.

[22] Asgharpour F, Çakiral K, Marar KH. Harnessing microbes for self-healing concrete – A review. Res Eng Struct Mater. 2024;

[23] Buswell RA, Leal de Silva WR, Jones SZ, Dirrenberger J. 3D printing using concrete extrusion: A roadmap for research. Cem Concr Res. 2018; 112:37–49.

[24] Pham LT, Trinh TD, Do QT, Huang JY. Flexural behavior of printed concrete wide beams with dispersed fibers reinforced. Res Eng Struct Mater. 2023;

[25] Cabeza LF, Rincón L, Vilariño V, Pérez G, Castell A. Life cycle assessment (LCA) and life cycle energy analysis (LCEA) of buildings and the building sector: A review. Renew Sustain Energy Rev. 2014; 29:394–416.

[26] Broomfield JP. *Corrosion of Steel in Concrete*. London: CRC Press; 2022.

[27] Torres A, Brandt J, Lear K, Liu J. A looming tragedy of the sand commons. Science (80-). 2017; 357(6355):970–1.

[28] Branigan T. Anger grows over quake schools in China. 2008. Available from: https://www.theguardian.com/world/2008/may/27/china

[29] Ozmen HB, Inel M. Effect of concrete strength and detailing properties on seismic damage for RC structures. Res Des. 2024; 1(1):1–11.

[30] Kou SC, Poon CS. Enhancing the durability properties of concrete prepared with coarse recycled aggregate. Constr Build Mater. 2012; 35:69–76.

[31] Kaabeche S, Belaoura M, Kahlouche R. The effects of the quality of recycled aggregates on the mechanical properties of roller compacted concrete. Res Eng Struct Mater. 2024;

[32] Eurostat. Waste statistics – Statistics Explained. 2022. Available from: https://ec.europa.eu/eurostat/statistics-explained

[33] Leal Filho W, Hunt J, Lingos A, Platje J, Vieira L, Will M, et al. The Unsustainable Use of Sand: Reporting on a Global Problem. Sustainability. 2021; 13(6):3356.

[34] Pandey S, Kumar G, Kumari N, Pandey R. Assessment of Causes and Impacts of Sand Mining on River Ecosystem. In: Hydrogeochemistry of Aquatic Ecosystems. Wiley; 2023. p. 357–79.

[35] H.S. O, E. U, J.E. A, F.C. A. Sand Mining: Economic gains, Environmental Ethics, and Policy Implications. African J Econ Sustain Dev. 2022; 5(2):119–38.

[36] Tastet E. Stealing beaches: A law and economics policy analysis of sand mining. LSU J Energy L \& Resour. 2019; 7:525.

[37] Akhtar N, Ahmad T, Husain D, Majdi A, Alam MT, Husain N, et al. Ecological footprint and economic assessment of conventional and geopolymer concrete for sustainable construction. J Clean Prod. 2022; 380:134910.

[38] Ding C, Dong W, Zhang A, Wang Z, Zhao N, Chen R, et al. Life cycle water footprint assessment of concrete production in Northwest China. Water Policy. 2021; 23(5):1211–29.

[39] Arosio V, Arrigoni A, Dotelli G. Reducing water footprint of building sector: concrete with seawater and marine aggregates. IOP Conf Ser Earth Environ Sci. 2019; 323(1):012127.

[40] Santamouris M. Analyzing the heat island magnitude and characteristics in one hundred Asian and Australian cities and regions. Sci Total Environ. 2015; 512–513:582–98.

[41] UN. Paris Agreement. 2015. Available from: https://sdgs.un.org/frameworks/parisagreement

[42] Guo Y, Luo L, Liu T, Hao L, Li Y, Liu P, et al. A review of low-carbon technologies and projects for the global cement industry. J Environ Sci. 2024; 136:682–97.

[43] Barbhuiya S, Das BB, Adak D, Kapoor K, Tabish M. Low carbon concrete: advancements, challenges and future directions in sustainable construction. Discov Concr Cem. 2025; 1(1):3.

[44] Lim S, Chen C, Akiyama M. State-of-the-Art Review of Recent Technologies and Applications of Carbon-Neutral and Low-Carbon Concretes in Japan, the US, and Europe. Struct Eng Int. 2025; 35(1):106–17.

[45] Xiao J, Shuai J, Deng W, Liu L, Wang P, Li L. Low-Carbon and Green Materials in Construction: Latest Advances and Prospects. Buildings. 2025; 15(9):1508.

[46] Mañosa J, Calderón A, Salgado-Pizarro R, Maldonado-Alameda A, Chimenos JM. Research evolution of limestone calcined clay cement (LC3), a promising low-carbon binder – A comprehensive overview. Heliyon. 2024; 10(3):e25117.

[47] El-Hassan H. Accelerated Carbonation Curing as a Means of Reducing Carbon Dioxide Emissions. In: Cement Industry - Optimization, Characterization and Sustainable Application. IntechOpen; 2021.

[48] Dixit A, Du H, Pang SD. Carbon capture in ultra-high performance concrete using pressurized CO2 curing. Constr Build Mater. 2021; 288:123076.

[49] Siegel RP. Cutting the Carbon from Concrete. Mech Eng. 2020; 142(02):38–43.

[50] Norouzi N, Choubanpishehzafar S. An Overview on the Carbon Utilization Technologies with an approach to the negative emission construction material. Int J New Chem. 2021; 8(3):298–328.

[51] Lourenço MEL. The concrete effect on Co2 emissions. Dissertation. Universidade de Lisboa (Portugal); 2023.

[52] Davidovits J. *Geopolymer chemistry and applications*. Geopolymer Institute; 2008.

[53] Churkina G, Organschi A, Reyer CPO, Ruff A, Vinke K, Liu Z, et al. Buildings as a global carbon sink. Nat Sustain. 2020; 3(4):269–76.

[54] Jaquin PA, Augarde CE. *Earth building: History, science and conservation*. 2012.

[55] Sharma B, Gatóo A, Bock M, Ramage M. Engineered bamboo for structural applications. Constr Build Mater. 2015; 81:66–73.

[56] Ip K, Miller A. Life cycle greenhouse gas emissions of hemp–lime wall constructions in the UK. Resour Conserv Recycl. 2012; 69:1–9.

[57] World Steel Association. Steel facts. 2023.

[58] Sonebi M, Ammar Y, Diederich P. Sustainability of cement, concrete and cement replacement materials in construction. In: Sustainability of Construction Materials. Elsevier; 2016. p. 371–96.

[59] Zabalza Bribián I, Valero Capilla A, Aranda Usón A. Life cycle assessment of building materials: Comparative analysis of energy and environmental impacts and evaluation of the eco-efficiency improvement potential. Build Environ. 2011; 46(5):1133–40.

Research & Design
www.jrede.org

Review Article

The strategic role of Game Theory in financial markets

Damla Yalçıner Çal*[a]

PhD, Independent Researcher, Isparta, Türkiye

Article Info

Article History:

Received:

4 Sept 2025

Accepted:

4 Oct 2025

Keywords:

Game Theory,
Financial Markets,
Strategic Decision-Making,
Nash Equilibrium,
Market Equilibria

Abstract

This study examines the strategic role of game theory in financial markets through a literature-based analysis. Game theory, as a powerful tool that enables the mathematical analysis of rational decision-makers' strategic interactions, provides significant contributions to understanding key processes such as competition, cooperation, arbitrage, pricing, speculation, and manipulation in financial markets. The study first explains the fundamental concepts of game theory (players, strategies, payoffs, and equilibrium points) and emphasizes the critical importance of the Nash equilibrium and its extensions in market analyses. Within the context of financial markets, different types of markets—such as money markets, capital markets, organized and over-the-counter markets—are examined, and the integration of game theory into strategic decision-making processes is discussed. The literature reveals that game theory has broad applications in areas such as portfolio optimization, risk management, market equilibrium analysis, oligopoly models, and the investigation of speculative bubbles in cryptocurrency markets. In conclusion, game theory emerges not only as a theoretical analytical tool but also as a practical method for understanding the dynamics of financial markets, supporting strategic decision-making processes, and strengthening market stability. In this regard, the study contributes to the theoretical literature while also offering insights for strategic decision-makers in financial markets.

1. Introduction

Game theory, as a mathematical and analytical discipline that examines the strategic interactions of rational decision-makers (players), has acquired a significant position across many fields of the social sciences. Its fundamental assumption is that players do not merely attempt to maximize their own payoffs, but must also take into account the strategies and behaviors of other actors [39, 65]. In this respect, game theory provides a framework for modeling strategic relationships among individuals, firms, and institutions, and offers a theoretical basis for analyzing different competitive environments. Particularly in the fields of economics and finance, game theory has found wide application, providing a rational and systematic approach to decision-making processes and contributing to a better understanding of market mechanisms [32, 79]

The increasing adoption of game theory in the economics literature from past to present clearly demonstrates its strength in analyzing decision-making processes within dynamic market structures and competitive settings. Core concepts such as Nash Equilibrium reveal how stable outcomes can emerge from strategic interactions among players, making them frequently used analytical tools in financial markets [59, 60]. Game theory, by considering elements such as information sharing, competition, cooperation, and uncertainty in

*Corresponding author: damlayalciner@gmail.com
[a]orcid.org/0000-0002-9232-3063
DOI: http://dx.doi.org/10.17515/rede2025-009ec0904rs

decision-making processes, stands out as a mathematical model that enables the identification of the most appropriate strategic equilibrium [2, 14, 75].

The aim of this study is to explore the role of game theory in strategic decision-making and market equilibria within financial markets. In this context, the research first focuses on game theory-based studies specifically addressing financial markets in both national and international literature, evaluating these studies comparatively in terms of their objectives, methods, and results. Subsequently, the study discusses in detail how game theory has been applied in financial markets, and which models and approaches have been used for analysis. In doing so, it seeks to provide a framework that enhances the understanding of the analytical contributions of game theory for both researchers and market participants.

Finally, the conclusion presents a general assessment of the role of game theory in financial markets, summarizing the findings with respect to strategic decision-making processes and market equilibria. In this regard, the study not only contributes to the theoretical literature but also offers insights for practitioners in developing policies and strategies.

2. Literature Review

A review of the literature on the applications of game theory in financial markets reveals that studies have concentrated on a wide variety of areas. Huang [39] examined the strategic effects of game theory on financial decision-making by combining qualitative and quantitative datasets, emphasizing its risk-reducing role particularly in mergers, acquisitions, and portfolio management. The role of game theory in energy markets is also noteworthy; Janan et al. [42] and Jiang et al. [43] focused on evolutionary games, Stackelberg models, and pricing strategies in blockchain-based energy trading. Vidler and Walsh [95] identified liquidity games in the bond market, while Song and Wu [87] discussed the effectiveness of Bayesian games in post-forecast decision-making processes.

In the field of portfolio optimization, Acar and Ünal [2] demonstrated, using BIST data, that game theory enhances Sharpe ratios; meanwhile, Simonion [85] applied the Shapley value in portfolio diversification. Similarly, Ibrahim et al. [40] and Pekkaya & Gümüş [71] analyzed the effects of political changes on portfolio selection and trends in the literature. In this context, cooperative models (e.g., Shapley value, coalition games) provide diversification benefits by distributing portfolio risk based on marginal contribution across assets, whereas non-cooperative models (e.g., minimax, robust games) generate conservative allocations under uncertainty, thereby reducing model risk. However, the outcomes of these two approaches sometimes diverge: cooperative models enhance diversification, while non-cooperative models yield more cautious but higher opportunity-cost strategies.

Regarding the relationship between financial regulation and innovation, An et al. [100] employed an evolutionary game theory model to reveal the mutual interdependence between regulatory policies and financial innovation, thereby providing an analytical framework for balancing regulation and innovation. In the context of financial risk management, Moosakhaani et al. [57] used Nash equilibrium in flood risk modeling, while Liu et al. [52] examined the role of game theory in blockchain security and mining economics. More recently, Wang [108] employed evolutionary game theory to study Chinese household financial investment behavior, and Langenohl [105] demonstrated how social coordination in decentralized finance (DeFi) projects can be achieved through game theory. These studies highlight the potential of game theory in blockchain-based financial applications, while also bringing to light significant challenges such as regulatory uncertainty, scalability, and security.

In terms of pricing and liquidity in financial markets, Evangelista et al. [103] modeled price formation processes using multi-player and mean-field game approaches; Pagliarani et al. [107] analyzed the strategic impact of renewable energy producers on market prices within the framework of Nash equilibrium. Lavigne and Tankov [106] examined the decarbonization of financial markets using a mean-field game approach, modeling how investors' strategies are shaped by carbon footprint considerations and contributing to the literature on sustainable finance. Bao [102] integrated game theory into option pricing through a binomial tree model, proposing a novel pricing method, while Azarberahman & Mohammadnejadi Modi [101] developed a fuzzy logic–based game-theoretic approach to financial market competition using a Kalman–Jacobi hybrid model.

Historically, Yıldırım [97] developed strategic investment models for ISE sectors, while Deng et al. [23] and Farias et al. [29] employed minimax models in portfolio selection. Thakor [90] on the other hand, provided a theoretical perspective on the potential applications of game theory in finance.

Overall, this literature demonstrates that game theory has a broad and growing influence on portfolio management, market equilibria, risk management, pricing strategies, and emerging technological platforms (e.g., blockchain and DeFi) in financial markets. However, common limitations in the literature include the predominance of theoretical models, the lack of empirical validations, and the uncertainty of regulatory frameworks, particularly in blockchain-based markets. A summary of the literature review is presented in Table 1.

Table 1. Literature review

Author(s)	Topic / Purpose	Method / Model	Findings	Contribution	Sources
Huang (2025)	Strategic effects on financial decision-making	Qualitative and quantitative datasets; Nash equilibrium, cooperative/non-cooperative games, evolutionary games	Game theory is critical in determining strategic actions; reduces risks in mergers and acquisitions	Enhances portfolio management, contributes to market stability	[39]
Janan et al. (2025)	Pricing and financing in blockchain-based energy markets	Evolutionary games, Stackelberg model	Optimization of energy sales prices; efficiency in financing processes	Proposal of a sustainable financing model in blockchain-based energy	[42]
Azarberahman & Mohammadnejadi Modi (2025)	Financial competition	Kalman–Jacobi hybrid model + fuzzy logic	Developed a hybrid equilibrium model in market competition	Proposed a hybrid game-theoretic model	[101]
Vidler & Walsh (2024)	Liquidity games in bond markets	Non-cooperative game; 'liquidity game' model	Strategic decisions determine market liquidity	New model proposal for market design and regulation	[95]
Bao (2024)	Option pricing	Binomial model + game theory	Developed an alternative approach to option pricing	Innovation in pricing literature	[102]
Pagliarani et al. (2024)	Renewable energy market	Nash equilibrium, stochastic game	Modeled price effects among renewable producers	Strategic game application at the energy-finance intersection	[107]

Author(s)	Topic / Purpose	Method / Model	Findings	Contribution	Sources
Song & Wu (2023)	Post-forecast game theory and decision-making	Bayesian games	Early action proves beneficial; forecasts influence investor behavior	Theoretical framework explaining forecasting behavior	[87]
Wang (2023)	Household investment behavior	Evolutionary game theory	Revealed strategic interactions of Chinese investors	Explains investment behavior at the micro level	[108]
Koliechkina & Vuzii (2023)	Automated stock trading systems	Analysis of game theory methods	Showed impact of strategic behavior on trading algorithms	Game-theoretic approach to algorithmic trading	[104]
Lavigne & Tankov (2023)	Decarbonization of financial markets	Mean-field game approach	Modeled interaction of investors considering carbon footprint in financial decisions	Opens new perspective on sustainable finance using game theory	[106]
Acar & Ünal (2022)	Portfolio optimization in BIST 100	Minimax + simplex algorithm	Portfolios calculated with game theory achieve higher Sharpe ratios	Application of game theory in portfolio management in Turkey	[2]
Moosakhaani et al. (2022)	Financial model for flood risk management	Nash equilibrium	Optimal equilibrium when insurance and state support are combined	Model for risk sharing and distribution of financial responsibilities	[57]
Evangelista et al. (2022)	Price formation	Mean-field games	Modeled price dynamics in multi-player interactions	New perspective on market microstructure	[103]
Langenohl (2022)	Social coordination in DeFi	Game theory + sociological analysis	Examined mechanisms of coping with uncertainty in DeFi projects	Demonstrated the social role of game theory in DeFi	[105]
An et al. (2021)	Inter-relationships between financial regulation and innovation	Evolutionary game theory model	Showed how regulatory policies and financial innovation influence each other dynamically	Provides analytical framework for balancing regulation and innovation	[100]
Pekkaya & Gümüş (2021)	Literature review on portfolio optimization	Review of 300 studies	Limited use of game theory in portfolio studies	Identification of a gap in the literature	[71]
Ibrahim et al. (2020)	Portfolio selection during Malaysian elections	Cooperative game; Shapley value	Changes observed in portfolio selection before and after elections	Explains political impacts on financial markets through game theory	[40]
Jiang et al. (2020)	Electricity trading in blockchain-based energy markets	Stackelberg game + algorithms	Win–win outcomes in buyer–seller interactions	Proposal of a blockchain-based pricing model	[43]
Liu et al. (2019)	Applications of game theory in blockchain	Selfish mining, majority attack, DoS models	Solutions proposed for security and economic challenges	Systematic framework for blockchain security using game theory	[52]
Simonion (2019)	Portfolio selection using Shapley value	Shapley value-based model	Facilitated portfolio diversification	Cooperative solution approach in portfolio selection	[85]
Yıldırım (2006)	Game theory in ISE sector analysis	Mathematical modeling	Sector-based monthly investment recommendations developed	One of the early applications in the Turkish stock market	[97]

Author(s)	Topic / Purpose	Method / Model	Findings	Contribution	Sources
Deng et al. (2005)	Portfolio selection with equilibrium prices	Minimax + linear programming	Developed a non-negative equilibrium price system	Analytical contribution to portfolio selection under uncertainty	[23]
Farias et al. (2004)	Portfolio optimization in the Brazilian stock market	MV, Minimax, Weighted Minimax models	Minimax model yielded higher returns	Comparison of different game-theoretic models	[29]
Thakor (1991)	Potential of game theory in finance	Theoretical analysis	Predicted growing importance of cooperative and evolutionary games	Pioneering contribution to finance	[90]

3. Game Theory

Game theory is a mathematical approach that enables the systematic analysis of decisions made by individuals under different conditions and the impact of these decisions on other actors. Rooted in human behavior, this discipline is not limited to a single field of study but has gained prominence for its applicability across economics, social sciences, biology, engineering, computer science, and even philosophy [24]. The central premise of game theory is that individuals' decisions directly influence the decisions and outcomes of others in society, and this interdependence requires an examination of how rational behavior is shaped in such contexts. For this reason, game theory is often described as the study of "cooperation or competition within mutual interaction."

For a game to emerge, there must first be players—decision-makers—who make choices under specific strategic conditions. The structure of a game is defined by the information available to players, their strategy sets, and the payoffs resulting from these strategies. Games are mathematical models that capture players' strategies for each possible situation, the potential outcomes of these strategies, and the resulting gains or losses. In this way, game theory provides a formal framework for analyzing how actors with different modes of reasoning make moves against each other [14].

One of the most important contributions of game theory is its ability to explain strategic decision-making in competitive environments. When considering the counter-moves of rival players, the key question becomes: "How should a player develop the most appropriate strategy while maximizing their own payoff in response to the rival's actions?" Accordingly, game theory contributes to the identification of optimal strategic decisions in any sector where competition exists [67]. Each player must therefore account not only for their own interests but also for their rivals' potential strategies. Since every strategy determines the player's payoff or loss, the mathematical analysis of these outcomes enables more rational decision-making [54].

The historical development of game theory dates back to the 17th century. The foundations were laid by Émile Borel's work in 1921, followed by John von Neumann's 1928 research on strategic games, which gave the discipline a mathematical character. In 1944, John von Neumann and Oskar Morgenstern published The Theory of Games and Economic Behavior, which systematized game theory and introduced it into modern economics [31]. From the 1960s onwards, the theory attracted not only mathematicians but also economists, rapidly advancing due to its robust theoretical foundations and practical success. After the 1980s, the development of more advanced models for addressing complex economic and social problems turned game theory into a vital analytical tool [61].

Over time, game theory has found applications not only in economics and finance but also in disciplines such as biology, genetics, engineering, industry, social sciences, sports sciences, and computer science. Particularly in economics and finance, game theory has guided both theoretical and applied research on market functioning, competitive strategies, auctions, portfolio management, and market equilibria. Concepts such as the Nash equilibrium have become indispensable analytical tools, showing how equilibrium states arise in strategic interactions [6, 27]. In this sense, game theory continues to provide a multidimensional perspective in strategic decision-making and market analysis, contributing significantly to interdisciplinary research.

3.1 Game Theory Terminology

Game theory is grounded in conceptual foundations that enable the systematic analysis of strategic interactions. These foundations are generally defined as players, strategies, payoffs, and equilibrium points [8, 32, 37, 59, 65].

3.1.1 Games and Players

One of the most fundamental concepts in game theory is the notion of players. Players are defined as actors who make decisions within strategic interactions; these actors may be individuals, firms, institutions, or even states. Each player seeks to maximize their own interests while simultaneously being influenced by the strategies of others. Therefore, game theory examines not only individual decisions but also the processes of mutual interaction [27, 65, 76, 89].

A game is defined within the framework of players' strategy sets, the payoffs or losses that result from these strategies, and the rules governing this process. In competitive environments, players do not merely pursue their own benefits; they also attempt to constrain or redirect the moves of their rivals. Thus, a game represents a decision-making environment where two or more actors engage in strategic interaction. Information asymmetry, uncertainty, and risk are significant elements in this decision-making environment [32, 59].

Games are generally divided into three categories: cooperative, non-cooperative, and mixed-motive games. In cooperative games, players form coalitions to maximize their common interests, and the resulting outcomes reflect both individual and collective benefits. In non-cooperative games, each player acts independently, with conflicts of interest becoming more pronounced as players conceal their strategies to gain advantage. Mixed-motive games, on the other hand, combine elements of both cooperation and competition, reflecting situations where players' interests partially converge and partially conflict [4, 50, 86].

In particular, zero-sum games represent situations in which one player's gain is exactly equal to the other player's loss. Conversely, in non-zero-sum games, all players may win or lose simultaneously. Hence, non-zero-sum games are of critical importance for understanding cooperation, bargaining, and negotiation processes [65, 86, 89].

In conclusion, the concepts of games and players form the foundation of the theoretical framework of game theory. The level of players' access to information, the range of available strategies, and the quality of their choices play a decisive role in shaping outcomes and equilibrium conditions within the game [4, 27, 32, 59, 76].

3.1.2 Strategies

One of the most fundamental elements of game theory is the concept of strategy. A strategy is defined as a comprehensive plan of action that specifies what moves a player will make under all possible circumstances. In other words, a strategy is not merely a momentary choice but a systematic decision rule that applies throughout the course of the game. Since players' efforts to maximize their own interests must take into account the potential moves of their opponents, strategy lies at the very core of both individual rationality and mutual interdependence [89, 99].

The concept of strategy was first introduced by John von Neumann as part of the mathematical foundation of game theory and has since been extensively developed in both theoretical and applied contexts. The decisions that players make against one another are shaped by the rules of the game, and each strategy reflects an attempt to anticipate the possible moves of rivals. Consequently, strategies constitute the basis for key solution concepts in game theory, such as the Nash equilibrium [32, 59].

In the game theory literature, strategies are generally divided into two main categories: pure strategies and mixed strategies. A pure strategy involves a player choosing a single specific action in every situation, while a mixed strategy refers to selecting among possible actions with certain probabilities. Under conditions of uncertainty, mixed strategies allow players to behave more flexibly and unpredictably. In recent years, the application of mixed strategies has expanded in fields such as artificial intelligence, algorithmic games, and market design, making them an indispensable component of modern equilibrium analysis [41, 50].

Strategies also differ depending on whether the game is static or dynamic. In static games, players make their decisions simultaneously, whereas in dynamic games, decisions are made sequentially, and past moves influence future strategies. In this context, "repeated games" and "reputation models" highlight the long-term dimensions of strategies [53].

In conclusion, strategy is not merely an abstract notion within game theory but a central concept with broad applications, ranging from economic models to political decision-making, from international negotiations to artificial intelligence algorithms. Strategies not only safeguard players' interests but also shape cooperation or competition, the resulting equilibrium conditions, and the overall functioning of the system [25].

3.1.3 Payoffs

One of the fundamental components of game theory is the concept of payoffs. In a game, players may face three basic outcomes: winning, losing, or withdrawing from the game. These outcomes are expressed as positive, zero, or negative values. In this way, the benefits players gain or the losses they incur can be represented in measurable numerical or proportional terms. An important point here is that the units of measurement must remain consistent under all conditions, ensuring that the payoffs and losses of different players can be compared reliably [88].

The results obtained by players, depending on their strategies, are systematically represented in a table known as the payoff matrix. The payoff matrix is one of the most important tools of the mathematical structure of game theory, as it demonstrates the gains or losses associated with every combination of strategies. The values in the matrix can take three forms: positive (benefit), negative (loss), or zero (neutral outcome). If the value is positive, the column player transfers or generates that amount of benefit for the row player. If it is negative, the row player pays the column player the absolute value of that number. If the value is zero, no transfer occurs [64, 68].

In a zero-sum game, where one player has n strategies and the other has m strategies, the payoff matrix is of size m × n. Each entry in the matrix, such as a_{11}, a_{12}, ..., a_{mn}, represents the payoff resulting from the chosen strategy pair, thus capturing the fundamental competitive logic of the game.

$$\begin{bmatrix} a_{11} & a_{12} & a_{13} & \cdots & a_{1n} \\ a_{21} & a_{22} & a_{23} & \cdots & a_{2n} \\ a_{31} & a_{32} & a_{33} & \cdots & a_{3n} \\ \cdots & \cdots & \cdots & \cdots & \cdots \\ a_{m1} & a_{m2} & a_{m3} & \cdots & a_{mn} \end{bmatrix} \tag{1}$$

In any payoff matrix, player A is placed in the rows, while player B is represented in the columns. If player A has m strategies and player B has n strategies, the payoff matrix becomes an m × n matrix. The entries of the matrix (a_{11}, a_{12}, ..., a_{mn}) indicate the payoffs corresponding to each pair of strategies chosen by the players [48, 84].

In the context of zero-sum games, the payoff matrix plays an even more critical role. In such games, the gain of one player is exactly equal to the loss of the other; therefore, the sum of all values in the payoff matrix is zero. This structure represents the mathematical embodiment of a perfectly competitive game. For example, if player A has m strategies and player B has n strategies, the resulting payoff matrix of size m × n specifies, through its entries, the exact gain or loss each player experiences under every strategic combination [48, 50].

Recent studies show that the payoff matrix is not only a theoretical tool but also a critical analytical method in applied economics, market design, international negotiations, and algorithmic game theory. Particularly in artificial intelligence systems and multi-agent digital platforms, payoff matrices are widely used to optimize different strategies and to model system behaviors [62, 80].

In conclusion, payoff matrices do not only display the individual gains and losses of the players but also provide a framework to understand the equilibrium structure and strategic dynamics of a game. For this reason, payoff matrices have become indispensable tools in modern game theory, both in classical economic analysis and in today's complex, data-driven decision-making processes.

3.1.4 The Outcome of the Game or the Equilibrium Point

One of the most critical concepts in game theory is the equilibrium point reached as a result of players' strategic interactions. Under the assumption that competing players proceed with unbiased strategies, the final outcome of the game is defined as the game's result or equilibrium point. The most well-known form of this concept is the Nash Equilibrium, developed by John Nash [60, 65].

Nash equilibrium refers to a situation in which no player can improve their payoff by unilaterally changing their strategy, given that the strategies of all other players remain fixed. In other words, no individual player has an incentive to deviate, since such deviation would not yield a better outcome. As such, Nash equilibrium embodies the principle of "mutual rationality" and remains one of the foundational concepts for analyzing games [32, 86].

The notion of equilibrium plays a vital role not only in theoretical discussions but also in practical applications. In financial markets, for instance, equilibrium concepts are employed to explain price formation, auction design, competitive behaviors in oligopolistic markets, and strategic decision-making in international relations [59, 89]. Moreover, extended forms of Nash equilibrium—such as subgame perfect equilibrium, Bayesian equilibrium, and the evolutionarily stable strategy—are widely applied today, especially in addressing games that involve uncertainty and asymmetric information [34, 53].

Recent studies demonstrate that Nash equilibrium has also found applications in artificial intelligence, machine learning, and algorithmic game theory. In particular, in multi-agent systems, Nash equilibrium serves as a basis for the coordination and cooperation of autonomous agents [50, 62]. More recently, AI-supported equilibrium analyses have been developed to predict player behavior in complex digital platforms [18, 80]. Additionally, research in behavioral economics has revealed discrepancies between Nash equilibrium predictions and actual human decision-making, enriching classical equilibrium theory with experimental and psychological insights [15, 20].

In conclusion, the outcome of the game or the equilibrium point lies at the core of game theory from both theoretical and practical perspectives. Nash equilibrium and its extensions not only reflect the maximization of individual payoffs but also represent the rational balance of strategic interdependence among players.

4. Financial Markets

Economic units initially use their own internal resources to meet their funding needs. When the savings of an individual or institution can be allocated to investment, this condition is defined in the literature as having "financial capacity." However, when internal resources are insufficient, investors must turn to other economic institutions to meet their financing requirements. At this point, investors direct their demands to companies or institutions with surplus funds and satisfy their needs through financial markets [97].

There are three primary economic units within economic activity: households, firms, and the government. These units may experience imbalances in their income–expenditure levels over time. In some periods, income exceeds expenditure, while in others, expenditures surpass income. Thus, economic units must either invest their savings or access financing sources to balance income and expenditure [45]. Units with a savings surplus make their funds available in exchange for a return, whereas those with a savings deficit seek to utilize these resources.

The fundamental rationale for the existence of financial markets lies in the inability of individual or institutional actors to balance savings and investment independently. Consequently, the mechanisms that bring together suppliers and demanders of funds constitute financial markets. In a country, the institutions that facilitate resource flows between fund suppliers and demanders, the securities that make these transactions possible, and the legal–administrative framework that regulates these interactions collectively form the structure of financial markets [13, 16].

Today, financial markets extend beyond traditional debt instruments and securities, having become increasingly complex due to technological advances and globalization. FinTech applications, crypto-assets, digital payment systems, and green bonds are now integral components of modern financial markets. Within this context, financial markets play a critical role in supporting economic growth, ensuring efficient capital allocation, and distributing risk [7, 49].

Financial markets are indispensable both at the micro and macro levels for ensuring economic stability, regulating the flow of funds, and enabling the efficient allocation of resources. Therefore, the institutions, instruments, and regulations within financial systems must be continuously updated in light of contemporary developments. Figure 1 presents the components of financial systems [13].

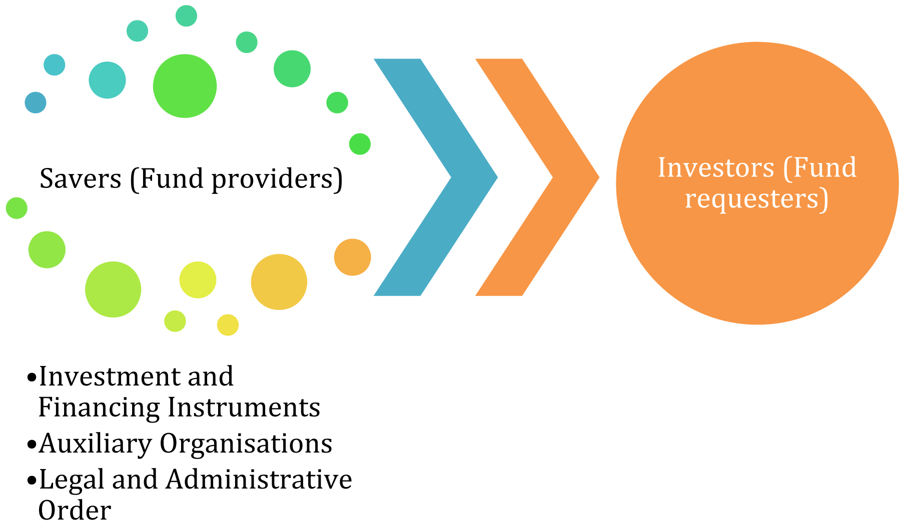

Figure 1. Components of the Financial System [13]

4.1 Types of Financial Markets

Financial markets can be classified from different perspectives based on their structure and functions. One of the most common classifications is made according to the maturity of funds being lent. In this context, markets are generally examined under two main groups: money markets and capital markets [56, 96].

4.1.1 Markets According to the Maturity of Funds Lent

Money Markets: Money markets are markets where financial instruments with maturities typically of one year or less are traded. In these markets, the supply and demand for funds are met through short-term instruments. Therefore, the risk of default is relatively low, while liquidity is high. These features make money markets critical for the short-term fund management of the economic system [13, 72, 96]

The main instruments used in money markets include checks, promissory notes, bills of exchange, commercial papers, certificates of deposit, repurchase agreements (repos), and treasury bills. Since these instruments are short-term, price fluctuations are limited while liquidity remains high. Especially during periods of high interest rates, investors tend to prefer short-term instruments, which increases the importance of money markets [28, 96].

Capital Markets: Capital markets are markets where the supply and demand for funds with maturities longer than one year meet. Because the maturity is longer, interest rates and risk factors are relatively higher. There is a continuous flow of funds between money markets and capital markets, and the two operate in a complementary manner [7, 45, 49].

Capital markets are further divided into primary and secondary markets:

•Primary Markets: These are markets where financial instruments (such as stocks, bonds, and promissory notes) that have never been traded before are issued and enter circulation for the first time. Thus, they serve as a direct source of capital for institutions demanding funds.

•Secondary Markets: These are markets where previously issued securities are traded among investors. Secondary markets not only provide liquidity for investors but also contribute to the pricing of financial assets and the improvement of market efficiency [5, 45, 56]

4.1.2 Markets by Transactions

Financial markets can also be classified according to the nature of the transactions carried out, and are divided into organized (regulated) markets and over-the-counter (OTC) markets [45, 56]

Organized Markets: Organized markets are those in which transactions take place within centralized exchanges under a set of well-defined rules. Their key characteristics include:

- The presence of a physical location or, in modern settings, advanced electronic trading platforms,
- Transactions conducted under strict supervision and regulatory oversight,
- Standardized rules and procedures governing transactions.

Financial instruments traded in organized markets typically operate under transparent pricing mechanisms and are subject to strong investor protection regulations. Examples include the Tokyo Stock Exchange, the New York Stock Exchange (NYSE), and Borsa Istanbul [45, 81].

Over-the-Counter (OTC) Markets: In contrast, OTC markets are decentralized markets where transactions are executed outside centralized exchanges, without a physical trading floor. Trades are often carried out via telecommunications networks, telephones, computer systems, or electronic platforms. The main feature of OTC markets is that oversight and regulation are either limited or more flexible. This provides participants with greater freedom of negotiation and the possibility of designing customized contracts. Examples include the London OTC market and the global foreign exchange (Forex) markets [5, 46, 96].

In recent years, the scale of OTC markets has expanded significantly, especially with the growth of derivative instruments, foreign exchange trading, and cryptocurrency markets. This development has raised critical questions about transparency, regulation, and systemic risk management in global financial systems [7, 9].

5. The Role of Game Theory in Financial Markets and Strategic Decision-Making

5.1 The Role of Game Theory in Financial Markets

In financial markets, game theory is used to model dynamic processes such as competition and cooperation, arbitrage and pricing strategies, and speculation and manipulation. The analysis of strategic interactions is critically important for understanding market mechanisms and enhancing rational decision-making processes [65, 91].

5.1.1 Traditional / Competition and Cooperation

In traditional competitive models, long-term information sharing is highly limited. The most important criterion in supplier selection is the price of the product to be purchased. Parties prefer to act independently while minimizing communication; information transfer is restricted to the features of the demanded products [63, 82].

Conversely, the importance of cooperative relationships has grown steadily. For example, when British manufacturers began to lose their global competitive advantage, they regained it by transforming competitive supplier relationships into collaborative models [58]. In cooperative market structures, the objective is not only to reduce prices but also to increase risk-sharing, knowledge transfer, and innovation capacity [11, 73].

5.1.2 Arbitrage and Pricing Strategies

Game theory is a powerful tool for analyzing arbitrage opportunities and pricing models. Arbitrage pricing strategies explain how investors optimize the risk–return balance. Within this framework, investors account for factors such as default risk, interest rate risk, market risk, purchasing power risk, and management risk to establish a risk–return relationship [30].

In modern literature, this approach has been extended through the Arbitrage Pricing Theory (APT) and game theory-based pricing methods. It has been demonstrated that, especially in multi-period models, investors' strategic behaviors play a decisive role in price stability [30]. Furthermore, in the context of artificial intelligence and algorithmic trading, game theory-based pricing models have emerged as a current research area for understanding market microstructure [10, 26].

5.1.3 Speculation and Manipulation

Manipulation refers to the attempts of individuals or institutions to influence markets for their own benefit by spreading false or misleading information [21, 66]. Such practices often involve generating false news, spreading rumors, or artificially inflating trading volumes [98].

Speculation, on the other hand, is the risky trading activity based on expectations about future price movements. Game theory models how speculation and manipulation can distort market pricing [78]. Recent studies highlight that speculative activities have been amplified by algorithmic trading, cryptocurrency markets, and the influence of social media [12, 19, 83].

5.2 Market Equilibria and Game Theory

Game theory is applied to the analysis of different types of market equilibria, such as perfect competition, oligopoly equilibrium, and speculative bubbles and crises.

Perfect Competition Equilibrium: Markets with many buyers and sellers where prices are not influenced by individual firms. Game theory is used to explain price formation and optimal strategies in these settings [3].

Oligopoly Equilibrium: Emerges in markets dominated by a small number of players. An example is when major banks set interest rates in the banking sector. Cournot, Bertrand, and Stackelberg models are widely used in these markets [91, 93].

Speculative Bubbles and Crises: Occur when players imitate one another, causing asset prices to deviate excessively from their intrinsic values, followed by sudden collapses. Typical examples include the 2000 Dot-Com Bubble and the 2008 Global Financial Crisis [1, 33, 47, 75]. More recently, bubbles observed in cryptocurrency markets have also been analyzed within the framework of game theory [17, 19].

5.3 Strategic Decision-Making

Strategic decisions are defined as choices made in environments characterized by intense competition, constant change, high levels of uncertainty, risk, and complexity. These decisions have long-term implications and directly shape the future direction of the organization. The primary objective of strategic decisions is to secure a more advantageous position relative to competitors and to ensure sustainable competitive advantage [70, 92].

Such decisions are expected to be original, pioneering, innovative, sustainable, and effective in addressing dynamic environmental conditions and organizational needs [69]. By their nature, strategic decisions often require the integration of analytical reasoning, managerial foresight, and adaptive capabilities. The fundamental characteristics of strategic decision-making are summarized in Table 2 [69].

One of the most decisive factors in the strategic decision-making process is the nature of the environment in which the decision is made. The decision-making environment directly influences the quality of the decision, as it determines the type of information available to managers, the level of uncertainty, and the perception of risk. Within this framework, strategic decisions are addressed under different classifications. In the literature, decision types are examined under five main categories: (i) decisions based on the environment in which they are made, (ii) decisions according to the level of management, (iii) decisions according to their structure, (iv) decisions based on the degree of interconnection, and (v) decisions according to the evaluation criteria considered [35, 69].

Table 2. Fundamental Features of Strategic Decision-Making

Category	Definition	Practical Implication
Creative and Innovative	The ability to adapt to change and respond to competitive conditions	Creating new businesses in competitive settings by disrupting (transforming) existing industries
Change-Oriented	Persistently pursuing transformation and development in the face of evolving expectations, needs, products, time, space, environment, and ideas	Anticipating the future of the organization and striving to differentiate from competitors
Sustainable	Ensuring continuity in competition, growth, permanence, and eco-environmental protection	Expanding the organization's access to resources and markets
Effective	The ability to set the right goals and achieve them, ensuring decision-makers reach accurate outcomes	Using resources at the right place and time while minimizing risks

This classification demonstrates that the strategic decision-making process cannot be reduced to a single dimension; rather, it is shaped by a combination of factors such as the level of information, risk conditions, organizational hierarchy, the structural characteristics of the decision, and the diversity of criteria. Particularly in recent years, with the growing prevalence of uncertain and risky decision-making environments, behavioral approaches [44], multi-criteria decision-making techniques [77, 94], and data-driven decision support systems [74] have become increasingly utilized.

Therefore, distinguishing decision types in this way enables a more systematic analysis of strategic decision-making processes and provides managers with the ability to make more rational choices under varying conditions [22, 38].

5.3.1 Decisions According to the Environment in Which They Are Made

The decision-making environment is one of the most critical factors shaping the nature of the decision process. In the literature, these environments are generally classified under three categories [22, 35, 36]:

•Certain Decision-Making Environment: Situations in which decision alternatives and possible outcomes are known, and information flow is relatively complete. Rational decision-making models dominate in such contexts.

•Uncertain Decision-Making Environment: Situations characterized by a lack of information, where probabilities of outcomes are unknown. Decision-makers typically operate under bounded rationality.

•Risky Decision-Making Environment: Circumstances where alternatives and probabilities are known, but outcomes remain uncertain. Decisions are often based on measures such as expected value, variance, and standard deviation. This environment is particularly common in modern financial markets [44, 55].

5.3.2 Decisions According to the Level of Management

Decisions can also be classified according to the hierarchical level of management [35, 51]:

•Strategic Decisions: Taken by top management, these decisions are long-term, complex, and have broad organizational consequences.

•Tactical Decisions: Made by middle-level managers, these decisions serve to implement and operationalize strategic goals.

•Operational Decisions: Taken by lower-level managers, these decisions focus on routine, day-to-day operations.

5.3.3 Decisions According to Their Structure

The structural nature of decisions further determines the characteristics of the decision-making Process [35, 51]:

•Structured Decisions: Routine and repetitive, these decisions follow standardized procedures.

•Semi-Structured Decisions: Partially guided by established procedures, but requiring intuition and judgment for unresolved aspects.

•Unstructured Decisions: Novel, non-routine decisions made under conditions of high uncertainty and complexity.

5.3.4 Decisions According to the Degree of Interconnection

Decisions may also be distinguished based on their degree of interdependence [35, 51]:

•Single-Stage Decisions: Independent decisions where outcomes are determined by a single choice.

•Multi-Stage Decisions: Sequential decisions in which one decision affects subsequent ones, creating a chain of interrelated outcomes.

5.3.5 Decisions According to Evaluation Criteria

Finally, decisions may be classified based on the number of criteria considered in the evaluation process [35, 51, 77]:

•Single-Criterion Decisions: Decisions based on the optimization of a single objective or criterion.

•Multi-Criteria Decisions: Decisions involving the simultaneous optimization of multiple objectives. In contemporary practice, these decisions are increasingly supported by Multi-Criteria Decision-Making (MCDM) methods, such as the Analytic Hierarchy Process (AHP).

6. Conclusion

Game theory emerges as an indispensable tool in analyzing complex and uncertain situations encountered both in daily life and in professional contexts. The resolution of strategic interactions through mathematical models allows for a deeper understanding of the processes of competition and cooperation among individuals, firms, and institutions. In particular, the determination of strategies and the accurate analysis of the information derived from these strategies are of critical importance for rational decision-making processes in markets. The reliability and timeliness of the datasets used directly affect the accuracy of the results obtained, which clearly highlights the necessity of proper modeling.

In this study, the role of game theory in strategic decision-making and market equilibria within financial markets has been examined, with national and international literature comparatively assessed in terms of objectives, methods, and findings. The results show that game theory makes significant contributions to portfolio optimization, risk management, market liquidity, pricing strategies, and blockchain/DeFi-based systems. Cooperative models provide advantages in risk sharing and diversification, while non-cooperative models generate more conservative strategies under uncertainty. This contrast offers a strong framework for explaining the strategic behaviors of market participants.

Nevertheless, certain limitations in the literature are noteworthy. Most studies remain at a theoretical level, while empirical validations and behavioral dimensions are insufficiently addressed. Applications concerning blockchain and cryptocurrency markets are promising; however, they face critical challenges such as regulatory uncertainties, scalability issues, and data reliability. Furthermore, the integration of experimental economics and AI-supported game theory models into financial markets remains quite limited.

In terms of future research, the following concrete directions stand out:

1. Broader applications of game theory in cryptocurrency and DeFi ecosystems,
2. Integration of behavioral game theory with investor psychology in decision-making models,
3. Development of game theory–based early warning mechanisms for speculative bubbles and financial crises,
4. Integration of multi-criteria decision-making (MCDM) methods with game theory,
5. Enhancement of market forecasts through AI-supported algorithmic game theory models.

In conclusion, game theory is not merely a theoretical modeling tool in financial markets; it also stands out as a powerful analytical approach that makes strategic decision-making processes more rational, effective, and realistic. This study provides both conceptual and applied contributions to the existing literature, while also offering concrete recommendations and shedding light on new research avenues for scholars and policymakers.

References

[1] Abreu D, Brunnermeier MK. Bubbles and crashes. Econometrica. 2003; 71(1): 173-204.

[2] Acar M, Ünal M. Multi-Teorik Portföy Optimizasyonu: Oyun Teorisi ile Bir Uygulama. Balkan

ve Yakın Doğu Sosyal Bilimler Dergisi. 2022; 8(1): 79-90.
[3] Akal M., Olgun MF. Tam Rekabetçi Piyasa Deneyimleri Üzerine Bir Bakış. Kastamonu Üniversitesi İktisadi ve İdari Bilimler Fakültesi Dergisi. 2021; 23(1): 45-61.
[4] Aktan CC, Bahçe AB. Kamu Tercihi Perspektifinden Oyun Teorisi. Hukuk ve İktisat Araştırmaları Dergisi. 2013; 5(2): 93-117.
[5] Allen F., Gu X, Kowalewski O. Financial structure, economic growth and development. In Handbook of finance and development. Edward Elgar Publishing; 2018.
[6] Aumann R J. Game theory ın the new palgrave a dictionary of economics. New York: Stockton; 1987.
[7] Beck T, Maksimovic V. Financial and legal constraints to firm growth: Does size matter?. World Bank Publications; 2002.
[8] Bennett PG. Modeling decisions in IR: Game Theory and Beyond, Mershon International Studies Review. 1995; 39: 19-52.
[9] BIS (Bank for International Settlements) OTC derivatives statistics at end-June 2019. BIS Quarterly Review; 2019. https://www.bis.org.
[10] Biais B, Hombert J, Weill PO. Equilibrium pricing and trading volume under preference uncertainty. The Review of Economic Studies. 2014; 81(4): 1401-1437.
[11] Brandenburger A, Nalebuff B. Co-opetition. Crown Business; 2021.
[12] Brunnermeier MK, Oehmke M. Bubbles, financial crises, and systemic risk. In G. Constantinides; 2013.
[13] Büker S, Bayar D. Finansal Yönetim. Anadolu Üniversitesi Yayınları, Eskisehir; 2000.
[14] Camerer CF. Behavioral Game Theory: Experiments in Strategic Interaction. Princeton University Press; 2003.
[15] Camerer CF. Behavioral game theory: Experiments in strategic interaction. Princeton University Press; 2011.
[16] Canbaş S. Finansal piyasalar. İstanbul: Beta Yayınları; 1997.
[17] Cheah ET, Fry J. Speculative bubbles in Bitcoin markets? An empirical investigation into the fundamental value of Bitcoin. Economics letters. 2015; 130: 32-36.
[18] Chen X, Deng X, Teng SH. Settling the complexity of computing two-player Nash equilibria. Journal of the ACM. 2007; 53(2): 1-53.
[19] Corbet S, Lucey B, Urquhart A, Yarovaya L. Cryptocurrencies as a financial asset: A systematic analysis. International Review of Financial Analysis. 2019; 62: 182–199.
[20] Crawford VP, Costa-Gomes MA, Iriberri N. Structural models of nonequilibrium strategic thinking: Theory, evidence, and applications. Journal of Economic Literature. 2013; 57(1): 5–62.
[21] Çelik K. Finansal Bilgi Manipülasyonu ve Manipülasyon Tespitine Yönelik BIST'te Bir Uygulama. Yüksek Lisans Tezi. Hitit üniversitesi, Sosyal Bilimler Enstitüsü, Çorum; 2016.
[22] Dean JW, Sharfman MP. Does decision process matter? A study of strategic decision-making effectiveness. Academy of Management Journal. 1996; 39(2): 368–396.
[23] Deng XT, Li ZF, Wang SY. A minimax portfolio selection strategy with equilibrium. E. J. of Operational Research. 2005; 166: 278-292.
[24] Dutta PK. Strategies and Games. Cambridge, Massachusetts, U.S.A: MIT Press; 2001.
[25] Easley D, Kleinberg J. Networks, crowds, and markets: Reasoning about a highly connected world. Cambridge University Press; 2010.
[26] Easley D, López de Prado M, O'Hara M. Flow toxicity and liquidity in a high-frequency world. The Review of Financial Studies. 2012; 25(5): 1457–1493.
[27] Evyapan B. Oyun Teorisi ve İMKB' de Sektörel Bir Uygulama. Yüksek Lisans Tezi, Dokuz Eylül Üniversitesi Sosyal Bilimler Enstitüsü; 2009.
[28] Fabozzi FJ, Mann SV. The handbook of fixed income securities (8th ed.). McGraw-Hill; 2012.
[29] Farias CA, Vieira W da C, dos Santos, ML. Portfolio Selection Models: Comparative Analysis and Applications to The Brazilian Stock Market. Revista De Economia E Agronegócio. 2015;

4(3): 1-22.
[30] Francis JC. Investments: Analysis and management (5th ed.). McGraw-Hill; 1993.
[31] Friedmann JW. Game Theory with Applications to Economics. New York: Oxford University Pres; 1996.
[32] Fudenberg D, Tirole J. Game Theory. MIT Press; 1991.
[33] Garber PM. Famous first bubbles: The fundamentals of early manias. mit Press; 2001.
[34] Gintis H. Game theory evolving: A problem-centered introduction to modeling strategic interaction (2nd ed.). Princeton University Press; 2009.
[35] Güngör S, Özcan U. Karar Kuramı ve Karar Verme. Avrupa Bilim Ve Teknoloji Dergisi. 2022; 33: 119-125.
[36] Harrison EF. The managerial decision-making process (5th ed.). Houghton Mifflin; 1999.
[37] Hausken K, Welburn JW, Zhuang J. A review of game theory and risk and reliability analysis in infrastructures and networks. Reliability Engineering & System Safety. 2025; 261: 1-26.
[38] Hu M, Don HJ, Worth DA. Distributional dual-process model predicts strategic shifts in decision-making under uncertainty. Communications Psychology. 2025; 3(61): 1-15.
[39] Huang K. The strategic influence of game theory on financial decision-making. Proctor Academy. 2025; 94-102.
[40] Ibrahim MAR, Pah CH, Islam A, Bahaludin H. Cooperative Game Theory Approach for Portfolio Sectoral Selection Before and After Malaysia General Elections: GE13 versus GE14. audi Journal of Economics and Finance 2020; 4(08): 390-399.
[41] Jackson MO, Zenou Y. Games on networks. In P. Young & S. Zamir (Eds.), Handbook of game theory with economic applications. 2015; 4: 95-163.
[42] Janan F, Li W, Chen Y. (2025). Evolutionary game and sustainable financing in blockchain-based energy trading. Energy Economics. 2025; 127: 106–123.
[43] Jiang Y, Zhou K, Lu X, Yang S. Electricity trading pricing among prosumers with game theory-based model in energy blockchain environment. Applied Energy, Elsevier, 2020; 271(C).
[44] Kahneman D, Tversky A. Choices, values, and frames. American psychologist. 1984; 39(4): 341.
[45] Karan MB. Yatırım Analizi ve Portföy Yönetimi. Gazi Yayınevi, Ankara; 2003.
[46] Kariya T, Liu RY. Options, futures and other derivatives. In Asset Pricing: -Discrete Time Approach Boston, MA: Springer US; 2003.
[47] Kindleberger CP, Manias P, Crashes A. History of financial crises. London: Macmilla.1996.
[48] Lange O. Introduction to econometrics. Pergamon Press; 1971.
[49] Levine R. Finance and growth: Theory and evidence. In P. Aghion & S. Durlauf (Eds.), Handbook of economic Growth. 2005; 1(A): 865–934.
[50] Leyton-Brown K, Shoham Y. Essentials of game theory: A concise, multidisciplinary introduction. Morgan & Claypool; 2008.
[51] Lezki Ş, Sönmez H, Şıklar E, Özdemir A, Alptekin N. İşletmelerde Karar Verme Teknikleri. Eskişehir: Anadolu Üniversitesi Yayınları; 2016.
[52] Liu Z, Luong NC, Wang W, Niyato D, Wang P, Liang YC, Kim DI. A survey on blockchain: A game theoretical perspective. IEEE Access. 2019; 7: 47615-47643.
[53] Mailath G, Samuelson L. Repeated games and reputations: Long-run relationships. Oxford University Press; 2015.
[54] Mandelbrot BB. Fractals and scaling in finance: Discontinuity, concentration, risk. Springer; 2002.
[55] March JG, Shapira Z. Managerial perspectives on risk and risk taking. Management Science. 1987; 33(11): 1404–1418.
[56] Mishkin FS, Eakins SG. Financial markets. Pearson Italia; 2019.
[57] Moosakhaani M, Salimi L, Sadatipour MT, Niksokhan MH, Rabbani M. Game theoretic approach for flood risk management considering a financial model. Environmental Engineering Research. 2022; 27(6): 210368.

[58] Morris J, Imrie R. Transforming Buyer-Supplier Relations: Japanese-Style Industrial Practices in a Western Context. Basingstoke, Hampshire: Macmillan Academic and Professional; 1992.

[59] Myerson RB. Game Theory: Analysis of Conflict. Harvard University Press; 1997.

[60] Nash J. Equilibrium points in n-person games. Proceedings of the National Academy of Sciences. 1950; 36(1); 48–49.

[61] Neumann JV, Morgenstren O. Theory of Games and Economic Behaviour. New York: John Wiley and Sons. Inc; 1967.

[62] Nisan N, Roughgarden T, Tardos É, Vazirani VV. Algorithmic game theory. Cambridge University Press; 2007.

[63] Olalla MF, Sanchez JIL, Rata BM. Cooperation with suppliers as a source of innovation. African Journal of Business Management. 2010; 4(16): 3491-3499.

[64] Osborne MJ, An introduction to game theory (2nd ed.). Oxford University Press; 2020.

[65] Osborne MJ, Rubinstein A. A Course in Game Theory. MIT Press; 1994.

[66] Özcan R. Hisse Senedi Piyasalarında Manipülasyon Stratejileri. İMKB Dergisi. 2013; 49: 1-23.

[67] Özer OO. Oyun Teorisi Ve Tarımda Uygulanması. Doktora Semineri, Ankara Üniversitesi Fen Bilimleri Enstitüsü; 2004.

[68] Öztürk A. Yöneylem Araştırması. Bursa: Ekin Basım Yayın; 2016.

[69] Papatya G, Uygur MN.Stratejik Karar Verme Sürecini Etkileyen Faktörler: Uluslararası Taşımacılık Sektörü İşletmelerinde Bir Araştırma. Kafkas Üniversitesi İktisadi ve İdari Bilimler Fakültesi Dergisi. 2019; 10(19): 338-358.

[70] Pearce JA, Robinson RB. Strategic management: Planning for domestic & global competition (14th ed.). McGraw-Hill; 2015.

[71] Pekkaya, M., & Gümüş, F. H. (2021). Oyun Teorisi Yaklaşımı ile Portföy Optimizasyonu Üzerine Literatür Değerlendirmesi. Uluslararası Yönetim İktisat ve İşletme Dergisi. 2021; (17): 1-19.

[72] Pilbeam K. Finance and financial markets. Bloomsbury Publishing; 2018.

[73] Porter ME. On competition. Harvard Business Press; 2008.

[74] Power DJ. Understanding data-driven decision support systems. Information Systems Management. 2008; 25(2): 149–154.

[75] Reinhart CM, Rogoff KS. This time is different: Eight centuries of financial folly. Princeton University Press; 2009.

[76] Romp G. Game theory: Introduction and applications. Oxford, UK: Oxford University Press; 1997.

[77] Saaty TL. Decision making with the analytic hierarchy process. International journal of ervices sciences. 2008; 1(1): 83-98.

[78] Sancak, E. (2012). Finansal piyasalarda spekülasyon ve etkileri. Ekonomi Bilimleri Dergisi. 2012; 4(2): 340–356.

[79] Sancak Y. Borsa İşlemlerinde Oyun Teorisi Kullanımı. Yüksek Lisans Tezi, Sakarya Üniversitesi, Fen Bilimleri Enstitüsü; 2008.

[80] Sandholm T. The state of solving large incomplete-information games, and application to poker. AI Magazine. 2010; 31(4): 13–32.

[81] Servais JP. The International Organization of Securities Commissions (IOSCO) and the new international financial architecture: what role for IOSCO in the development and implementation of cross-border regulation and equivalence?. European Company and Financial Law Review. 2020; 17(1): 3-10.

[82] Shapiro IR, Towards effective supplier management: international comparisons. Harvard Business School Working Paper. 1986; 9: 785-062.

[83] Shiller RJ. Irrational exuberance (3rd ed.). Princeton University Press; 2015.

[84] Shubik M. Game theory in the social sciences: Concepts and solutions (Vol. 1). MIT Press;

1982.

[85] Simonian J. Portfolio selection: a game-theoretic approach. Journal of Portfolio Management. 2019; 45(6): 108-116.

[86] Slantchev BL. Game theory: Lecture notes. University of California, San Diego; 2009. Retrieved from http://slantchev.ucsd.edu/courses/gt/03-basic-models.pdf

[87] Song J, Wu Y. Post financial forecasting game theory and decision making. Finance Research Letters, 2023; 58(A): 104288.

[88] Şahin A. Risk Koşullarında Tarım İşletmelerinin Planlanması: Oyun Teorisi Yaklaşımı. Doktora Tezi, Ege Üniversitesi Fen Bilimler Enstitüsü; 2008.

[89] Tadelis S. Game theory: An introduction. Princeton, NJ: Princeton University Press; 2013.

[90] Thakor AV. Game Theory in Finance. Financial Management. 1991; 20(1): 71-93.

[91] Tirole J. Economics for the common good. Princeton University Press; 2017.

[92] Ülgen H, Mirze SK. İşletmelerde stratejik yönetim. Beta Yayıncılık; 2010.

[93] Ünsal E. Makro iktisat. Ankara: İmaj Yayıncılık; 2005.

[94] Velasquez M, Hester PT. An analysis of multi-criteria decision making methods. International Journal of Operations Research. 2013; 10(2): 56–66.

[95] Vidler A, Walsh T. Non-cooperative Liquidity Games and their application to bond market trading. 2024; arXiv preprint arXiv:2405.02865.

[96] Yıldırım E. Finansal piyasalar: Teori ve uygulama (2. baskı). Ankara: Detay Yayıncılık;2024.

[97] Yıldırım S. Oyun Teorisi İle IMKB'de Sektör Analizi. Yüksek Lisans Tezi. Marmara Üniversitesi, Sosyal Bilimler Enstitüsü, İstanbul; 2006.

[98] Yılmaz E. Hukuk Sözlüğü. Ankara, Yetkin Yayınları, 10. Baskı; 2011.

[99] Zagare FC. Game theory: Concepts and applications. Sage Publications; 1989.

[100] An H, Yang R, Ma X, Zhang S, Islam SMN. An evolutionary game theory model for the inter-relationships between financial regulation and financial innovation. The North American Journal of Economics and Finance. 2021; 55: 101341.

[101] Azarberahman A, Mohammadnejadi Modi M. A Kalman–Jacobi hybrid model for game theory: A fuzzy logic approach to financial market competition. Journal of Business and Socio-economic Development. 2025; Advance online publication. https://doi.org/10.1108/JBSED-03-2024-0030

[102] Bao Z. Application of game theory in option pricing: A binomial tree model approach. In Proceedings of the 16th International Conference on Agents and Artificial Intelligence (ICAART 2024). 2024; https://www.scitepress.org/Papers/2024/130096/130096.pdf

[103] Evangelista D, Saporito Y, Thamsten Y. Price formation in financial markets: A game-theoretic perspective. 2022; arXiv preprint arXiv:2202.11416.

[104] Koliechkina L, Vuzii V. Analysis of the application of game theory methods in financial markets and opportunities for creating automatic exchange trading systems. Modeling and Information Systems in Economics. 2023; 103: 104–116.

[105] Langenohl A. Making uncertainty operable: Social coordination through game theory in decentralized finance. Journal of Cultural Economy. 2022; 15(5): 688–703.

[106] Lavigne P, Tankov P. Decarbonization of financial markets: A mean-field game approach. 2023; arXiv preprint arXiv:2301.09163.

[107] Pagliarani S, Pesce A, Vargiolu T. Nash equilibrium in a singular stochastic game between two renewable power producers with price impact. 2024; arXiv preprint arXiv:2407.00666.

[108] Wang X. Evolutionary game theory and stock market investment behavior: Based on Chinese household finance survey. EAI Endorsed Transactions on Finance and Economics. 2023; 10(1): e5.

Research & Design

www.jrede.org

Research Article

Gamifying emotional labor: A human-centered framework for sustainable workplace emotional intelligence development through interactive learning systems

Ceren Demir*[a]

Department of Public Administration, Muğla Sıtkı Koçman University, Muğla, Türkiye

Article Info

Article History:

Received:

04 Sept 2025

Accepted:

8 Oct 2025

Keywords:

Emotional Labor, Gamification, Emotional Intelligence, Workplace Communication, Human-Centered Design, Organizational Behavior, Employee Engagement

Abstract

This study presents a theoretically-grounded gamification framework designed to address the critical challenge of maintaining emotional labor at sustainable levels within organizational contexts. The research introduces a comprehensive approach that integrates emotional intelligence development with interactive learning methodologies, specifically targeting the enhancement of empathy, communication culture, and collaborative feedback processes among employees and managers. Through the implementation of the "Emotional Journey Mapping with Emotion Cards" game system, this framework addresses three distinct player types: philanthropic, social, and questioning personalities. The methodology employs both intrinsic and extrinsic reward mechanisms while incorporating assessment tools to measure behavioral transformation and skill acquisition. Importantly, this framework represents a conceptual design proposal synthesized from existing empirical literature rather than a tested intervention. Based on meta-analytic evidence from similar interventions in the literature, this framework hypothesizes potential improvements of 10-40% in team collaboration, employee engagement, and conflict resolution effectiveness, pending empirical validation through controlled implementation studies. The study concludes that gamified approaches to emotional labor management offer significant potential for contributing to organizational wellbeing while maintaining productivity standards. Key limitations include the absence of empirical validation and dependency on organizational commitment for successful implementation. Future research should prioritize controlled implementation studies to validate the framework's effectiveness across diverse organizational contexts. This research contributes to the growing body of literature on workplace emotional intelligence and provides practical implications for human resource management practices.

1. Introduction

Emotional labor has emerged as a critical factor influencing employee wellbeing, productivity, and organizational culture in contemporary organizations [1]. Emotional labor, defined as the regulation of feelings and expressions to fulfill organizational expectations, represents a significant yet often overlooked aspect of workplace dynamics [2]. Organizations increasingly recognize emotional intelligence as critical for collaborative environments. This recognition creates urgent demand for systematic approaches that develop and sustain emotional competencies.

*Corresponding author: demircerennn@gmail.com

[a]orcid.org/0000-0001-8721-8261

DOI: http://dx.doi.org/10.17515/rede2025-010ga0904rs

The challenge of maintaining emotional labor at sustainable levels while enhancing organizational performance requires innovative solutions that address both individual development and systemic cultural transformation. Traditional training approaches often fail to create lasting behavioral change in emotional and social skills development [3]. Consequently, there is a growing interest in gamification as a methodology for enhancing learning engagement and promoting sustained behavioral modification in professional contexts.

This study introduces a comprehensive gamification framework specifically designed to address the dual objectives of strengthening emotional labor sustainability and creating improved communication cultures within organizations. By systemic cultural transformation, we refer to organization-wide shifts in norms, values, and behavioral patterns that influence how emotions are expressed, managed, and valued in professional contexts—moving beyond individual skill development to reshape collective workplace practices and expectations. The framework incorporates human-centered design principles, targeting the enhancement of emotional intelligence among both employees and managers through interactive, collaborative learning experiences. By examining the intersection of emotional labor theory, gamification principles, and organizational development practices, this research contributes to the understanding of how innovative learning methodologies can address complex workplace challenges.

The primary research question guiding this investigation focuses on how gamified approaches to emotional intelligence development can effectively support sustainable emotional labor practices while fostering improved communication cultures in organizational settings. Additionally, this study explores the differential impacts of gamification on various personality types and examines the long-term sustainability of behavioral changes achieved through game-based interventions.

2. Literature Review

2.1 Emotional Labor in Organizational Contexts

Hochschild [1] established the theoretical foundation of emotional labor by examining the commodification of human feelings in service industries. Subsequent research has expanded this concept to encompass the broader organizational context, recognizing emotional labor as a fundamental component of job performance across various sectors [4]. Contemporary studies demonstrate that excessive emotional labor demands lead to burnout, job dissatisfaction, and decreased organizational commitment. Conversely, appropriate emotional regulation enhances team cohesion and customer satisfaction [5].

Recent investigations have highlighted the bidirectional relationship between emotional labor and organizational culture, suggesting that supportive work environments can mitigate the negative effects of emotional demands while enhancing the positive outcomes associated with emotional regulation [6]. This perspective underscores the importance of developing organizational interventions that address both individual emotional competencies and systemic factors that influence emotional labor sustainability.

2.2 Emotional Intelligence and Workplace Performance

Goleman [7] conceptualized emotional intelligence as encompassing four key domains: self-awareness, self-management, social awareness, and relationship management. Empirical research has consistently demonstrated positive correlations between emotional intelligence and various organizational outcomes, including leadership effectiveness, team performance, and employee satisfaction [8]. Furthermore, studies have shown that emotional intelligence can be developed through targeted interventions, making it a viable focus for organizational development initiatives [9].

Meta-analytic reviews reveal that emotional intelligence training programs demonstrate moderate to large effect sizes when implemented with methodological rigor [10]. However, traditional training approaches often struggle with engagement and retention issues, particularly when addressing complex behavioral competencies that require sustained practice and application.

2.3 Gamification in Organizational Learning

Gamification, defined as the application of game design elements in non-game contexts, has emerged as a promising approach for enhancing learning engagement and motivation [11]. The theoretical foundation for gamification effectiveness draws from self-determination theory, which emphasizes the importance of autonomy, competence, and relatedness in driving intrinsic motivation [12].

Research demonstrates that well-designed gamification interventions significantly improve learning outcomes, engagement levels, and behavioral change sustainability [13]. Recent studies have particularly emphasized the importance of temporal focus and flow theory in gamified environments, where participants' temporal orientation affects their engagement with game-based learning activities [14]. Key design principles include meaningful challenges, immediate feedback, social interaction opportunities, and progress visualization [15]. However, the effectiveness of gamification approaches depends heavily on alignment with learning objectives and careful consideration of individual differences in motivation and engagement preferences.

2.4 Integration of Emotional Intelligence and Gamification

The intersection of emotional intelligence development and gamification represents a relatively nascent area of research, with limited empirical investigations examining the effectiveness of game-based approaches to emotional competency development [16]. Preliminary studies suggest that gamified emotional intelligence interventions may be particularly effective due to the social and experiential nature of game-based learning, which aligns well with the interpersonal focus of emotional competencies.

Recent advances in escape room design have demonstrated the educational potential of puzzle-based gamification approaches across various learning contexts [17]. The typological classification of mental, physical, and meta-puzzles provides a framework for understanding how different game mechanics can support emotional intelligence development through collaborative problem-solving and narrative engagement.

The theoretical rationale for combining these approaches rests on the assumption that emotional intelligence development requires safe spaces for practice, immediate feedback, and opportunities for reflection—all elements that can be effectively incorporated into game-based learning environments [18]. Furthermore, the collaborative nature of many emotional intelligence competencies aligns well with multiplayer game formats that emphasize teamwork and communication.

3. Methodology

3.1 Framework Development Approach

It is crucial to establish at the outset that this study adopts a theoretical framework development methodology, explicitly positioning the research as a conceptual contribution rather than an empirical investigation involving primary data collection from organizational settings. This methodological positioning aligns with design science research principles, wherein the primary objective is to create and specify innovative artifacts—in this case, a gamification framework—that address identified practical problems through theory-informed design decisions. Consequently, the framework presented herein represents a theoretically-grounded design proposal synthesized from existing research evidence, rather than a framework validated through empirical testing in actual workplace environments. This approach suits nascent research areas where limited validated tools exist, such as gamified emotional intelligence development in organizational contexts.

The gamification framework development followed human-centered design methodology through iterative cycles and stakeholder feedback. The approach integrated principles from instructional design theory, game design best practices, and organizational development methodologies to create a comprehensive intervention framework.

The framework emerged through an iterative, cyclical process rather than linear development. This process consisted of four interconnected phases: (1) systematic literature review and theoretical foundation establishment, (2) framework conceptualization and design specification, (3) player typology development based on motivational theory, and (4) assessment mechanism design informed by evaluation frameworks in organizational learning. Each of these phases is described in detail in the subsequent sections to enhance methodological transparency, enable potential replication or adaptation by other researchers and practitioners, and clearly communicate the evidence-based rationale underlying each design decision.

The framework development process consisted of five primary phases: problem definition, goal setting, target audience analysis, mechanics design, and assessment planning. Each phase incorporated evidence-based design principles and drew from established theoretical frameworks in emotional intelligence, gamification, and organizational learning.

The first phase involved a comprehensive, structured review of the peer-reviewed literature in three key areas: (a) emotional labor and emotional intelligence in organizational settings, (b) gamification theory and application in professional learning contexts, and (c) instructional design principles for behavioral competency development. Systematic database searches employed Boolean strategies across Google, Scholar and ResearchGate. Keyword combinations included: "emotional labor", "emotional intelligence training", "workplace gamification", "organizational learning", "behavior change interventions", "game-based learning", and "employee development." The search strategy specifically prioritized systematic reviews and high-impact empirical research to ensure both current validity and the inclusion of key theoretical work that has shaped the field. Inclusion criteria required that studies address organizational or workplace contexts, explicitly focus on behavioral or competency development outcomes, and provide empirical evidence or robust theoretical frameworks relevant to intervention design.

From this comprehensive literature synthesis, several key evidence-based design principles were extracted and integrated into the framework development process. These principles included: (a) the demonstrated necessity of addressing both surface-level emotional display and deep-acting emotional regulation strategies to achieve sustainable emotional labor management, as evidenced by Mesmer-Magnus et al.'s [6] discordance-congruence perspective; (b) the centrality of autonomy, competence, and relatedness in sustaining intrinsic motivation within learning interventions, as articulated in Ryan and Deci's [12] self-determination theory; (c) the proven effectiveness of collaborative, team-based learning formats in developing interpersonal and emotional competencies, as demonstrated by research on group emotional intelligence; and (d) the critical requirement for immediate feedback, progress visualization, and meaningful challenge progression in gamified learning environments to maintain long-term engagement, as established by Kapp [15] and Deterding et al. [11]. These synthesized principles served as the theoretical foundation and primary design criteria for all subsequent framework development decisions, thereby ensuring that the proposed intervention was firmly grounded in established empirical evidence rather than untested assumptions or unexamined intuitions. The hierarchical structure of this framework is illustrated in Figure 1, which demonstrates the progression from theoretical foundations through design components to expected outcomes at individual, team, and organizational levels.

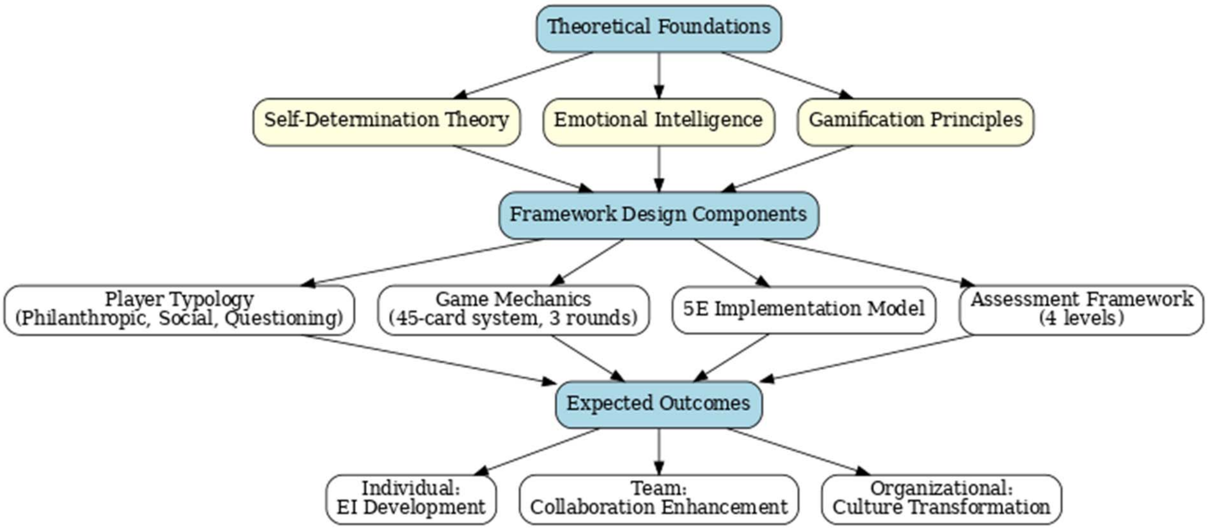

Figure 1. Total economic losses from earthquakes as % of national GDP

Note: Figure 1 illustrates the hierarchical structure of the gamification framework, showing the progression from theoretical foundations through design components to expected outcomes at individual, team, and organizational levels. This hierarchical architecture demonstrates how self-determination theory and emotional intelligence theory inform design decisions, which subsequently shape implementation strategies and multilevel outcomes.

3.2 Game Design: Emotional Journey Mapping with Emotion Cards

Building upon the theoretical foundations established through the literature review, the second phase systematically translated abstract principles into concrete, actionable design features for the gamification framework. This translation process drew extensively on established instructional design models, particularly the ADDIE framework (Analysis, Design, Development, Implementation, Evaluation) and the 5E instructional model (Entice, Enter, Engage, Exit, Extend), which together provided both structural rigor and learner-centered implementation guidance.

The core intervention, "Emotional Journey Mapping with Emotion Cards," is a collaborative card-based game targeting emotional recognition, communication skills, and empathy development. The game utilizes 45 specially designed cards, including 30 cards featuring emotion words paired with symbolic representations and 15 blank cards for participant customization. The game structure consists of three distinct phases, as detailed in Table 1, which outlines the duration, primary learning objectives, and assessment methods for each round.

Table 1. Game Structure and Learning Objectives

Game Round	Duration	Primary Learning Objective	Assessment Method
Round 1: Emotion Recognition	5 minutes	Accurate emotion identification and communication	Correct guesses (10 points each)
Round 2: Emotion Mapping	2 minutes	Emotional categorization and decision-making	Proper emotion placement (10 points each)
Reflection Phase	10 minutes	Application to workplace contexts	Qualitative feedback and discussion

Note: Table 1 was created by the author based on the game framework specifications.

The game mechanics operationalize Goleman's [7] four emotional intelligence domains, ensuring direct alignment between game activities and learning objectives. As shown in Table 1, Round 1 (Emotion Recognition, 5 minutes) explicitly targets the self-awareness and social awareness domains by requiring participants to accurately identify and communicate emotional states through multiple modalities—specifically, verbal description, visual representation, and physical action. This multimodal approach accommodates different communication preferences and learning styles while developing emotion recognition accuracy, which represents a foundational emotional intelligence skill upon which other competencies are built. Round 2 (Emotion Mapping, 2 minutes) addresses the self-management domain by necessitating rapid categorization decisions based on emotional valence (positive/negative continuum) and energy dimensions (high/low arousal levels), activities that directly mirror the cognitive processing and evaluative decision-making required for effective emotional regulation in complex workplace contexts. The Reflection Phase (10 minutes) integrates the relationship management domain by facilitating structured discussions about workplace application scenarios, collaborative problem-solving exercises, and peer feedback exchanges—activities that directly develop the interpersonal emotional competencies essential for effective team functioning and organizational citizenship.

The game incorporates multiple communication modalities, including verbal description, visual representation, and physical action, to accommodate different learning preferences and communication styles. Participants work in teams to identify emotions, categorize them according to valence and energy dimensions, and apply their insights to workplace scenarios.

3.3 Player Type Classification System

The third phase developed a theoretically-grounded player typology by synthesizing motivational theory and existing player classification frameworks in gamification research. The theoretical foundation drew primarily from Ryan and Deci's [12] self-determination theory, which identifies autonomy, competence, and relatedness as fundamental psychological needs driving human motivation across diverse contexts. Additionally, the typology incorporated insights from Bartle's [19] taxonomy of player types in gaming contexts (achievers, explorers, socializers, killers), while deliberately adapting these categories for organizational learning environments where motivational dynamics differ substantially from recreational gaming contexts due to factors such as organizational authority structures, professional identity concerns, and instrumental versus intrinsic participation motivations.

The three-category classification system was derived through systematic integration of Bartle's [19] player taxonomy, Ryan and Deci's [12] self-determination theory, and organizational motivation research, specifically adapting these frameworks for workplace emotional intelligence contexts. Bartle's [19] taxonomy identified four player types: achievers, explorers, socializers, and killers. This framework excludes the "killer" archetype—characterized by competitive dominance and disruption—as incompatible with collaborative emotional intelligence development. The remaining three types were reconceptualized through the lens of workplace motivation research. The philanthropic type emerged from synthesizing Bartle's "socializer" with organizational citizenship behavior theory [20], emphasizing prosocial contribution over mere social interaction. The social type retained Bartle's relational emphasis while incorporating principles from social learning theory [21]. The questioning type was developed by merging Bartle's "achiever" and "explorer" characteristics with competence-oriented motivational research and continuous improvement literature, reflecting analytically-oriented employees who seek systematic understanding and optimization opportunities. HR practitioners and organizational psychologists validated this adapted typology to ensure ecological validity in workplace contexts.

The framework incorporates a three-category player typology designed to address different motivational orientations and engagement preferences within the organizational context: Table 2 presents the comprehensive characteristics of each player type, including their primary motivations, onboarding strategies, scaffolding approaches, and anticipated mastery outcomes.

Table 2: Player Type Characteristics and Journey Stages

Player Type	Primary Motivation	Onboarding Strategy	Scaffolding Approach	Mastery Outcome
Philanthropic	Supporting others and creating harmonious environments	HR-organized training announcement	Team-based communication channels and peer motivation	Knowledge transfer to colleagues needing assistance
Social	Building relationships and sharing knowledge	Voluntary participation in HRM-announced training	Efficient interpersonal communication and teammate insight	Human relations awareness-raising with others
Questioning	Systematic improvement and innovative solutions	HRM selection and process inclusion	Perspective sharing through enhanced social relations	Process deficiency identification and correction

Note: Table 2 was created by the author based on the player type analysis in the framework. The motivational underpinnings of these three player types are visually represented in Figure 2, which maps each type to the core psychological needs identified in Self-Determination Theory [12].

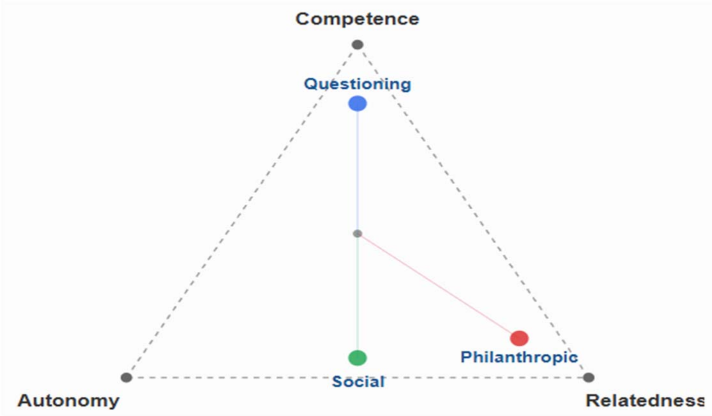

Figure 2: Player Type Motivational Profiles

Note: Table 2 maps the three player types to the core psychological needs identified in Self-Determination Theory [12]. The philanthropic type primarily aligns with relatedness (supporting others and creating harmonious environments), the social type balances relatedness with autonomy (building relationships while maintaining voluntary engagement), and the questioning type predominantly aligns with competence (systematic understanding and optimization). The triangular structure illustrates that while each type has a dominant motivational driver, all three types remain connected to all three psychological needs, reflecting the integrated nature of human motivation in organizational contexts.

As illustrated in Figure 2, the philanthropic player type was conceptualized based on prosocial motivation theory and research on organizational citizenship behavior, thereby recognizing individuals who are driven primarily by contribution to collective welfare, supporting others' success, and creating harmonious work environments that benefit all members. This type aligns closely with the "relatedness" component of self-determination theory and resonates with the "socializer" element of Bartle's taxonomy, though it is specifically adapted to emphasize workplace helping behaviors and collective benefit orientation rather than purely social interaction for its own sake. The social player type, as depicted in Figure 2, draws more directly from social learning theory [21] and research demonstrating the importance of interpersonal connection, knowledge sharing, and collaborative learning in workplace satisfaction and learning effectiveness. This type is particularly relevant in organizational gamification contexts because workplace learning is inherently social and collaborative, occurring primarily through interaction with colleagues rather than through individual study.

The questioning player type incorporates characteristics from innovation literature, problem-solving orientation research, and studies of workplace learning preferences that emphasize systematic improvement, analytical approaches, and evidence-based decision-making. This type resonates strongly with the "competence" component of self-determination theory and specifically addresses the needs of analytically-oriented employees who engage most effectively when they understand underlying mechanisms, can identify improvement opportunities, and perceive learning activities as contributing to process optimization. While these three categories necessarily simplify the full complexity of human motivation and represent ideal types rather than discrete, mutually exclusive groups into which all individuals perfectly fit, they nevertheless provide a practically useful framework for customizing implementation strategies based on workforce composition and organizational culture characteristics without requiring extensive individual psychological assessment.

Each player type was systematically characterized across four dimensions to enable practical application, as comprehensively outlined in Table 2: (a) primary motivational drivers that energize engagement and sustained participation, (b) optimal onboarding strategies for generating initial interest and facilitating entry into the learning experience, (c) scaffolding approaches that support progressive skill development and maintain motivation through challenge calibration, and (d) anticipated mastery outcomes representing the distinctive contribution each type makes to organizational learning culture. This multidimensional characterization enables organizations to design differentiated implementation pathways while maintaining a coherent overall framework structure, thereby addressing individual differences without fragmenting the intervention into disconnected components.

3.4 Assessment and Evaluation Framework

The fourth and final phase involved designing a comprehensive assessment framework to enable multi-level evaluation of intervention effectiveness, explicitly aligned with Kirkpatrick and Kirkpatrick's [3] four-level training evaluation model, which remains the predominant and most widely accepted framework for assessing organizational learning interventions. This model evaluates interventions hierarchically across four levels: Level 1 (Reaction—participant satisfaction, engagement, and affective responses), Level 2 (Learning—knowledge acquisition, skill development, and competency improvement), Level 3 (Behavior—workplace application, behavioral transfer, and sustained behavioral change), and Level 4 (Results—organizational outcomes, performance impacts, and return on investment). The framework specifies both quantitative metrics and qualitative feedback mechanisms for each level, thereby reflecting best practices in mixed-methods evaluation design that captures both measurable outcomes and nuanced insights into participant experiences.

The assessment methodology incorporates both quantitative metrics and qualitative feedback mechanisms to evaluate intervention effectiveness. Key performance indicators include badge acquisition rates, correct response frequencies, behavioral change indicators, and participant engagement levels.

At Level 1 (Reaction), assessment focuses on measuring immediate participant responses through participation rates (indicating initial appeal and accessibility), engagement indicators observed during sessions (such as active discussion, question-asking, and collaborative behavior), and satisfaction scores collected through post-session questionnaires employing Likert-scale items. At Level 2 (Learning), quantitative metrics include badge acquisition rates indicating successful completion of specific learning objectives, correct response frequencies during game rounds measuring emotion recognition accuracy and categorization skill, and pre-post comparisons using standardized emotional intelligence assessments such as the Emotional and Social Competency Inventory (ESCI) or the Trait Emotional Intelligence Questionnaire (TEIQue). At Level 3 (Behavior), assessment employs behavioral observation protocols implemented by trained observers, peer and supervisor ratings of emotional intelligence competencies using 360-degree feedback approaches, and frequency counts of specific target behaviors such as constructive conflict resolution attempts, empathetic communication instances, or emotional support provision to colleagues. At Level 4 (Results), organizational-level outcomes are assessed through longitudinal tracking of employee engagement survey scores, voluntary turnover statistics, team performance metrics on collaborative tasks, and organizational climate measures administered at regular intervals.

These projections serve multiple important methodological and practical purposes within the research design: (a) they provide theoretically-justified benchmarks against which future empirical implementations can be systematically evaluated, enabling researchers to determine whether actual outcomes align with, exceed, or fall short of evidence-based expectations; (b) they offer organizations considering adoption of the framework reasonable, research-grounded expectations for potential outcomes, thereby facilitating informed decision-making about resource allocation and implementation investment; and (c) they establish explicit hypotheses that can be formally tested through controlled implementation studies, quasi-experimental designs, or randomized controlled trials. Consequently, future research implementing this framework should systematically track actual outcomes against these theoretically-grounded projections using appropriate statistical methods to validate the framework's effectiveness, identify necessary design refinements or contextual adaptations, and contribute substantively to the evidence base on gamified emotional intelligence interventions in organizational settings.

To ensure methodological clarity, it is essential to acknowledge both the strengths and limitations of this theoretical framework development approach. The primary strength lies in the systematic, evidence-based design specification, wherein all decisions are traceable to established theoretical frameworks, empirical research findings, and meta-analytic syntheses, ensuring the framework represents a rigorous synthesis of best practices rather than untested innovation. However, this study does not present empirical data from actual organizational implementations, pilot testing, or field trials; consequently, the effectiveness claims and projected outcomes are based on extrapolation from related research rather than direct observation of this specific framework's impact. Actual implementation outcomes may vary significantly from theoretical projections due to contextual factors including organizational culture, implementation fidelity, participant characteristics, leadership support, and environmental conditions. This methodological positioning is both appropriate and valuable within intervention development research, as theoretical framework development represents an essential preliminary stage that provides the foundation for subsequent empirical investigation. Future research should build upon this theoretical foundation through controlled implementation studies, quasi-experimental designs, or randomized controlled trials to empirically validate the framework's effectiveness, identify boundary conditions, and determine necessary modifications for diverse organizational contexts.

The evaluation framework addresses five primary outcome areas: game element statistics, player level distribution, improvement metrics, permanent behavioral change indicators, and interaction frequency measures. Pre- and post-intervention assessments utilize validated emotional intelligence instruments and organizational climate surveys to measure systemic changes.

4. Implementation Framework

4.1 The 5E Model Application

The implementation strategy follows the 5E instructional model (Entice, Enter, Engage, Exit, Extend), originally developed for science education but adapted here for organizational gamification. This structured five-stage approach was selected based on its proven effectiveness in facilitating systematic participant progression through sequential learning stages while simultaneously maintaining engagement and motivation throughout the intervention lifecycle. The model's alignment with both constructivist learning principles and self-determination theory makes it particularly suitable for emotional intelligence development, where learners must actively construct understanding through experience rather than passively receive information.

Each 5E stage serves distinct pedagogical and motivational functions supporting comprehensive learning and behavioral change. The Entice stage addresses the critical challenge of initial participant recruitment and interest generation in organizational settings where training participation may be perceived as mandatory or burdensome rather than genuinely valuable. The Enter stage facilitates the transition from awareness to active participation, recognizing that initial engagement requires careful scaffolding and social support. The Engage stage represents the core learning experience where participants actively develop targeted competencies through structured game-based activities. The Exit stage ensures appropriate closure, recognition, and assessment that validate participant effort and achievement. Finally, The Extend stage addresses the crucial challenge of transfer and sustainability, ensuring that learning translates into lasting workplace behavioral change rather than remaining confined to the training context. These five stages are operationalized through specific employee actions, HR actions, and expected outcomes, as detailed in Table 3.

Table 3: 5E Model Implementation Strategy

Stage	Employee Actions	HR Actions	Expected Outcomes
Entice	Awareness of HR activities through workplace channels	Information dissemination via email and internal communications	Initial interest and curiosity generation
Enter	Participation in emotional mapping competition	Team formation ensuring emotional awareness development	Active engagement initiation
Engage	Active participation in Emotional Journey Mapping game	Team management and game facilitation	Skill development and learning reinforcement
Exit	Game completion and performance assessment	Badge, reward, and progress indicator determination	Achievement recognition and validation
Extend	Feedback provision and system personalization	Performance comparison and motivation analysis	Sustained behavioral change and transfer

Note: Table 3 was created by the author based on the 5E implementation framework. The iterative and cyclical nature of this implementation process is visually represented in Figure 3, which emphasizes how the Extend phase connects back to renewed engagement cycles.

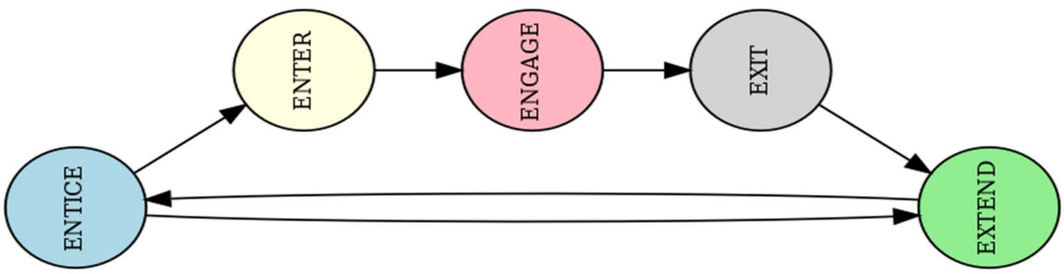

Figure 3: The 5E Implementation Cycle

Note: Figure 3 illustrates the iterative nature of the 5E implementation model, emphasizing that the Extend phase can lead to renewed engagement cycles through continuous improvement and personalization.

As shown in Figure 3, the Entice stage strategically leverages multiple organizational communication channels to generate initial awareness and curiosity among potential participants. Rather than relying solely on top-down mandates, this stage emphasizes informational messaging that highlights the personal and professional benefits of participation, thereby appealing to intrinsic motivation. Employee actions at this stage are primarily passive (awareness building), while HR actions focus on strategic information dissemination through emails, internal communications platforms, team meetings, and informal networks. The expected outcome—initial interest and curiosity generation—establishes the motivational foundation necessary for subsequent engagement.

The Enter stage, as detailed in Figure 3, facilitates the critical transition from passive awareness to active participation through carefully designed entry mechanisms. The framing of participation as involvement in an "emotional mapping competition" serves multiple strategic purposes: it introduces game-like elements that reduce anxiety associated with formal training, creates social motivation through team-based participation, and positions the activity as an opportunity for achievement rather than a remedial intervention. HR actions during this stage focus on team formation that ensures diverse composition and emotional awareness development potential, recognizing that team dynamics significantly influence learning outcomes. The expected outcome—active engagement initiation—represents successful onboarding into the learning experience.

According to Figure 3, the Engage stage constitutes the primary learning experience where participants actively develop emotional intelligence competencies through structured gameplay. Employee actions involve full participation in the Emotional Journey Mapping game, including emotion recognition activities, categorization exercises, and collaborative discussions. HR actions shift to facilitation roles that involve team management, game administration, conflict resolution, and ensuring adherence to game rules while maintaining psychological safety. The expected outcomes—skill development and learning reinforcement—represent the core pedagogical objectives of the intervention, with learning occurring through experiential practice, immediate feedback, and social interaction.

Figure 3 outlines how the Exit stage provides appropriate closure to the game experience while ensuring recognition and validation of participant achievement. Employee actions include game completion and participation in performance assessment activities that may involve self-reflection, peer evaluation, or formal testing. HR actions focus on determining and distributing badges, rewards, and progress indicators that recognize different levels of achievement and competency development. The expected outcome—achievement recognition and validation—addresses fundamental psychological needs for competence acknowledgment and social recognition, which are essential for sustaining motivation and reinforcing the value of participation.

As indicated in Figure 3, the Extend stage addresses the crucial challenge of ensuring that learning transfers to actual workplace contexts and produces sustained behavioral change rather than temporary engagement spikes. Employee actions include providing feedback on the intervention experience, identifying opportunities for personalization based on role-specific needs, and committing to specific behavioral goals for workplace application. HR actions involve conducting performance comparisons across teams or departments, analyzing engagement patterns and learning outcomes, and developing strategies to maintain motivation beyond the initial intervention. The expected outcome—sustained behavioral change and transfer—represents the ultimate success criterion, as emotional intelligence development only generates organizational value when it translates into improved workplace behaviors, enhanced communication patterns, and more effective emotional labor management.

This structured implementation approach offers several advantages over less systematic intervention strategies. First, it provides clear role definition for both employees and HR professionals at each stage, reducing ambiguity and facilitating coordinated action. Second, it ensures that critical implementation elements are not overlooked or inadequately addressed, as each stage has explicit action requirements and outcome expectations. Third, it enables systematic evaluation of intervention effectiveness at each stage, allowing organizations to identify and address implementation challenges before they compound. Finally, it aligns implementation strategy with established learning theory and instructional design principles, increasing the likelihood of achieving intended outcomes. However, successful implementation requires adequate HR capacity, organizational support, and flexibility to adapt the model to specific organizational contexts while maintaining its core structural elements.

4.2 Reward System Architecture

The reward system incorporates both intrinsic and extrinsic motivational elements, designed to address different player preferences and sustain long-term engagement. Intrinsic rewards focus on recognition, access privileges, and status indicators, while extrinsic rewards include tangible benefits such as vouchers and holiday opportunities.

The achievement progression system includes three levels: novice (first-time participants), expert (minimum three departmental participations), and master (inter-departmental competition promotion). This tiered approach provides clear advancement pathways while maintaining motivation across different experience levels.

5. Results & Discussion

5.1 Projected Performance Improvements

Based on established research, the framework projects significant improvements across multiple organizational metrics. Employee engagement and satisfaction improvements are estimated at 10-30%, reflecting the enhanced sense of recognition and competency development that typically accompany successful emotional intelligence interventions.

Team collaboration and performance metrics demonstrate projected improvements of 15-40%, attributable to enhanced communication skills, empathy development, and conflict resolution capabilities. These estimates align with existing research demonstrating the positive correlation between emotional intelligence and team effectiveness [22].

Turnover reduction projections of 10-25% reflect the anticipated improvement in workplace satisfaction and employee connection that typically result from enhanced emotional intelligence and communication culture. Additionally, innovation and creativity increases of 10-30% are projected based on the improved psychological safety and open communication fostered by the intervention.

5.2 Framework Strengths and Limitations

The framework demonstrates several notable strengths, including its comprehensive approach to both individual skill development and organizational culture transformation. The integration of multiple learning modalities accommodates diverse learning preferences, while the team-based format addresses the inherently social nature of emotional intelligence competencies. Furthermore, the theoretically-grounded design synthesizes established principles from self-determination theory, emotional intelligence research, and gamification science, providing a robust conceptual foundation. The framework's flexibility in accommodating different player types (philanthropic, social, and questioning) enables customization based on workforce characteristics, while the structured 5E implementation model offers clear procedural guidance for systematic deployment across varied organizational contexts.

However, several substantial limitations require acknowledgment for appropriate interpretation and realistic implementation. First and fundamentally, this framework represents a theoretical design proposal that has not undergone empirical validation through organizational implementation. The projected outcome improvements are derived from meta-analytic evidence on related interventions rather than direct empirical observation of this specific framework's effectiveness. Consequently, actual implementation results may vary significantly from theoretical projections based on contextual factors, organizational culture characteristics, implementation fidelity, and participant demographics.

Second, the framework's effectiveness depends heavily on sustained organizational commitment, adequate resource allocation, and supportive leadership. Organizations lacking robust human resource infrastructure, dedicated training budgets, or leadership buy-in may encounter significant implementation challenges. The requirement for 40-60 hours of HR facilitation time per intervention cycle, combined with participant time away from regular duties, necessitates substantial organizational investment that may not be feasible in resource-constrained environments.

Third, gamification approaches carry inherent risks that require careful management. The competitive elements embedded within the framework (point systems, badges, inter-team comparisons) may inadvertently generate performance anxiety, interpersonal conflict, or unhealthy competitive dynamics. These risks are particularly salient in high power-distance cultures or organizationally anxious environments, potentially undermining the collaborative spirit essential for emotional intelligence development. Participants who perceive themselves as "losing" or performing poorly relative to peers may experience reduced psychological safety, potentially triggering disengagement or defensive behaviors that contradict the intervention's core objectives. Additionally, gamification systems are vulnerable to gaming behaviors, wherein participants focus on maximizing scores through strategic manipulation rather than genuinely developing emotional competencies. For instance, participants might prioritize rapid correct responses over thoughtful reflection, or engage in performative empathy displays to earn recognition rather than cultivating authentic emotional understanding.

Fourth, cultural factors significantly influence the framework's applicability and effectiveness across diverse organizational contexts. Emotional expression norms, display rules, and the acceptability of discussing feelings in professional settings vary substantially across cultures. The framework was conceptualized primarily within Western organizational paradigms that emphasize individualism, direct emotional communication, and egalitarian team structures. Organizations operating in high power-distance cultures, collectivist societies, or contexts where emotional restraint is professionally valued may require substantial adaptations. For example, the framework's emphasis on openly sharing emotional experiences and providing peer feedback may conflict with cultural norms favoring hierarchical deference, emotional reserve, or indirect communication. Similarly, the player typology's emphasis on individual motivational profiles may inadequately capture collectivist orientations wherein group harmony supersedes personal preferences. Cross-cultural implementations would necessitate careful examination of emotional labor conceptualizations, appropriate emotional display expectations, and culturally-congruent facilitation approaches.

Fifth, the framework's focus on emotionally-intensive content necessitates adequately trained facilitators capable of managing complex group dynamics and supporting participants through potentially vulnerable experiences. Facilitators require specialized competencies beyond standard training delivery skills, including emotional attunement, conflict de-escalation capabilities, trauma-informed approaches, and ethical sensitivity regarding emotional disclosure boundaries. Discussing workplace emotional experiences may surface unresolved conflicts, trigger distressing memories, or expose interpersonal tensions that require skillful navigation. Facilitators lacking appropriate training may inadvertently create unsafe learning environments, mismanage emotional disclosures, or fail to recognize participants experiencing psychological distress. Consequently, organizations must invest in comprehensive facilitator training programs that address psychological safety creation, ethical boundaries in emotional work, crisis response protocols, and culturally-responsive facilitation techniques. This training requirement represents an additional implementation cost and prerequisite that organizations must address before deployment.

Finally, the long-term sustainability of behavioral changes achieved through gamification remains an open empirical question. While the framework incorporates design elements intended to promote transfer and maintenance—such as workplace application exercises, reflection phases, and extended follow-up activities—the extent to which game-based emotional intelligence development translates into sustained workplace behavioral modification requires longitudinal investigation. Organizations should anticipate the need for reinforcement strategies, periodic refresher interventions, and environmental supports that maintain and strengthen initial learning gains beyond the immediate intervention period.

5.3 Implications for Practice

The practical implications of this framework extend beyond immediate training applications to encompass broader organizational development strategies. The human-centered design approach provides a replicable methodology for developing gamified interventions targeting other organizational competencies.

When compared to existing emotional intelligence training models, this framework offers several distinctive advantages. Traditional classroom-based emotional intelligence programs, such as those described by Cherniss and Goleman [8], typically employ lecture-based instruction, role-playing exercises, and individual reflection activities. While effective for knowledge transfer, these approaches often struggle with sustained engagement and workplace application. Digital emotional intelligence platforms, such as competency-based e-learning modules, provide scalability and self-paced learning but frequently lack the social interaction essential for developing interpersonal emotional competencies. In contrast, this gamified framework combines the engagement benefits of game mechanics with the collaborative learning advantages of team-based formats, while maintaining cost-effectiveness through physical rather than technological infrastructure. Unlike purely competitive gamification systems used in some sales training contexts—which can generate anxiety and undermine psychological safety—this framework balances competitive elements with collaborative objectives, explicitly addressing multiple player motivations through typological differentiation. Compared to experiential learning interventions such as outdoor team-building exercises or simulation-based training, the card-based format offers greater accessibility, lower logistical complexity, and more direct alignment with workplace emotional intelligence competencies. The structured 5E implementation model provides clearer procedural guidance than many existing interventions, facilitating consistent deployment across organizational units while maintaining fidelity to theoretical principles.

Furthermore, the player type classification system offers insights into how different personality orientations respond to gamified learning environments, potentially informing future intervention design decisions. The integration of assessment mechanisms provides organizations with data-driven approaches to measuring intervention effectiveness and identifying areas for improvement.

6. Future Research Directions

Future research should empirically validate the framework through controlled organizational interventions examining both short-term learning outcomes and long-term behavioral sustainability. Longitudinal studies investigating the durability of emotional intelligence improvements and their impact on organizational climate would provide valuable insights into intervention effectiveness.

Comparative studies should examine gamified versus traditional emotional intelligence interventions to strengthen the evidence base for game-based professional development. Cross-cultural investigations could explore the applicability of the framework across different organizational contexts and cultural settings.

Research into the optimal balance between intrinsic and extrinsic reward systems within gamified emotional intelligence interventions would provide practical guidance for implementation decisions. Finally, investigations into the scalability of such interventions across different organizational sizes and structures would inform broader adoption strategies.

7. Conclusion

This study presents a theoretically-grounded gamification framework addressing sustainable emotional labor maintenance while enhancing workplace communication culture and emotional intelligence competencies. The "Emotional Journey Mapping with Emotion Cards" intervention represents an innovative synthesis of emotional intelligence theory, gamification principles, and human-centered design methodologies, offering organizations a structured, evidence-based approach to developing emotional competencies through engaging, collaborative learning experiences. Drawing upon established theoretical foundations in self-determination theory, instructional design models, and emotional intelligence research, the framework provides a comprehensive blueprint for organizations seeking to address the complex interplay between emotional labor demands and employee wellbeing.

The framework's primary contribution lies in simultaneously addressing individual competency development and systemic organizational transformation. By integrating Goleman's four emotional intelligence domains with evidence-based gamification design principles, the intervention moves beyond traditional, often ineffective training approaches that fail to produce lasting behavioral change. Moreover, the incorporation of player type differentiation—encompassing philanthropic, social, and questioning personalities—recognizes the heterogeneity of organizational populations and provides practical guidance for customizing implementation strategies to accommodate diverse motivational profiles. The structured 5E implementation model (Entice, Enter, Engage, Exit, Extend) further enhances practical applicability by offering clear procedural guidance that facilitates systematic deployment across different organizational contexts while maintaining theoretical integrity.

Nevertheless, several critical considerations must inform potential implementation efforts. Fundamentally, organizations considering adoption must recognize that this framework represents a theoretical proposal requiring rigorous empirical validation before definitive effectiveness claims can be substantiated. The projected outcome improvements, while grounded in meta-analytic evidence from related interventions, remain hypothetical for this specific design. Consequently, early adopters should approach implementation with appropriate measurement strategies to document actual outcomes and identify necessary refinements. Additionally, the framework's success depends critically on organizational readiness factors, including leadership support, resource availability, cultural alignment, and existing communication infrastructure.

From a practical implementation perspective, organizations must carefully consider scalability and resource requirements when evaluating the feasibility of adopting this framework. Based on current market research and industry benchmarks in Turkey, the initial material investment for the 45-card game set (30 emotion cards with professionally designed symbolic representations and 15 customizable blank cards) represents a relatively modest one-time cost. According to 2024-2025 custom game card printing data, professional-quality card sets with premium cardstock (280-310 GSM) range from approximately 250-400 TL per complete deck when ordered in quantities of 500-1,000 units, translating to an initial material investment of approximately 125,000-400,000 TL for organizations planning to equip multiple facilitators or departments simultaneously. However, the more substantial and ongoing investment involves human resource allocation, particularly for HR professionals who must facilitate game sessions, coordinate team formations, manage assessment processes, and analyze intervention outcomes. For a medium-sized organization (200-500 employees), comprehensive implementation requires approximately 40-60 hours of dedicated HR facilitation time per complete intervention cycle, including preparation, delivery, and follow-up activities. When accounting for average HR professional compensation rates—according to Eleman.net [23] data, HR specialists earn an average salary of 36,000 TL monthly, equivalent to approximately 160 TL per hour—this translates to roughly 6,400-9,600 TL in direct personnel costs per cycle. Additionally, organizations must budget for participant time away from regular duties; a typical 90-minute intervention session with 20 participants represents approximately 30 person-hours of opportunity cost, estimated at 2,940-5,880 TL depending on average employee compensation levels—as of 2025, the net minimum wage is 22,104.67 TL/month, equivalent to approximately 98 TL per hour [24]. Therefore, the total cost per comprehensive intervention cycle ranges from approximately 134,000-415,000 TL for medium-sized organizations, positioning this framework as a cost-effective alternative to traditional training programs. Importantly, the framework's scalability characteristics strongly favor larger organizations, as material costs remain relatively fixed while per-participant costs decrease substantially with scale. Organizations implementing the framework across multiple departments can achieve significant economies of scale by training internal facilitators rather than relying exclusively on external consultants, thereby reducing ongoing facilitation costs by an estimated 40-60% after initial implementation. Furthermore, the card-based physical format enables simultaneous sessions across geographically dispersed locations without requiring technological infrastructure, platform subscriptions, or ongoing software licensing fees, making the framework particularly cost-effective compared to digital gamification solutions. When evaluating return on investment, organizations should consider that employee turnover rates in Turkey are substantial and departures create significant costs. As noted by İdenfit [25], high turnover rates generate direct costs through recruitment, training, and orientation processes, while also producing indirect costs such as productivity losses and quality deterioration. According to Kolay İK [26] data, in 2025 the employer cost for a minimum wage employee is 30,555.53 TL, with this cost increasing when recruitment, orientation, and training expenses are included. If the framework achieves even conservative estimates of 10-15% reductions in voluntary turnover- a realistic projection based on meta-analytic evidence- the intervention costs could be recovered within 6-12 months exclusively through decreased recruitment, onboarding, and replacement training expenses, without accounting for additional substantial benefits in productivity enhancement, collaborative effectiveness, and employee satisfaction improvements.

The theoretical and practical implications extend beyond immediate emotional labor management to encompass broader questions about innovative learning methodologies in addressing complex organizational challenges. As organizations increasingly recognize that technical competencies alone are insufficient for contemporary work environments, frameworks that systematically develop interpersonal and emotional capabilities become increasingly valuable. Future research endeavors should prioritize empirical validation through carefully designed implementation studies that track both proximal learning outcomes and distal organizational impacts. Longitudinal investigations are particularly crucial for understanding whether game-based emotional intelligence development produces lasting behavioral changes. Ultimately, the success of such initiatives will depend not only on design quality but also on organizational commitment, sustained implementation support, and continuous refinement based on empirical feedback and participant experiences.

References

[1] Hochschild AR. The managed heart: Commercialization of human feeling. University of California Press, Berkeley, 1983, ISBN 0-520-05454-1.

[2] Grandey AA. Emotional regulation in the workplace: A new way to conceptualize emotional labor. Journal of Occupational Health Psychology. 2000; 5(1):95-110.

[3] Kirkpatrick JD, Kirkpatrick WK. Kirkpatrick's four levels of training evaluation. ATD Press, Alexandria VA, 2016; 1-45, ISBN 978-1-56286-967-1.

[4] Brotheridge CM, Grandey AA. Emotional labor and burnout: Comparing two perspectives of "people work." Journal of Vocational Behavior. 2002; 60(1):17-39.

[5] Hülsheger UR, Schewe AF. On the costs and benefits of emotional labor: A meta-analysis of three decades of research. Journal of Occupational Health Psychology. 2011; 16(3):361-389.

[6] Mesmer-Magnus J, DeChurch LA, Wax A. Moving emotional labor beyond surface and deep acting: A discordance–congruence perspective. Organizational Psychology Review. 2012; 2(1):6-53.

[7] Goleman D. Emotional intelligence: Why it matters more than IQ. Bantam Books, New York, 1995, ISBN 0-553-09503-X.

[8] Cherniss C, Goleman D (Eds.). The emotionally intelligent workplace: How to select for, measure, and improve emotional intelligence in individuals, groups, and organizations. Jossey-Bass, San Francisco, 2001, ISBN 0-7879-5690-2.

[9] Boyatzis R, Goleman D, Rhee K. Clustering competence in emotional intelligence: Insights from the emotional competence inventory (ECI). Handbook of Emotional Intelligence, San Francisco, 2000; 343-362.

[10] Mattingly V, Kraiger K. Can emotional intelligence be trained? A meta-analytical investigation. Human Resource Management Review. 2019; 29(2):140-155.

[11] Deterding S, Dixon D, Khaled R, Nacke L. From game design elements to gamefulness: Defining "gamification." Proceedings of the 15th International Academic MindTrek Conference. 2011; 9-15.

[12] Ryan RM, Deci EL. Self-determination theory and the facilitation of intrinsic motivation, social development, and well-being. American Psychologist. 2000; 55(1):68-78.

[13] Landers RN, Auer EM, Collmus AB, Armstrong MB. Gamification science, its history and future: Definitions and a research agenda. Simulation & Gaming. 2018; 49(3):315-337.

[14] Demir C. Oyunlaştırılmış iş ortamlarında akış teorisi: Gamfed gönüllülerinde zamansal akış göreliliği [Flow theory in gamified work environments: Temporal flow relativity in Gamfed volunteers]. Academic Journal. 2025a; 1(1):1-25.

[15] Kapp KM. The gamification of learning and instruction: Game-based methods and strategies for training and education. Pfeiffer, San Francisco, 2012, ISBN 978-1-118-09634-5.

[16] Dichev C, Dicheva D. Gamifying education: What is known, what is believed and what remains uncertain. International Journal of Educational Technology in Higher Education. 2017; 14(1):1-36.

[17] Demir C. Gamifying learning through escape room design: Educational potential, puzzle typologies, and technology integration. Educational Technology Research. 2025b; 2(1):45-78.

[18] Kiili K. Digital game-based learning: Towards an experiential gaming model. The Internet and Higher Education. 2005; 8(1):13-24.

[19] Bartle R. Hearts, clubs, diamonds, spades: Players who suit MUDs. Journal of MUD Research. 1996; 1(1):Article 19.

[20] Organ DW. Organizational citizenship behavior: The good soldier syndrome. Lexington Books, Lexington MA, 1988, ISBN 0-669-19281-7.

[21] Bandura A. Social learning theory. Prentice Hall, Englewood Cliffs NJ, 1977, ISBN 0-13-816614-3.

[22] Druskat VU, Wolff SB. Building the emotional intelligence of groups. Harvard Business Review. 2001; 79(3):80-90.

[23] Eleman.net. İnsan Kaynakları Uzmanı maaşları 2025. https://www.eleman.net/meslek/insan-kaynaklari-uzmani/maas (Erişim tarihi: 2025).

[24] T.C. Çalışma ve Sosyal Güvenlik Bakanlığı. Asgari ücret 2025. https://www.csgb.gov.tr/poco-pages/asgari-ucret/ (Erişim tarihi: 2024).

[25] İdenfit. Turnover rate nedir? Nasıl hesaplanır? https://idenfit.com/blog/turnover-rate-nedir-nasil-hesaplanir/ (Erişim tarihi: 3 Şubat 2025).

[26] Kolay İK. 2025 bordro parametreleri. https://kolayik.com/blog/2025-bordro-parametreleri (Erişim tarihi: 2025).

Research & Design
www.jrede.org

Research Article

Predicting financial failure of non-life insurance companies in Turkey using the Altman Z-score model

Yener Şentürk*[a]

Department of Insurance, Ankara Haci Bayram Veli Üniversitesi, Ankara, Türkiye

Article Info

Article History:

Received:

7 Sept 2025

Accepted:

10 Oct 2025

Keywords:

Financial Failure,
Altman Z-Score,
Non-Life Insurance Companies

Abstract

Insurance companies operate with the aim of generating profit, growing, and establishing trust in the sector in order to sustain their existence. Achieving these goals depends on companies having a sustainable and sound financial structure. Insurance companies with weaknesses or fragility in their financial structure, or those showing signs of such weaknesses, are more likely to experience financial failure, which in some cases can lead to bankruptcy. Therefore, identifying potential negative factors that could lead to financial failure at an early stage and taking necessary measures in a timely manner is crucial for reducing or completely eliminating the risk of failure. In this context, regular financial analysis and measurements that contribute to the current and future decision-making processes of insurance companies must be performed periodically. This study attempts to predict the financial success of non-life insurance companies operating in Turkey. The research focuses on financial failure prediction models and uses ten years of financial data covering the period 2014–2023. The Altman Z-Score model was applied by calculating the companies' annual financial ratios, thereby assessing each company's probability of financial failure. According to the findings, among the companies analyzed, only one company was financially successful throughout the entire period, two companies showed financial success for five years, while twelve companies failed to achieve financial success in any year during the ten-year period examined. This situation indicates that these companies are at risk of bankruptcy and that uncertainty prevails across the sector. For companies whose financial success status was determined to be uncertain, it is considered useful to conduct additional analyses using alternative financial failure prediction models (e.g., logit, probit, or machine learning-based approaches) to evaluate the current findings in greater depth.

1. Introduction

People have always sought to develop systems that can provide security against the uncertainties and risks inherent in life [7]. Societies' perception of risk and cultural structure have played a decisive role in shaping these systems; over time, this process has paved the way for the emergence of the insurance system as it is practiced today in its modern sense. The insurance system is an important component of the financial sector due to its capacity to generate funds. In addition to contributing to economic growth, it also contributes significantly to the development of a culture of solidarity and mutual aid in society [18]. The insurance system, which can be defined as a pool mechanism where individuals or organizations obtain coverage against risks by paying a certain premium, can also be considered a risk transfer and risk management tool [13]. The establishment,

*Corresponding author: senturkyener@hotmail.com
[a]orcid.org/0000-0003-0712-3516
DOI: http://dx.doi.org/10.17515/rede2025-011ec0907rs

execution, and supervision of insurance activities are carried out within the framework of legal regulations determined by the state. In Turkey, insurance companies are established as joint-stock companies or cooperatives and begin their insurance activities after completing the necessary licensing processes. These companies assume certain risks under the insurance contracts they issue and are responsible for fulfilling their obligations to cover any damages arising from these risks . Insurance is considered a system based on trust. Therefore, the competitiveness and sustainability of insurance companies in the sector are directly related to the soundness of their financial structure. Consequently, it is of great importance for companies to use all their resources effectively and efficiently. Otherwise, inefficient use of resources can lead to negative consequences, ranging from financial difficulties to even bankruptcy [3]. A decrease in a company's cash inflows can cause liquidity problems, making it difficult to meet short- and long-term obligations on time and in full. In this case, the business faces the risk of financial failure. Financial failure can be defined as the company's current cash flows or assets being insufficient to cover its debts. In contrast, bankruptcy is a legal process that arises when the company's total debts exceed its assets and this situation is certified by a court decision. In other words, bankruptcy is the legally defined and formalized form of failure to meet financial obligations. The financial failure or bankruptcy of insurance companies has the potential to create chain reactions not only in the insurance sector but also in the general economy, among policyholders, and all stakeholders involved in the sector [19]. Therefore, it is crucial to take comprehensive measures to strengthen risk management, internal audit, and capital adequacy mechanisms in order to reduce the likelihood of insurance companies being exposed to similar financial risks and to prevent potential crises. As of 2023, a total of 72 insurance companies operate in the insurance sector in Turkey. Fifty of these companies operate in non-life insurance, 15 in pensions, 3 exclusively in life insurance, and 4 in reinsurance. By the end of 2023, the total assets of insurance companies reached TRY 1.471 trillion; the share of the insurance and private pension sectors in the financial system was 5.3%. During the same period, total premium production reached TRY 1.427 trillion, while premium production in the non-life branch alone reached TRY 507 billion [23]. According to the Swiss Re Institute's (2022) World Insurance Report, while the ratio of total premium production, defined as insurance penetration, to gross domestic product (GDP) was 7% worldwide in 2021, this ratio was only 1.3% in Turkey. The same report states that the annual premium per capita was $874 worldwide and $124 in Turkey. Considering these indicators, Turkey ranks 68th in terms of premium production per capita [18–29]. Global insurance sector data show that approximately 80% of total insurance premium production in the 2004–2023 period belonged to OECD member countries [10]. In this context, Turkey's share in the global insurance market rose from 0.11% in 2003 to 0.24% in 2022. The amount of direct premium production in the insurance sector worldwide for the period 1980–2022 is presented in Figure 1 in five-year periods.

Figure 1 show that there has been a significant increase in the amount of direct premium production in the global insurance sector over the years. While total direct premium production was $497.987 billion in 1980, this figure increased approximately 13.61 times to reach $6.782 trillion in 2022. Total premium production, which stood at US$2.760 trillion in 2000, increased approximately 2.46 times in 2022. Non-life insurance premium production also showed a remarkable increase during the same period. Non-life direct premium production, which was 1.169 trillion US dollars in 2000, rose to 3.969 trillion US dollars as of 2022. While life insurance premium production was higher than non-life insurance premiums in 2000, the non-life insurance sector has come to the fore with a faster growth rate since 2015. According to Swiss Re Institute (2023) data, total premium production in the life and nonlife sectors worldwide reached US$7.2 trillion. During this period, the real growth rate was 1.3% in the life sector and 3.9% in the non-life sector. When evaluated on a regional basis, the highest growth in life insurance premium production was recorded in the Asia-Pacific region, while the highest growth in non-life insurance premiums was recorded in the Americas. Direct premium production amounts for the global insurance sector for the period 1980–2022 are presented in five-year periods in Figure 2. Similarly, premium production amounts for the insurance sector in Turkey for the period 2014–2023 are presented in five year periods in Table 1 and Figure 2.

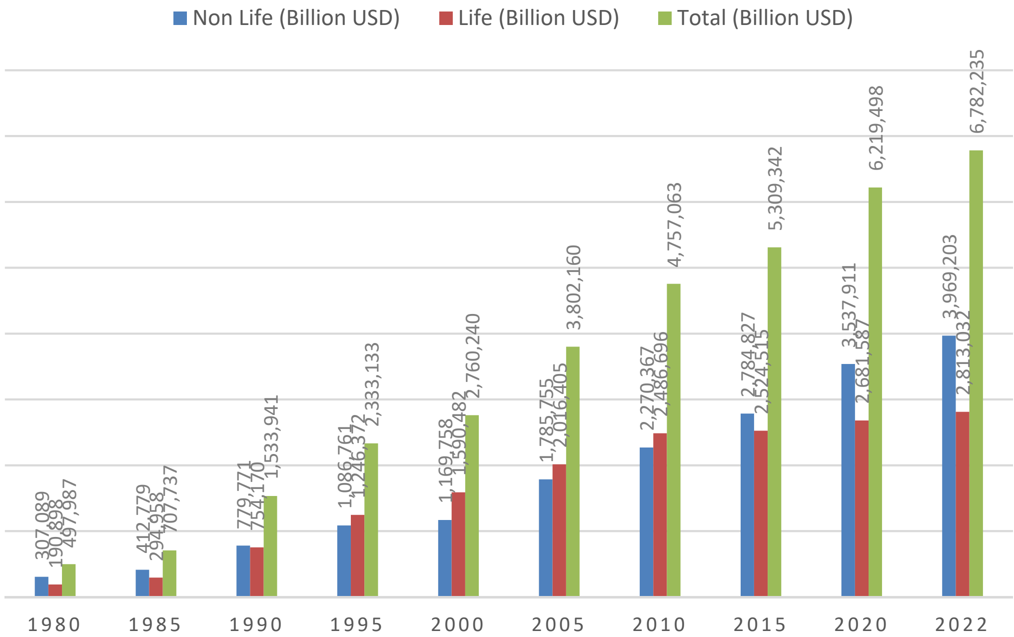

Figure 1. Direct premium production worldwide (billions of $) (1980-2022) [8]

When the SEDDK Activity Report data and the indicators presented in Table 2 are evaluated together, a significant upward trend in the share of non-life insurance branches in the Turkish insurance sector has been observed in recent years. The non-life insurance branch, which had an 81.96% share of total premium production in 2004, increased by approximately 7.7% to reach 88.26% in 2023. These data reveal that awareness and confidence in non-life insurance products are gradually increasing in society. The increasing share indicates that both individuals and institutions have developed risk management awareness, and therefore participation in the insurance system has evolved into a stronger structure.

Table 1. Premium production amounts of the insurance sector in Türkiye [17]

Premium Production	**2014**	**2018**	**2023**
Non-Life (TL)	14.978.744.186	47.742.569.680	426.020.334.846
Life (TL)	3.395.325.062	6.920.646.675	56.648.419.662
Total	18.374.069.248	54.663.221.655	482.668.754.508
HD/Total(%)	81,52	87,34	88,26

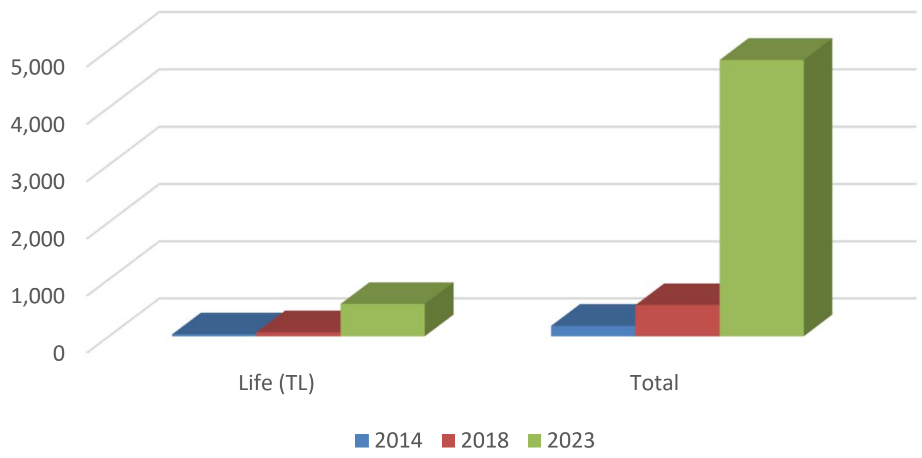

Figure 2. Insurance premium production pmounts in our country [17]

When examining global insurance market data, it is seen that Turkey's share in total insurance premium production decreased from 0.248% in 2014 to 0.239% in 2022. This situation shows that, despite our country's high insurance potential, its share in the global insurance market remained relatively stagnant during the period under review. This study aims to predict the probability of financial failure of non-life insurance companies operating in Turkey. To this end, the Altman Z-Score model, one of the most widely used financial early warning models in the literature, was used. In applying the model, various financial ratios commonly used in the insurance sector were calculated using Microsoft Excel 2016, and a data set was created for use in the analyses. The concept of financial failure began to appear in the literature in the 1960s; its importance for businesses has increased, particularly since the oil crisis of the 1970s. Different statistical models and empirical formulas have been developed to enable businesses to anticipate potential risks before experiencing financial collapse. Today, artificial intelligence-based methods are also widely used in these forecasting processes. Literature reviews show that statistical models are frequently preferred for predicting financial failure. These models are classified as univariate or multivariate statistical models, depending on the number of independent variables used in the model. Financial failure modeling provides managers with early warning information due to its potential to identify the risk of bankruptcy in advance. Indeed, research shows that such models provide effective and reliable results to businesses, making it possible to reduce or completely prevent the effects of potential failures [6]. In this context, while there are many financial prediction models developed in the literature, the Altman Z-Score model, one of the most widely used methods, has been chosen as the primary analytical tool in this study.

The study consists of four main sections. The first section explains the subject, purpose, and scope of the research; the second section covers previous studies on financial failure prediction. The third section details the research method and the analysis process applied; the fourth and final section discusses the findings and presents conclusions and recommendations.

2. Literature Review

A review of the literature reveals that the Altman Z-Score model is frequently used to measure the financial soundness and performance levels of businesses. This model is considered one of the most common statistical tools that enables the early identification of financial failure risk. However, although the model's scope of application has expanded in recent years, it is noteworthy that its application to the insurance sector remains relatively limited. Specifically, the complex and multi-component nature of insurance companies' financial structures has resulted in fewer studies in this area compared to other sectors. Based on this situation, the present study aims to contribute to this gap in the literature by examining the applicability of the Altman Z-Score model specifically to the insurance sector and to provide a comparative basis for future research.

The Altman Z-Score model is considered an advantageous method for measuring financial soundness and bankruptcy risk because it allows meaningful results to be obtained through simple calculations using accounting-based financial data. Thanks to this feature, the model is more widely used than other statistical methods in evaluating the financial structure of businesses, particularly in the banking sector [1-11-15]. However, the unique risk structure of the insurance sector and differences in accounting practices have led to the limited use of the Altman Z-Score model in financial analyses in this field. The model is considered a tool with limited validity for this sector because it cannot comprehensively cover the risk factors specific to the operational structure of insurance companies [16].

Altman developed the Z-Score model using multivariate discriminant analysis based on the financial data of 66 companies (33 successful and 33 unsuccessful) operating in the manufacturing sector between 1946 and 1965. His study revealed that bankruptcy could be predicted two years in advance and that the model could correctly classify future failures at a 95% rate one year before bankruptcy. However, it was also emphasized that the model's predictive power decreased as the period preceding failure lengthened. The Altman working model has laid the foundation for its widespread use today due to both its ease of application and high predictive accuracy [5].

Gülençer and Hazar (2020) applied the Altman Z-Score model to test the financial failure and bankruptcy risks of companies traded on the Istanbul Stock Exchange (BIST). In the study, which analyzed the financial data of 19 companies for 2019, it was concluded that only the Index company was in the risky zone, while the other companies did not carry a risk of bankruptcy [9].

İşseveroğlu (2005) developed an original model to measure the financial success of insurance companies and predict the probability of failure. The study used data from 45 insurance companies and formed two hypotheses based on one dependent and seventeen independent variables. Comparing multiple discriminant analysis and multiple regression analysis methods, the study concluded that the developed model accurately reflected the actual situation and met the analysis requirements [12].

Kendirli and Çıtak (2022) assessed the bankruptcy risks of companies in the paper and forest products sector traded on BIST using the Altman Z-Score model; the analysis determined that 7 out of 15 companies were at risk of bankruptcy [14].

Moreno et al. [2022] examined 1,382 observations from 183 insurance companies operating in Spain between 2010 and 2017, aiming to determine the most appropriate Z-Score calculation approach for insurance companies. The study concluded that the indicator obtained by dividing the sum of return on assets and the ratio of equity to assets by the standard deviation of return on assets is the most appropriate performance measure for insurance companies [16].

Pavić Kramarić et al. (2019) analyzed the determinants of financial soundness of insurance companies in Croatia, Hungary, and Poland (2013–2017) using the Altman Z-Score model. The findings showed that company size in Croatia and reinsurance practices in Hungary and Poland had positive effects on the financial soundness of insurance companies [20].

Puławska (2021) examined the effects of the COVID-19 pandemic on the financial performance of insurance companies operating in Europe. The study used return on assets, Z-Score values, and the capital adequacy ratio calculated according to the Solvency II Directive as dependent variables. The findings revealed that the pandemic negatively affected the overall functioning of the European insurance sector, but there was no statistically significant effect on Z-Score values [21].

Yıldız and Gürkan (2022) analyzed the bankruptcy risks of companies in the tourism sector using the Altman Z, Springate, and Fulmer models. The study determined that the results regarding bankruptcy risk varied depending on the different models used [26].

Yi (2012) analyzed the financial risk and uncertainty levels of real estate companies operating in China and concluded that the accuracy rate of the Altman Z-Score model remained below 90%. The researcher emphasized that due to the structural differences between the Chinese stock market and American markets, the model did not yield accurate results during global crises and that alternative bankruptcy prediction models should be developed in this context [27].

A review of the literature revealed that the Altman Z-Score model, commonly used to predict financial failure, is effectively applied in various sectors, particularly banking, manufacturing, tourism, and real estate. However, the number of studies on the insurance sector is quite limited. The risk structure of insurance activities, capital adequacy, reinsurance ratio, and technical reserves, which are specific financial dynamics of the sector, have made it difficult to adapt the model to this field. This situation reveals a significant research gap in the form of a lack of empirical studies testing the applicability of the Altman Z-Score model in the insurance sector.

Furthermore, most studies in the literature focus on a single country, and there are very few international studies comparing the impact of economic conditions and accounting systems in different countries on the model's predictive performance. In this context, a comprehensive analysis using data specific to the Turkish insurance sector would contribute significantly to the literature by testing the model's applicability in emerging economies.

Furthermore, most existing studies analyze specific periods using cross-sectional data, while longitudinal studies evaluating the impact of crisis periods or macroeconomic fluctuations on the model's predictive power remain limited. Increasing uncertainties in financial markets following the COVID-19 pandemic, in particular, necessitate a reassessment of the Altman Z-Score model's performance across different periods.

On the other hand, the Altman Z-Score model has mostly been applied using traditional statistical analyses. However, the increasing use of artificial intelligence, machine learning, and hybrid models in predicting financial failure in recent years highlights the need to integrate classical models with these new approaches. The lack of studies in the insurance sector that use the Altman model in conjunction with these modern methods presents new research opportunities from a methodological perspective. In this context, the current study aims to:

- To test the validity of the Altman Z-Score model by applying it specifically to the Turkish insurance sector,
- To adapt the model to the sector by including financial ratios specific to the insurance industry,
- contribute to the early prediction of financial failure risk.

In this respect, the study not only fills the existing gap in the insurance sector literature but also aims to establish a methodological basis for future comparative, multi-period, and artificial intelligence-supported research.

3. Research Methodology

This section introduces the mathematical and statistical models most frequently used in the literature for financial failure prediction; explains the theoretical framework of the model used in the analysis process; and presents the relevant analysis results and evaluations in the findings section.

3.1 Methods Used in Financial Failure Prediction: Altman Z-Score

Although numerous different models have been developed in the literature for predicting the financial failure of businesses, the most commonly used methods include the Altman Z-Score Model, Beaver Model, Springate S-Score Model, Fulmer H-Score Model, Ohlson O-Score Model, and Zmijewski J-Score Model [22–26]. In this study, the Altman Z-Score model was chosen from among these models. The reason for choosing this model is that it offers a structure based on multivariate discriminant analysis using accounting-based financial data and can quantitatively measure the risk of financial failure in businesses. Below are some basic details about the model's development and structure.

Edward I. Altman (1968) argued that traditional financial ratio analysis alone was insufficient for predicting corporate financial failure and developed a model based on multivariate discriminant analysis to overcome this limitation [5]. In his study, he examined the financial data of 33 successful and 33 unsuccessful (bankrupt) publicly traded companies in the manufacturing sector (bankruptcy) for the period 1946–1965. Altman tested the 22 financial ratios identified for these companies for their significance levels and grouped them into five main categories: profitability, liquidity, debt-paying power, financial leverage, and operating efficiency. Representative ratios selected from each group were weighted using coefficients obtained through discriminant analysis, and the sum of these values was defined as the company's Z-Score [4-5].

In the years following the model's introduction, various researchers debated its generalizability and sectoral applicability. In response to these criticisms, Altman developed three separate models to accommodate the financial structures of different sectors. These models are [5]:

- Publicly traded manufacturing sector companies,
- Non-publicly traded (privately owned) industrial companies,
- Three different versions of the Altman Z-Score developed for service sector companies.

This has transformed the model from one specific to the manufacturing sector into a versatile tool that can be used to measure the risk of financial failure for companies in different sectors.

The calculation formula and variables used in the Altman Z-Score model developed for publicly traded manufacturing companies are presented in Equation (1) [5].

$$Z = 0.012\ X1 + 0.014\ X2 + 0.033\ X3 + 0.006\ X4 + 0.999\ X5 \quad (1)$$

X1: Net Working Capital / Total Assets
X2: Retained Earnings / Total Assets
X3: Pre-tax Profit / Total Assets
X4: Market Value of Equity / Total Liabilities

X5: Net Sales / Total Assets

The calculation formula and variables used in the Altman Z-Score model developed for privately owned industrial enterprises are presented in Equation (2) [24].

$$Z = 0.717\ X1 + 0.847\ X2 + 3.107\ X3 + 0.420\ X4 + 0.998\ X5 \tag{2}$$

X1: Net Working Capital / Total Assets
X2: Retained Earnings / Total Assets
X3: Pre-tax Profit / Total Assets
X4: Book Value of Equity / Total Liabilities
X5: Net Sales / Total Assets

The calculation formula for the Altman Z-Score model, developed based on four key financial ratios for companies operating in the service sector, is presented in Equation (3) [28].

$$Z = 6.56\ X1 + 3.26\ X2 + 6.72\ X3 + 1.05\ X4 \tag{3}$$

X1: Net Working Capital / Total Assets
X2: Retained Earnings / Total Assets
X3: Pre-tax Profit / Total Assets
X4: Book Value of Equity / Total Liabilities

The Altman Z-Score reference values for these three models are presented comparatively in Table 2.

Table 2. Altman Z-score reference values [2-22-25]

Z-score values for publicly traded manufacturing companies	**Z-score values for private industrial companies**	**Z-score values for service sector companies**
Z>2.99 ; Successful (Low probability of bankruptcy) (Green zone)	Z>2.90; Successful (Low probability of bankruptcy) (Green zone)	Z >2.60; Successful (Low probability of bankruptcy) (Green zone)
1.81<Z<2.99; Uncertain (Gray zone)	1.23<Z<2.9; Uncertain (Gray zone)	1.10<Z<2.60 ;Uncertain (Gray zone)
Z<1.81; Failed (Red zone)	Z<1.23 ; Failed (Red zone)	Z<1.10;Failed (Red zone)

As indicated in Table 2, if the Z-Score value calculated for publicly traded manufacturing companies is greater than 2.99 (Z>2.99), the company is financially successful and has a low risk of bankruptcy. If it is greater than 1.81 but less than 2.99 (1.81<Z<2.99), it means that the company is in an uncertain financial position and its financial situation needs to be monitored. If it is less than 1.8 (Z<1.81), it is interpreted and evaluated as the company being financially unsuccessful with a high risk of bankruptcy. For private industrial companies, a Z-Score value greater than 2.90 (Z>2.90) indicates that the company is financially successful and has a low risk of bankruptcy, while a value greater than 1.23 and less than 2.90 (1.23<Z<2.90), it means that the business is in a financially uncertain area and its financial situation needs to be monitored. If it is less than 1.23 (Z<1.23), it is interpreted and evaluated as the business being financially unsuccessful and having a high risk of bankruptcy. For service sector businesses, a calculated Z-Score value greater than 2.60 (Z>2.60) indicates that the business is financially successful and has a low risk of bankruptcy, while a value greater than 1.10 and less than 2.60 (1.10<Z<2.60), it means that the company is in an uncertain financial position and its financial situation needs to be monitored. If it is less than 1.10 ($Z<1.10$), it is interpreted and evaluated as the company being financially unsuccessful with a high risk of bankruptcy [22]. In financial failure prediction studies conducted using Altman Z-Score models, the Z-Score values calculated for businesses are compared with the reference values specified in Table 2, and evaluations are made for financial failure prediction.

3.2 Findings and Analysis

In this study, ten years of financial data from 2014 to 2023 for 37 non-life insurance companies operating in Turkey were used. The Altman Z-Score model, developed for the service sector, was applied to determine the probability of financial failure for the companies. The names of the companies included in the analysis have not been disclosed in accordance with the principle of confidentiality; each company has been coded as C1, C2, C3 ... C37, respectively.

The financial data used in the research was obtained from the financial statements published by the companies on open sources and their official websites. Four basic financial ratios required by the model were calculated for each company:

- X_1: Ratio of net working capital to total assets,
- X_2: Ratio of retained earnings to total assets,
- X_3: Ratio of pre-tax profit to total assets,
- X_4: Ratio of book value of equity to total liabilities.

Using these ratios, Z-Score values were calculated for each company on an annual basis using the following formula in Equation (4):

$$Z=6.56X1+3.26X2+6.72X3+1.05X4Z = 6.56X\_1 + 3.26X\_2 + 6.72X\_3 + 1.05X\_4Z=6.56X1+3.26X2+6.72X3+1.05X4 \quad (4)$$

The obtained Z-Score values are presented in Table 3 and Figure 3 to show the change in the financial status of the companies over years.

Table 3. Calculated Z-score values for non-life insurance companies

Company	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	Mean
C1									1,99	0,56	1,28
C2	1,85	1,29	1,61	1,70	1,61	1,59	1,49	1,50	1,05	1,26	1,50
C3	2,03	1,45	1,28	1,78	1,40	1,45	1,32	2,86	0,83	1,31	1,57
C4							3,82	4,02	1,48	1,28	2,65
C5	1,47	1,18	1,01	1,09	1,13	1,09	1,01	1,84	0,68	0,42	1,09
C6	3,90	3,57	3,28	1,38	2,16	1,77	1,87	2,23	0,83	0,86	2,18
C7								15,37	1,49	2,42	6,43
C8									1,93	1,06	1,49
C9	2,64	1,89	1,91	1,64	1,94	1,69	1,74	3,06	1,45	2,00	2,00
C10				1,57	0,90	1,16	1,26	1,32	0,47	0,93	1,09
C11						0,81	1,45	2,04	0,77	1,03	1,22
C12	1,92	1,49	1,59	0,56	0,58	1,17	1,35	2,28	0,60	0,75	1,23
C13									3,85	3,34	3,59
C14			1,50	1,55	1,20	1,07	1,63	2,19	0,80	0,93	1,36
C15	1,40	1,23	1,39	1,47	1,37	1,52	1,48	3,23	1,24	1,25	1,56
C16										4,50	4,50
C18	4,15	4,14	5,74	4,11	5,33	5,46	5,08	6,35	3,83	3,78	4,80
C18							10,87	-1,86	1,34	-	2,58

Company	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	Mean
C19			8,66	3,38	2,84	2,73	2,41	4,09	1,40	1,15	3,33
C20	2,99	2,54	2,44	2,29	1,63	1,28	1,45	2,06	1,06	1,78	1,95
C21										1,27	1,27
C22	6,56	2,58	3,12	2,53	1,95	1,55	1,86	2,41	0,76	0,68	2,40
C23	15,49	13,98	11,84	0,35	2,01	1,38	1,47	1,01	1,81	1,00	5,03
C24	2,12	1,50	1,35	1,68	0,95	0,95	1,33	1,95	0,43	0,41	1,27
C25	6,11	2,43	1,81	1,77	2,35	3,55	3,95	6,29	2,87	2,01	3,31
C26									8,98	4,07	6,53
C27				1,18	0,94	0,97	1,53	1,80	1,26	1,40	1,30
C28	3,20	2,65	2,67	2,21	1,64	1,52	1,22	2,28	0,83	1,05	1,93
C29	1,03	0,71	0,80	1,38	1,20	1,25	1,21	2,83	0,57	1,21	1,22
C30				1,92	1,94	1,73	2,26	2,76	1,23	1,34	1,88
C31						14,75	1,03	-0,98	3,13	-	3,59
C32						2,59	1,79	2,72	1,09	0,91	1,82
C33	3,23	2,95	1,76	1,32	1,24	1,16	1,04	0,74	0,99	1,20	1,56
C34							2,05	3,43	0,70	1,05	1,80
C35		3,93	1,07	1,46	1,29	1,32	1,16	2,79	0,84	1,44	1,70
C36									1,89	1,98	1,93
C37	2,59	2,10	1,83	2,03	2,05	1,60	2,35	3,84	1,36	1,37	2,11
Average	3,69	2,87	2,83	1,75	1,72	2,20	2,15	2,88	1,59	1,43	2,31

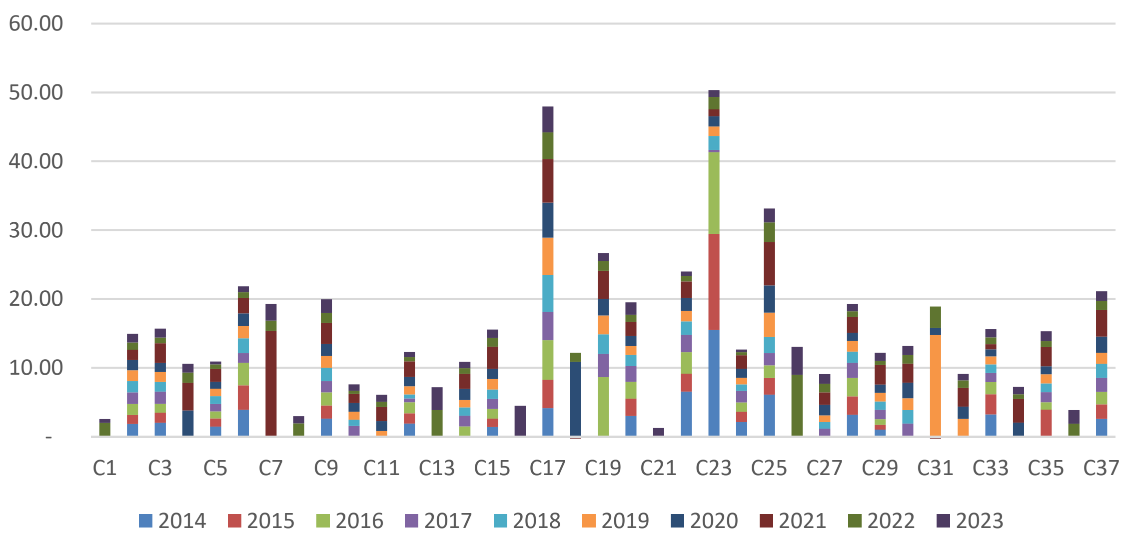

Figure 3. Companies' annual Z-Score value

The classification of non-life insurance companies' financial performance based on their calculated Z-Scores is shown in Table 4.

Table 4. Classification of financial performance based on calculated z-scores for non-life insurance companies

Company	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
C1									1,99	0,56
C2	1,85	1,29	1,61	1,70	1,61	1,59	1,49	1,50	1,05	1,26
C3	2,03	1,45	1,28	1,78	1,40	1,45	1,32	2,86	0,83	1,31
C4							3,82	4,02	1,48	1,28
C5	1,47	1,18	1,01	1,09	1,13	1,09	1,01	1,84	0,68	0,42
C6	3,90	3,57	3,28	1,38	2,16	1,77	1,87	2,23	0,83	0,86

Company	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
C7								15,37	1,49	2,42
C8									1,93	1,06
C9	2,64	1,89	1,91	1,64	1,94	1,69	1,74	3,06	1,45	2,00
C10				1,57	0,90	1,16	1,26	1,32	0,47	0,93
C11						0,81	1,45	2,04	0,77	1,03
C12	1,92	1,49	1,59	0,56	0,58	1,17	1,35	2,28	0,60	0,75
C13									3,85	3,34
C14			1,50	1,55	1,20	1,07	1,63	2,19	0,80	0,93
C15	1,40	1,23	1,39	1,47	1,37	1,52	1,48	3,23	1,24	1,25
C16										4,50
C18	4,15	4,14	5,74	4,11	5,33	5,46	5,08	6,35	3,83	3,78
C18							10,87	-1,86	1,34	-
C19			8,66	3,38	2,84	2,73	2,41	4,09	1,40	1,15
C20	2,99	2,54	2,44	2,29	1,63	1,28	1,45	2,06	1,06	1,78
C21										1,27
C22	6,56	2,58	3,12	2,53	1,95	1,55	1,86	2,41	0,76	0,68
C23	15,49	13,98	11,84	0,35	2,01	1,38	1,47	1,01	1,81	1,00
C24	2,12	1,50	1,35	1,68	0,95	0,95	1,33	1,95	0,43	0,41
C25	6,11	2,43	1,81	1,77	2,35	3,55	3,95	6,29	2,87	2,01
C26									8,98	4,07
C27				1,18	0,94	0,97	1,53	1,80	1,26	1,40
C28	3,20	2,65	2,67	2,21	1,64	1,52	1,22	2,28	0,83	1,05
C29	1,03	0,71	0,80	1,38	1,20	1,25	1,21	2,83	0,57	1,21
C30				1,92	1,94	1,73	2,26	2,76	1,23	1,34
C31						14,75	1,03	-0,98	3,13	-
C32						2,59	1,79	2,72	1,09	0,91
C33	3,23	2,95	1,76	1,32	1,24	1,16	1,04	0,74	0,99	1,20
C34							2,05	3,43	0,70	1,05
C35		3,93	1,07	1,46	1,29	1,32	1,16	2,79	0,84	1,44
C36									1,89	1,98
C37	2,59	2,10	1,83	2,03	2,05	1,60	2,35	3,84	1,36	1,37
	Successful		Unclear		Unsuccessful					

As indicated in Table 4, a total of 255 Z-Score values were calculated for the companies for the period under review. Based on these values, 56 were unsuccessful (22%), 56 were successful (22%), and 143 were uncertain (56%). Furthermore, considering these Z-Score values, it can be said that the financial success of companies is gradually shifting towards uncertainty over the years. Numerical data showing the success status of companies during their operating period, based on Z-Score values for the companies examined, are provided in detail in Table 5.

Table 5. Numbers related to the financial performance of non-life insurance companies based on their Z-scores

Company	Successful	Uncertain	Unsuccessful	Company	Successful	Uncertain	Unsuccessful
C1	0	1	1	C20	1	8	1
C2	0	10	0	C21	0	1	0
C3	1	8	1	C22	2	6	2
C4	2	2	0	C23	3	4	3
C5	0	4	6	C24	0	6	4
C6	3	5	2	C25	5	5	0
C7	1	2	0	C26	2	0	0
C8	0	1	1	C27	0	5	2

C9	2	8	0	C28	3	5	2
C10	0	4	3	C29	1	5	4
C11	0	2	3	C30	1	6	0
C12	0	6	4	C31	2	0	3
C13	2	0	0	C32	1	2	2
C14	0	5	3	C33	2	5	3
C15	1	9	0	C34	1	1	2
C16	1	0	0	C35	2	5	2
C17	10	0	0	C36	0	2	0
C18	1	1	2	C37	1	9	0
C19	5	3	0				

5. Discussion & Conclusion

In this study, the financial failure situations of 37 non-life insurance companies operating in Turkey were analyzed using financial data from the 2014–2023 period and the Altman Z-Score model developed for the service sector. Z-Score values were calculated for each company, and financial success, failure, and uncertainty situations were determined based on these values. During the analysis process, since not all companies were active throughout the study period, only the years in which they were active were considered. Thus, a total of 255 Z-Score values were calculated over the ten-year study period (see Table 4). According to the results obtained, 22% of the companies were financially unsuccessful, 22% were successful, and 56% were in the uncertainty zone. These findings show that there is a trend towards uncertainty in the financial situation of companies over the years. In other words, while the sector generally presented a stronger financial outlook in its early years, this picture weakened towards the end of the period, with an observed increase in the likelihood of uncertainty and failure. This situation indicates that financial risks in the non-life insurance sector have entered an upward trend over time. The calculated Z-Score values range from 0.35 to 15.37, and it has been determined that the annual average values vary between 3.69 and 1.43. When examining the average Z-Score values of the companies, the highest average was 3.69 in 2014, and the lowest average was 1.43 in 2023. This result indicates a downward trend in the sector's financial soundness over time. When comparing the annual average Z-Score values with the model's reference ranges, it was found that nonlife insurance companies were financially successful in 2014, 2015, 2016, and 2021, while they were mostly in the uncertainty zone in other years. Therefore, it is not possible to speak of a clear trend of success regarding the sector's financial situation throughout the analysis period. Furthermore, it was determined that no company showed continuous financial failure throughout the period, but some companies entered a risky position in certain years. Examining Table 5, it is seen that only company C17 was financially successful in all years during the 2014–2023 period. However, company C19 was successful five times and unsuccessful three times, while company C25 was successful five times and in the uncertainty zone five times. The financial performance of these companies is considered to be above average. In terms of financial failure risk, company C5 was unsuccessful six times, while companies C12, C24, and C29 were unsuccessful four times each. It can be stated that these companies carry a risk of bankruptcy. When examining the companies that were in the uncertainty zone the most, it was seen that Company 2 was in the uncertainty zone 10 times, Company 37 was in the uncertainty zone 9 times, and Companies 3, 9, and 20 were in the uncertainty zone eight times each. This finding indicates that the financial structures of these companies followed an unstable course. For companies in the uncertainty zone, when Z-Score values are close to the financial success threshold, it is considered useful to conduct additional assessments using alternative financial failure measurement models (e.g., logit/probit analyses or artificial intelligence-based classification methods). It was determined that 12 of the 37 companies examined during the research period did not achieve financial success in any given year. When a general assessment is made, it is seen that a significant portion of the companies are concentrated in the uncertainty zone. The findings obtained are limited by the scope and period of the study. A review of existing studies in the literature reveals that the Altman Z-Score model is generally applied to businesses outside the insurance sector, while studies related to the insurance sector focus on fewer companies and shorter time periods. In this context, this study's comprehensive analysis of 37 non-life insurance companies operating in Turkey over a long period of 10 years provides a unique and in-depth contribution to the literature.

References

[1] Adu DA. Competition and Bank Risk-Taking in Sub-Saharan Africa Countries. SN Business & Economics. 2022; 2(7):1-26.

[2] Aslan T. Altman Z-Skor Modeli ile Finansal BaCarısızlık Tahmini: Borsa İstanbul'da İClem Gören Elektrik Üretim Cirketleri Üzerine Bir Uygulama. Üçüncü Sektör Sosyal Ekonomi Dergisi. 2024; 59(2):876-889.

[3] Akdeniz F, Güven B. Altman Z ve Springate S Skor Modelleri ile Finansal BaCarısızlık Tahmini: Çimento Sektörü Üzerine Borsa İstanbul'da Bir AraCtırma. GümüChane Üniversitesi Sosyal Bilimler Enstitüsü Elektronik Dergisi. 2023; 14(2):728-738.

[4] Akyüz F. TaC ve Toprağa Dayalı Sektörde Faaliyet Gösteren Cirketlerin Finansal BaCarısızlık Risklerinin Tahmin Edilmesi. Ömer Halisdemir Üniversitesi İktisadi ve İdari Bilimler Fakültesi Dergisi. 2020; 13(1):40-51.

[5] Altman EI. Financial Ratios, Discriminant Analysis and The Prediction of Corporate Bankruptcy. The Journal of Finance. 1968; 23(4):589-609.

[6] Bağcı H, Sağlam C. Sağlık ve Spor KuruluClarında Finansal BaCarısızlık Tahmini: Altman, Springate ve Fulmer Modeli Uygulaması. Hacettepe Sağlık İdaresi Dergisi. 2020; 23(1):149-164.

[7] Baltensperger E, Bodmer F. The Social and Economic Value of Insurance: A Primer. Zurich Financial Services Publication. 2012.

[8] Gül M, Yılmaz T. Altman Z-S Modeline Göre Finansal BaCarı ve Belirleyicileri. İCletme Ekonomi ve Yönetim AraCtırmaları Dergisi. 2023; 6(2):202-218.

[9] Gülençer S, Hazar A. Borsa İstanbul Teknoloji Endeksi (XUTEK) Cirketlerinin Altman Z-Skor Analizi ile Değerlendirilmesi. ISPEC Journal of Social Sciences & Humanities. 2020; 4(2):59-76.

[10] GümüC UT, Bilge E, Özdemir G, Sarak G. Bist 100'de IClem Gören Çimento Cirketlerinin Finansal Performanslarının Altman-Z Skor Yöntemiyle İncelenmesi. Journal of Academic Value Studies. 2017; 3(12):129-135.

[11] Hafeez B, Li X, Kabir MH, Tripe D. Measuring Bank Risk: Forward-Looking Z-Score. International Review of Financial Analysis. 2022; 80(C):102039, https://doi.org/10.1016/j.irfa.2022.102039.

[12] İCseveroğlu G. Sigorta Cirketlerinde Finansal BaCarının Ölçülmesi ve Bir Uygulama. Doktora Tezi, T.C. Uludağ Üniversitesi Sosyal Bilimler Enstitüsü, Bursa. 2005.

[13] Jadi Diara M. An Empirical Analysis of Determinants of Financial Performance of Insurance Companies in the United Kingdom (Doctoral Dissertation). University of Bradford Faculty of Management and Law University of Bradford. 2015.

[14] Kendirli S, Çıtak F. Altman Modeli ile Finansal BaCarısızlık Tahmini: Bist Orman, Kâğıt Ve Basım Endeksinde Faaliyet Gösteren Cirketlerde Bir Uygulama. International Academic Journal. 2022; 6(1):86-97.

[15] Laeven L, Levine R. Bank Governance, Regulation and Risk Taking. Journal of Financial Economics. 2009; 93(2):259-275.

[16] Moreno I, Parrado-Martínez P, Trujillo-Ponce A. Using The Z-Score to Analyze The Financial Soundness of Insurance Firms. European Journal of Management and Business Economics. 2022; 31(1):22-39.

[17] Ovalı A. Türkiye'de Faaliyet Gösteren Hayat DıCı ve Hayat/Emeklilik Sektörlerinin Performans Analizi. Finans Ekonomi ve Sosyal AraCtırmalar Dergisi. 2022; 7(3):348-360.

[18] Öner Kaya E. Türkiye'de Hayat DıCı Sigorta Cirketlerinin Finansal Sağlamlığının Z-Skoru Kullanılarak Ölçülmesi, AraCtırma Makalesi. Üçüncü Sektör Sosyal Ekonomi Dergisi. 2023; 58(1):860-876.

[19] Pasiouras F, Gaganis C. Regulations and soundness of insurance firms: International evidence. Journal of Business Research. 2013; 66(5):632-642.

[20] Pavić Kramarić T, Miletić M, Kožul Blaževski R. Financial Stability of Insurance Companies in Selected CEE Countries. Business Systems Research Journal. 2019; 10(2):163-178. https://doi.org/10.2478/bsrj-2019-025.

[21] Puławska K. Financial Stability of European Insurance Companies During The COVID-19 Pandemic. Journal of Risk and Financial Management. 2021; 14(6):266.

[22] Turaboğlu TT, Yıkılmaz Erkol A, Topaloğlu EE. Finansal BaCarısızlık ve Sermaye Yapısı Kararları: BİST 100 Endeksindeki Firmalar Üzerine Bir Uygulama. İCletme ve Ekonomi AraCtırmaları Dergisi. 2017; 8(2):247-258.

[23] Türkiye Sigorta Birliği (2023). Mali Tablolar ve İstatistikler. Web: https://www.tsb.org.tr/tr/istatistikler (Access Date: 04.10.2025).

[24] Yaman K, Cakar T. Borsa'da İClem Gören Sigorta Cirketlerinin İflas Riskini Tahmin Etmede Altman Modeli Uygulaması. Toros Üniversitesi İİSBF Sosyal Bilimler Dergisi. 2022; 9(17):28-41.

[25] Yıldız A. Kurumsal Yönetim Endeksi ve Altman Z-Skoruna Dayalı Lojistik Regresyon Yöntemiyle Cirketlerin Kredi Derecelendirmesi. Süleyman Demirel Üniversitesi İktisadi ve İdari Bilimler Fakültesi Dergisi. 2014; 19(3):71-89.

[26] Yıldız C, Gürkan S. Finansal BaCarısızlık Tahmin Modellerinin KarCılaCtırılması: Borsa İstanbul Turizm Cirketlerinde Bir AraCtırma. Ekonomi, İCletme ve Yönetim Dergisi. 2022; 6(2):235-262.

[27] Yi W. Z-Score Model on Financial Crisis Early-Warning of Listed Real Estate Companies in China: A Financial Engıneering Perspective. Systems Engineering Procedia. 2012; 3:153-157.

[28] http://hdl.handle.net/10454/14383 (Access Date: 24.08.2024,09:48:25).

Research & Design
www.jrede.org
Research Article

Semiotic analysis of multivitamin advertisements

Sunay Güngör Gülsoy [*a]
Department of Business, Süleyman Demirel University, Isparta, Türkiye

Article Info

Article History:
Received:
10 Sept 2025
Accepted:
18 Oct 2025

Keywords:
Vitamin brands;
Semiotic analysis method;
Color analysis;
Consumer satisfaction;
Brand perception

Abstract

Associations and visual imagery are frequently used in advertisements and represent a significant focus within semiotic studies. This study aims to analyze the online advertisements of leading multivitamin brands in Turkey within the context of consumer perception, examining how their visual and textual strategies affect the target audience. The main research question is: "How are multivitamin advertisements in Turkey perceived by consumers, and how is this perception related to the use of color, visual symbols, and messaging in the ads?" Here, consumer perception is defined as the combination of users' reviews, star ratings, and impressions formed through engagement with advertisement visuals. The study focuses on the online advertisements of Supradyn, Orzax, Solgar, and Pharmaton, employing Roland Barthes' semiotic framework to analyze color usage, figures, and symbolic elements. The analysis demonstrates that brands produce both denotative and connotative meanings: Supradyn conveys energy and renewal, Orzax emphasizes preparedness and conscious living, Solgar promotes a scientific and gender-specific approach, and Pharmaton communicates inclusive energy and dynamism. Color analysis reveals that yellow and white dominate across all brands, while blue and black appear in some, reinforcing perceptions of energy, trust, and purity. Consumer evaluations show high satisfaction for Pharmaton and Supradyn, while Orzax and Solgar cater to a more niche audience. Overall, the findings indicate that optimizing visual and strategic meaning layers can enhance both consumer perception and brand loyalty.

1. Introduction

Advertising is one of the most influential communication tools designed to shape audience perceptions and persuade consumers by promoting products and services [23]. In order for such perception to be formed, the target audience must first be aware of the product. Advertising—carried out in exchange for payment—has the power to construct gender roles and alter human behavior [9]. As David Ogilvy famously states, "If your advertising doesn't sell, it isn't creative," emphasizing the importance of accurate positioning for shaping consumer perception. Advertising conveys multiple messages to consumers within a short timeframe. While these messages seemingly aim at informing and persuading consumers to purchase, they simultaneously seek to implant certain meanings in their minds. At this point, semiotics becomes relevant, as it aids in decoding the linguistic and visual layers of advertising messages. Semiotics serves as a positioning tool that helps clarify both explicit and implicit meanings behind the verbal and visual components presented in advertisements.

Semiotic analysis in advertising gained momentum during the 1980s. Semiotics has made significant contributions to marketing and consumer studies, particularly through the models introduced by Saussure and Peirce [6,14]. Mick et al. [24] emphasize that semiotics-based advertising research reveals how consumers interpret and construct meaning from signs within

[*]Corresponding author: sunaygulsoy@sdu.edu.tr
[a]orcid.org/0000-0001-8390-9030
DOI: http://dx.doi.org/10.17515/rede2025-012so0910rs

institutional, societal, and cultural contexts. Semiotics substantially contributes to addressing methodological challenges in advertising research by simplifying complex messages and ensuring effective communication [25]. It provides a key framework for brands seeking to build strong emotional and symbolic connections with consumers.

This study examines the advertisements of the four most highly rated multivitamin brands on Turkish online platforms, considering their impact on consumer perceptions. Employing Roland Barthes' semiotic framework enables an analysis of how textual and visual elements convey not only surface meanings but underlying ideological and cultural messages. Although semiotic analysis in advertising has a long history, only a small number of recent studies (2021-2025) systematically adopt Barthes' perspective-and those that do are generally limited to certain product categories (e.g., beauty, fast food) rather than nutritional or wellness advertising. By focusing on multivitamin advertising in Turkey and positioning consumers as active co-creators of meaning (rather than passive recipients), this research fills a clear gap in the literature and offers an original contribution: the integration of Barthesian semiotics with contemporary digital advertising contexts to illuminate how wellness oriented brands construct symbolic meaning and how target audiences negotiate it.

2. Roland Barthes' Semiotic Analysis Method

The term semiology originates from the Greek word semeion (sign). John Locke (1632–1704) conceptualized the analysis of signs under the term semeiotics. Later, the American philosopher Charles Sanders Peirce used the term semeiotic, while the Swiss linguist Ferdinand de Saussure referred to the field as sémiologie. Today, the term semiotics is the most widely used. Semiotics is an interdisciplinary field that examines how meaning is constructed through signs, how individuals produce and interpret signs, and how communication systems function within these sign structures. Saussure's linguistic work precedes formal semiotic studies, focusing on language's function, coding, and communicational significance in society. Over time, linguistic research evolved into a subfield of semiotics [22]. Saussure conceptualized the sign as composed of a signifier (expression) and signified (content). While signifiers carry universal meaning, signifieds vary culturally [10,21,26]. Peirce, on the other hand, defined sign processes through the triadic model: the sign itself, the object, and the interpreter [17]. Roland Barthes (1915–1980) significantly expanded semiotics in the second half of the 20th century by applying it in social sciences and across fields such as advertising, architecture, and medicine [20]. Barthes' key contribution lies in distinguishing between denotation (literal meaning) and connotation (cultural meaning). According to Barthes, meaning emerges through the interaction of visual elements, and analysis should proceed through formal description, semantic exploration, evaluation of alternative meanings, and final synthesis [5,13].

3. Roland Barthes' Semiotic Model and Its Use in Advertising Research

Roland Barthes' semiotic model most commonly applied in advertising research involves examining signs within the framework of the signifier and the signified. Signs identified in advertisements are analyzed at both denotative and connotative levels. As the connotative dimension of signs is shaped by diverse subcultural structures within society, researchers are expected to conduct detailed analyses of the historical and cultural context surrounding the signs. Otherwise, they may limit their interpretations to only the denotative level or risk making inaccurate evaluations in an attempt to extract meaning. In many advertising studies utilizing Barthes' signifier–signified framework, researchers also incorporate his other semiotic models into the analytical process. Toptaş [11] for instance, examined how the female image is represented in promotional posters of domestically produced films released in Türkiye. Treating film posters as commercial products that function similarly to advertisements, the researcher analyzed them as advertising texts. Unlike many studies employing Barthes' model in an exploratory manner, Toptaş formulated hypotheses regarding the characteristics of female figures across different film genres and gender norms. These hypotheses were tested by analyzing the denotative–connotative meanings, codes, and syntagmatic and paradigmatic relationships of the signs present in the posters. Similarly, Özkantar [18] first explored the concepts of racism and semiotics and then analyzed Benetton advertisements using Barthes' approach to ideology as a cultural construct. The study demonstrated that although the advertisements appear to embrace an anti-discriminatory approach at first glance, a deeper analysis revealed the presence of racially charged meanings. The research indicated that Benetton advertisements—selected through purposive sampling and analyzed semiotically—contributed negatively to racial discourse, reflecting implicit racist undertones. Boyacı Yıldırım [7] examined the "Turkcell Fiber Support for Families" advertisement, aiming to identify the associative mechanisms used to shape consumers' cognitive perceptions. Employing Barthes' semiotic method, the study decoded the linguistic and visual messages and revealed that the brand enriched meaning through various associations. The analysis showed how the advertisement employed linguistic codes, audiovisual symbols, myths, metaphors, metonymies, and archetypes to construct rich layers of meaning and influence consumer perception through cultural symbols. Arı [1] applied Barthes' semiotic method to analyze two Elidor commercials, highlighting the influence of modern advertising on gender politics and cultural values. The study demonstrated that the advertisements strongly emphasized themes of female empowerment and challenged traditional gender norms, contributing to broader cultural transformations. In this study, Barthes' model was selected as the most appropriate method for analyzing the online advertisements of four major multivitamin brands. The model allows for the examination of both the messages conveyed to consumers and the cultural and social connotations embedded in the underlying meanings through the use of color, figures, and symbols. Thus, the study enables the analysis of advertisements not only as marketing strategies but also as sites of cultural and social meaning production, contributing to the broader tradition of semiotic research.

4. Method and Materials

The aim of this study is to conduct a semiotic analysis of advertisements published on Facebook, Instagram, and YouTube for the multivitamin brands Supradyn, Orzax, Solgar, and Pharmaton, which operate in the over-the-counter pharmaceutical sector, and to decipher the perceptions created in the target audience. The research employs a non-probability purposive sampling method, frequently used in qualitative studies. In qualitative research, the primary goal is not generalization, but rather developing an in-depth and holistic understanding. Purposive sampling techniques are particularly useful for exploring and explaining phenomena and events in detail [19]. Accordingly, this study adopted purposive sampling and identified four advertisements from the specified multivitamin brands across relevant social media platforms. In the analysis of the advertisements, Roland Barthes' semiotic analysis model was applied to decode the messages embedded within the commercials.

4.1 Findings

Using Roland Barthes' semiotic framework, the advertisements of the four leading multivitamin brands that received the highest engagement on social media—Supradyn, Orzax, Solgar, and Pharmaton—were analyzed. The analysis was conducted across the dimensions of Sign, Signifier (visual representation), Signified (conceptual meaning), Denotation (surface meaning), and Connotation (cultural and ideological meaning). The evaluations are presented in Table 1.

Table 1. Semiotic analysis of Supradyn, Orzax, Solgar, and Pharmaton advertisements

Brand	Sign	Signifier	Signified	Denotation	Connotation
Supradyn	A woman running	A woman jogging on a tree-lined path where leaves transition from green to yellow, wearing grey sportswear and fluorescent running shoes	A physically fit and healthy woman	A woman with her hair tied up, wearing a fitness tracker on her arm, running outdoors	Women who use Supradyn can maintain their vitality and perform regular, healthy exercise even during autumn; Supradyn supports energy and renewal

Orzax	A woman walking	A woman wearing a white top, brown-white polka-dot skirt, with long brown hair, black sunglasses, grey boots, standing in front of Istanbul's Maiden's Tower; her phone rings and she removes eight Orzax Ocean products from her bag	A woman preparing for autumn	A woman who stops while walking as her phone rings and places her vitamins on the pavement	A woman who is prepared for life's surprises and carries valuable supplements with her, symbolizing conscious health and readiness
Solgar	Two vitamin bottles	A split background in purple and mint green; the purple background (women) features a small vase with flowers, and a pink bottle with yellow cap and purple tablets in front; the mint background (men) features a coffee cup and eyeglasses, and a blue bottle with yellow cap and green tablets in front	Gender-specific multivitamin products	Multivitamins formulated separately for women and men	Since 1947, the brand has emphasized scientific innovation, sustainable high-quality ingredients, and global production; products reflect a vision of meeting gender-specific daily nutritional needs, reinforcing a premium and science-driven identity
Pharmaton	Appearing multivitamin boxes with orange and yellow bubbles	A background split into orange and yellow with floating bubbles; multiple Pharmaton boxes appear in sequence, featuring male and female silhouettes; the hashtag "Don't Stop Yourself with Pharmaton Vitality" appears	A multivitamin designed for both genders	A product suitable for both men and women	A message of continuous energy and vitality, promoting an active lifestyle and energetic weekends shared with a partner; inclusivity and motivation highlighted

In Supradyn's advertisement, the image of a woman running in a forested area where the leaves shift from green to yellow, wearing grey sportswear and fluorescent running shoes, represents a fit, healthy, and energetic body. At the denotative level, the viewer sees "a woman exercising." At the connotative level, however, she is constructed as "a modern woman who maintains her energy in every season and derives her vitality from Supradyn." The fitness tracker on her arm and her tied-up hair symbolize order and self-discipline. Thus, the advertisement presents the female body as a symbol of health and willpower, while positioning the brand as "the key to resisting seasonal fatigue."

In the Orzax advertisement, the woman walking in front of the Maiden's Tower—an iconic landmark of Istanbul—who pauses when her phone rings and takes Orzax Ocean products out of her bag, constructs the image of a modern individual who takes care of herself amid the fast pace of daily life. At the denotative level, the scene is simply "a woman walking in the city." At the connotative level, it represents "a lifestyle that is balanced, self-confident, and prepared for life's surprises." Her colorful outfit and interaction with her phone highlight the brand's reference to an urban, youthful, and active target audience. Orzax positions health not only as a physical state, but also as a form of social empowerment.

In Solgar's advertisement, the vitamin bottles placed against a background split into purple and mint green emphasize a gender-specific approach to health. While the denotative message is "two vitamin bottles," the connotative layer foregrounds "a vision of personalized health that respects biological differences between women and men." The purple background symbolizes elegance, while the mint green connotes freshness and naturalness. With a reputation built on sustainable production and science-based innovation since 1947, Solgar reinforces its reliability. Accordingly, the advertisement encodes a message of "science-driven individualized wellness."

Pharmaton's advertisement, designed in orange and yellow tones, foregrounds themes of energy and vitality. The sequential appearance of multivitamin boxes creates the impression of "continuously renewed energy." The message accompanied by the hashtag "Don't Stop Yourself" refers to the modern individual's capacity for motivation and renewal amid a fast-paced lifestyle. The denotative image—"a multivitamin suitable for both men and women"—transforms at the connotative level into an ideal of "living life energetically and together." Thus, Pharmaton constructs an inclusive health image that supports gender equality.

4.2 Semiotic Analysis of Color Use

Colors are among the most powerful meaning-making elements in advertising discourse. Barthes (1977) notes that colors are not merely aesthetic components, but also cultural codes that function as "myths." Vitamin brands imbue their products with meanings beyond health—such as life energy, dynamism, and modern identity—through their use of color. The colors used by Supradyn, Orzax, Solgar, and Pharmaton in their advertisements, along with the overlapping colors among the brands, are evaluated in Table 2.

Table 2. Color usage in advertisements of multivitamin brands

Colors	Supradyn	Orzax	Solgar	Pharmaton	Colors Used by All Brands	Colors Common to Three Brands
Yellow	✓	✓	✓	✓	✓	
Red		✓				
Blue		✓	✓	✓		✓
Orange	✓	✓		✓		
Green		✓	✓			
Purple		✓	✓			
Pink			✓			
Gray		✓				
Brown			✓			
Shadow tones						
Black	✓	✓	✓			✓
White	✓	✓	✓	✓	✓	

- Yellow: Yellow is defined as the color of energy and vitality. Kress & Van Leeuwen [16] emphasize that yellow functions as a symbol of "high energy and attention-grabbing appeal," particularly in health and food advertisements. Present in all four brands, yellow evokes myths of "sunlight," "life force," and "optimism." In Supradyn and Pharmaton advertisements, yellow is associated with metabolic strength and alertness; in Orzax and Solgar campaigns, it conveys balance, natural energy, and zest for life.

- Orange: Orange, a hybrid of red and yellow, symbolizes movement, warmth, and enthusiasm. Heller [15] notes that orange triggers "social energy" and "optimism." As a shared color in Supradyn, Orzax, and Pharmaton advertisements, orange communicates messages of an "active lifestyle" and "continuous motivation." In Barthes' terms [3], this color becomes a "mythic representation of energy."
- Blue: Blue is a signifier of trust and scientific credibility [12]. Used by Orzax, Solgar, and Pharmaton, blue represents "rationality, reliability, and stability." In Solgar advertisements, it highlights scientific production processes; in Orzax, it symbolizes inner balance and calm; and in Pharmaton, it functions as a metaphor for "scientific energy." According to Kress & Van Leeuwen [16], blue is the most effective color for constructing "institutional trust."
- Green: Green symbolizes naturalness, renewal, and sustainability. Arnheim [2] states that green creates a sense of "balance and tranquility" in visual perception. In Orzax and Solgar advertisements, green is associated with botanical ingredients, environmentally friendly production, and sustainability values. This positions both brands within a "nature-derived health" ideology.
- Purple: Purple has historically been associated with luxury, sophistication, and wisdom [15]. In Orzax and Solgar advertisements, purple conveys meanings of "conscious consumer identity" and "quality." Solgar's purple background invokes wisdom and scientific depth, while in Orzax it represents self-awareness and self-care ideals. On the connotative level, purple becomes a symbol of "modern femininity" in Barthesian terms.
- White: White appears across all brands, evoking "purity, cleanliness, and trust." Chandler [8] argues that white acts as a metaphor for "clarity and purification" in advertising. Associated closely with the vitamin concept, white reinforces perceptions of health and freshness. It also functions as a visual balancing element, enhancing the impact of other colors.
- Black: Seen in Supradyn, Orzax, and Solgar, black signifies power, professionalism, and authority. Arnheim [2] explains that black generates a sense of "visual weight and seriousness." In Solgar's packaging, black underscores the brand's scientific prestige. Aligned with Barthes' mythology concept [3], black supports a myth of science-based strength and authority.
- Other Colors: In the Orzax advertisement, red signifies "attention and action." Solgar's use of pink represents "elegance and feminine sensitivity," while brown symbolizes "naturalness and roots." Gray tones in Orzax reflect what Kress & Van Leeuwen [16] describe as the "neutral security of modern metropolitan life."
- Shared Color Code Universe: Yellow and white, common across all brands, converge around values of "energy and purity." Meanwhile, blue and black shared by three brands represent a semantic network of "scientific credibility and trustworthiness." This pattern indicates that vitamin brands aim to construct meaning simultaneously on emotional (energy and happiness) and rational (science and trust) levels.

Semiotic analysis of color demonstrates that advertisements are not merely visual compositions but cultural sites of meaning production. Colors are reconstructed as Barthesian "myths" that reinforce the ideological narrative of each brand and establish emotional resonance with consumers.

4.3 Semiotic Analysis of Star Ratings

User evaluations on social media platforms serve not only as indicators of a brand's marketing performance but also as reflections of brand perception in the consumer's mind. Accordingly, star ratings are considered meaningful semiotic markers of both brand image and consumer satisfaction. Table 3 presents the distribution of star ratings for the four brands:

Table 3. Star Rating Distribution of Multivitamin Brands

Star Rating	Supradyn	Orzax	Solgar	Pharmaton
1 ★	86	13	138	487
2 ★★	29	2	15	179
3 ★★★	106	8	6	482
4 ★★★★	226	22	5	1100
5 ★★★★★	1348	178	1	6789
Total	1348	223	165	9037

In the Supradyn brand, the highest concentration of ratings is found at the 5-star level (1348 votes). This suggests that the brand's promises of "energy, continuity, and renewal" are positively received by consumers. The relatively low number of total ratings for Orzax (223) indicates a comparatively limited market presence; however, the high proportion of 5-star reviews (178) demonstrates a strong satisfaction level among its existing users. For Solgar, the high proportion of 1-star reviews (138 out of 165) suggests that the brand's premium pricing strategy and "exclusive" brand positioning may not be perceived as accessible or satisfactory by certain consumer groups. Pharmaton, with 6789 five-star reviews, reinforces its image as a brand associated with "trust, vitality, and consistency." This result indicates that Pharmaton has evolved into a widely internalized "trust myth" among consumers [4].

5. Conclusion and Recommendations

In this study, the online advertisements of four leading multivitamin brands in Turkey were examined through their use of color, figures, and symbols, alongside consumer evaluations, and analyzed using Barthes' semiotic approach. The findings indicate that vitamin brands not only communicate messages about physical health but also construct identity through lifestyle, dynamism, self-care, and cultural layers of meaning. Supradyn conveys the theme of "active energy," Orzax "prepared living," Solgar "scientific personalization," and Pharmaton "shared energy," delivering unique and mythical messages to their target audiences. Barthes' semiotic framework reveals both the denotative and connotative levels of these messages, clarifying how advertisements consciously employ cultural codes and social roles in their underlying narratives.

Consumer evaluation data demonstrates how these meanings are perceived by users. The high five-star ratings for Pharmaton and Supradyn confirm the impact of color and visual strategies on perception, while Orzax and Solgar's more niche user bases indicate the limited effect of their communication and accessibility strategies. These findings show that "energy and trust myths," created through color, movement, and iconography, directly influence consumer perception and can enhance the effectiveness of brand marketing strategies. Theoretically, this study makes significant contributions to understanding the relationship between semiotic analysis and consumer perception. While previous studies [7,18] have examined the layers of meaning in advertisements within cultural and social contexts, an analysis at this level has not been conducted specifically for vitamin brands. By integrating semiotic analysis with consumer evaluations, this study concretely demonstrates both the production of mythical meanings and their impact on user perception, thereby offering a unique contribution to both semiotic theory and consumer perception literature. For future research, similar semiotic analyses could be conducted across a broader range of products and industries to better understand how cultural codes operate in different product categories. Additionally, a deeper analysis of social media interactions and user comments could evaluate the impact of digital marketing strategies on consumer perception. Finally, experimental studies could be designed to measure the psychological effects of color and visual strategies on consumer perception and brand loyalty.

In conclusion, this study provides significant theoretical and academic insights: advertisements shape consumer perception not only as a tool for product promotion but also as part of a cultural and social meaning-making process. Barthes' semiotic model offers a powerful tool for analyzing these layers of meaning and demonstrates the link between marketing and cultural meaning production with concrete evidence. Within this framework, the findings from multivitamin advertisements offer new insights for the semiotic research tradition and guide future academic investigations.

References

[1] Arı İ. The concept of gender in the context of femvertising advertising strategy: A semiotic analysis of Elidor advertisements. Nişantaşı University Journal of Social Sciences. 2024;12(2):669-84. https://doi.org/10.52122/nisantasisbd.1518489
[2] Arnheim R. Art and visual perception: A psychology of the creative eye. Berkeley: University of California Press; 1974. https://doi.org/10.1525/9780520351271
[3] Barthes R. Mythologies. New York: Hill and Wang; 1972.
[4] Barthes R. Image, music, text. London: Fontana; 1977.
[5] Barthes R. Empire of signs. Rifat M, translator. İstanbul: Yapı Kredi Publications; 2016. (Originally published 1982.)
[6] Bianchi C. Semiotic approaches to advertising texts and strategies: Narrative, passion, marketing. Semiotica. 2011;183:243-71. https://doi.org/10.1515/semi.2011.012
[7] Boyacı Yıldırım M. Enriching meaning with associations in advertisements: A semiotic analysis of the Turkcell Fiber advertisement. Gaziantep University Journal of Social Sciences. 2021;20(1):90-109. https://doi.org/10.21547/jss.836625
[8] Chandler D. Semiotics: The basics. London: Routledge; 2007. https://doi.org/10.4324/9780203014936
[9] Elden M, Bakır U. Advertisement appeals: Sexuality, humor, fear. İstanbul: İletişim Publishing; 2010.
[10] Berger AAS. The objects of affection: Semiotics and consumer culture. New York: Palgrave Macmillan; 2010. https://doi.org/10.1057/9780230109902
[11] Toptaş R. Representation of the female image in film posters: A semiotic analysis of domestically produced films released in Turkey. Istanbul: Istanbul University, Institute of Social Sciences; 2021. Master's Thesis.
[12] Gage J. Color and meaning: Art, science and symbolism. Berkeley: University of California Press; 1999.
[13] Gökalp N. Essays on semiotics and meaning. Ankara: İmge Publishing; 1998.
[14] Harmon T. The meaning behind marketing: Semiotic-oriented research in marketing and consumer research. In: Neilson LC, editor. The future of marketing's past: Proceedings of the 12th Conference on Historical Analysis and Research in Marketing (CHARM). East Lansing: Association for Historical Research in Marketing; 2005.
[15] Heller E. The psychology of color: How colors affect us and how we affect colors. Berlin: Springer; 2009.
[16] Kress G, van Leeuwen T. Colour as a semiotic mode: Notes for a grammar of colour. Visual Communication. 2002;1(3):343-68. https://doi.org/10.1177/147035720200100306
[17] Mattelart A, Mattelart M. History of communication theories. Zıllıoğlu M, translator. 8th ed. İstanbul: İletişim Publishing; 2010.
[18] Özkantar MÖ. Racism and its semiotic reflections in the advertising industry: Benetton advertisements. Zirve University Journal of Art and Communication (Zirv-E). 2016;1(2).
[19] Yıldırım A, Şimşek H. Sosyal bilimlerde nitel araştırma yöntemleri. 3rd ed. Ankara: Seçkin Yayıncılık; 1999.
[20] Rıfat M. Annotated semiotics dictionary: Concepts, methods, theorists, schools. İstanbul: Türkiye İş Bankası Cultural Publications; 2013.
[21] Sığırcı İ. Applications of semiotics: Reading texts, visuals, and events. Ankara: Seçkin Publishing; 2016.
[22] Tekinalp Ş, Uzun R. Communication research and theories. 4th ed. İstanbul: Derin Publishing; 2013.
[23] Yıldız HN. Culture and advertising relationship. MANAS Journal of Social Studies. 2022;11(1):293-308. https://doi.org/10.33206/mjss.886628
[24] Mick DG, Burroughs JE, Hetzel P, Brannen MY. Pursuing the meaning of meaning in the commercial world: An international review of marketing and consumer research founded on semiotics. Semiótica. 2004;152(1-4):1-74. https://doi.org/10.1515/semi.2004.2004.152-1-4.1
[25] Oswald LN. Marketing semiotics: Signs, strategies, and brand value. Oxford: Oxford University Press; 2015.
[26] Saussure F de. Course in general linguistics. Bally C, Sechehaye A, editors; Baskin W, translator. London: Bloomsbury Academic; 2014.

Research & Design
www.jrede.org

Research Article

The economic impact of earthquakes: A global assessment of direct and indirect losses

Hayri Baytan Ozmen*[1a], Damla Yalçıner Çal[2b]

[1]*Department of Civil Engineering, Faculty of Engineering and Natural Sciences, Uşak University, Uşak, Türkiye*
[2]*PhD, Independent Researcher, Isparta, Türkiye*

Article Info

Article History:

Received:

07 July 2025

Accepted:

10 Sept 2025

Keywords:

Disaster risk financing, Economic resilience, Earthquake damage, GDP impact, Indirect losses, Insurance systems, Seismic risk, Supply chain disruption

Abstract

This study examines the economic impact of earthquakes through a comparative analysis of eight major seismic events. The research evaluates both direct damages—such as the destruction of housing and infrastructure—and indirect consequences, including business interruption, supply chain disruption, and GDP contraction. Total losses per event ranged from US$8 billion (Haiti 2010) to US$510 billion (Japan 2011), with the ratio of indirect to direct losses spanning 0.42–0.60, underscoring the systemic economic consequences beyond physical destruction. Losses as a share of GDP varied dramatically, from 3% in China to 120% in Haiti, highlighting structural vulnerability in lower-income economies. On average, housing (35%) and infrastructure (25%) comprised the bulk of direct losses, while business interruption (20%), transport/logistics disruptions (12%), and spoilage (5%) accounted for other costs. High-income economies experienced elevated indirect losses due to supply chain interdependence, while low-income countries faced disproportionate economic scarring from service delays and governance gaps. These different vulnerability profiles demonstrate that post-disaster economic impacts stem not only from the magnitude of damage but also from the organizational structure of economic systems and the level of institutional capacity. Therefore, the need for more comprehensive loss accounting frameworks and integrated resilience planning that prioritize both structural safety and economic continuity is of critical importance. Earthquakes function as macroeconomic shocks whose true costs extend far beyond immediate physical destruction, particularly in a globalized economy.

1. Introduction

Earthquakes are not only considered disasters that cause widespread loss of life and serious physical destruction, but also complex socio-economic events that create deep and long-term disruptions in economic systems at local, national, and even global levels. The economic consequences of seismic disasters have a multidimensional structure and encompass both direct and indirect economic losses.

Direct economic losses are mostly related to physical damage occurring during or immediately after an earthquake. This damage includes the destruction of housing stock, commercial and industrial buildings, critical infrastructure networks (transportation, energy, communications, etc.), and public service facilities. Such losses can generally be expressed in measurable monetary terms, such as insurance claims, reconstruction costs, and emergency response expenditures.

*Corresponding author: baytan.ozmen@usak.edu.tr
[a]orcid.org/0000-0001-6750-8632; [b]orcid.org/0000-0002-9232-3063;
DOI: http://dx.doi.org/10.17515/rede2025-007en0716rs

In contrast, indirect economic losses consist of more complex and often difficult-to-measure effects, seriously disrupting the continuity of economic activity in the post-disaster period. The cessation of production activities, disruptions in supply chains and logistics networks, bottlenecks in transportation corridors, and high losses, particularly in perishable products such as food, are the main components of these losses. Furthermore, these effects are not limited to regional economies but can also affect global trade flows and price balances.

Although it is known that indirect economic effects play a decisive role in long-term socio-economic stability, these effects have often been insufficiently considered, and in some cases completely ignored, in disaster risk management, economic assessment, and recovery planning processes. This situation reduces the effectiveness of the post-disaster recovery process and can lead decision-makers to act on incomplete or misleading information in resource allocation and policy development processes.

Over the last four decades, the economic toll of earthquakes has surged dramatically, with total losses from all natural disasters—earthquakes being a major contributor—tripling since the 1980s [1]. The 20th century alone witnessed 1,248 major earthquakes, collectively causing over US$1 trillion in damages when adjusted for inflation [2]. Recent high-profile disasters illustrate the gravity of this trend: the 2011 Great East-Japan earthquake and tsunami resulted in just direct losses of approximately US$360 billion, making it the most expensive natural disaster on record [3]. Similarly, the 2008 Sichuan earthquake in China caused direct economic damage of around US$130 billion [4], while the 2015 Nepal earthquake incurred losses equivalent to nearly 50% of the nation's GDP [5]. In the United States, annualized earthquake damage is estimated at US$14.7 billion [6].

The global economic implications of these events are particularly pronounced in urban settings, where the concentration of infrastructure, housing, and industry multiplies vulnerability. Disasters that strike densely populated and economically integrated regions (such as Tokyo, Istanbul, or Los Angeles) not only result in overwhelming property losses but also disrupt national and international supply chains, delay exports, and halt manufacturing operations. These ripple effects can depress GDP, reduce employment, and increase inflation through elevated transport and goods costs, as shown in post-disaster Japan [2, 7].

Yet, current economic impact assessments tend to privilege direct physical damage over more complex, harder-to-measure indirect effects. While quantifying collapsed buildings is straightforward, evaluating how long a port closure affects automotive exports or how power outages lead to perishable goods spoilage requires more advanced modeling frameworks, such as Computable General Equilibrium (CGE) models, Input–Output (IO) simulations, or Synthetic Control Methods [8–12]. These tools have proven essential in exposing the full scale of post-earthquake economic disruption.

This paper aims to provide a comprehensive and comparative assessment of the direct and indirect economic losses resulting from large-scale earthquakes occurring worldwide. The research is based on case studies selected from different geographical regions and various economic structures, thereby enabling it to highlight the differences in the effects of seismic disasters between developed and developing countries. The analysis examines not only direct damage to physical assets such as housing and infrastructure, but also indirect effects on the functioning of the economic system, such as disruption of transportation networks, disruption of business continuity, and disruptions in production and supply chains.

In this context, the study addresses the macroeconomic, industrial, and infrastructural dimensions of seismic disasters in a multifaceted manner, assessing their effects on both short-term economic contractions and long-term development processes. The findings emphasize that disaster preparedness plans, policy interventions, and resilient urban planning approaches must take into account not only visible physical destruction but also the invisible economic disruptions that emerge after an earthquake, which are often difficult to measure. Thus, the study aims to contribute to the development of a holistic and system-based assessment framework for disaster risk management.

The paper ultimately seeks to understand the patterns of direct and indirect economic losses resulting from major earthquakes. It aims to improve awareness for quantifying indirect costs, with a particular focus on disruptions in manufacturing, logistics, and the supply of perishable goods. Furthermore, the study utilizes comparative case studies to identify vulnerabilities and capacities within diverse economies, specifically contrasting developing and developed nations. By addressing these fundamental points, the research aims to contribute to the development of the interdisciplinary field of disaster economics and to provide actionable recommendations for various stakeholders. The outputs will guide policymakers in developing pre-disaster preparedness and post-disaster recovery strategies, urban planners in designing resilient cities, the insurance sector in properly managing risk, and global supply chain strategists in creating plans to mitigate the effects of disruptions.

2. Literature Review

The economic assessment of earthquake impacts has evolved considerably over the past several decades, shaped by growing access to empirical data, the refinement of economic modeling techniques, and a deepening awareness of the multifaceted nature of disaster-induced losses. While early studies primarily focused on direct damages (the measurable costs associated with destroyed assets, collapsed infrastructure, and emergency relief efforts) recent literature has expanded to address the indirect and systemic economic consequences that persist long after the seismic event has subsided. This section provides a critical overview of the major strands of research, the methodologies used in estimating economic losses, and the identified gaps in existing approaches.

2.1 Direct Economic Losses: Scope and Estimation

Direct economic losses from earthquakes are typically the easiest to observe and quantify. These include the destruction of housing stock, commercial buildings, transportation infrastructure, energy systems, and public facilities such as hospitals and schools. Methodologically, these losses are often assessed using engineering-based damage models, Geographic Information Systems (GIS), and scenario-based simulations such as FEMA's HAZUS-MH (Hazards U.S. Multi-Hazard), which has been widely used in the United States for estimating probable physical and financial losses from future earthquakes [6]. HAZUS integrates ground motion modeling with building inventory data and fragility curves to project structural and economic damage at the city or regional scale.

Numerous empirical studies have reinforced the dominant role of housing and infrastructure in the direct economic footprint of earthquakes. For instance, it is reported that in the 2008 Sichuan earthquake, housing accounted for over half of the estimated ¥845 billion in losses (~US$130 billion) [4]. Similarly, the Earthquake Commission of New Zealand estimated that residential property losses during the 2010–11 Canterbury earthquake sequence reached approximately NZ$9 billion, out of a total NZ$15 billion in overall damages [13]. These examples underscore the disproportionate burden borne by the built environment and the critical importance of building standards and retrofitting policies in reducing vulnerability.

2.2 Indirect Losses: Business Interruption, Supply Chains, and Macroeconomic Effects

Direct economic losses are usually observable immediately after a disaster and can be measured in the short term, while indirect economic losses generally emerge over a longer period of time and affect a much broader segment of the economy. Such losses are not limited to the area where the damage occurred; they encompass multidimensional processes such as the cessation or disruption of production activities, the temporary or permanent displacement of the workforce, the knock-on effects of delays in transportation and logistics networks, and, in particular, the loss of perishable goods with a short shelf life or those requiring a cold chain. According to Botzen et al., indirect effects can, in some cases, surpass direct damages in monetary terms, particularly when supply chain networks are tightly integrated or geographically concentrated [14].

Empirical evidence increasingly supports this assertion. In the aftermath of the 2011 Great East Japan Earthquake, Tokui et al. documented widespread industrial slowdowns not only in the directly affected Tohoku region but also in peripheral zones hundreds of kilometers away [7]. Disruptions to automotive and electronics supply chains caused temporary production halts in companies such as Toyota and Sony, revealing the systemic fragility of just-in-time manufacturing models. A study by the European Bank for Reconstruction and Development (EBRD) employing synthetic control methods estimated that the real GDP of Japan declined by 0.43 percentage points due to earthquake-induced disruptions, a figure notably higher than the regional share of output directly affected by the disaster. These findings align with broader evidence indicating that even five years post-quake, countries impacted by major seismic events experienced export volumes approximately 16% below counterfactual levels [2].

Similar dynamics have been observed in other regions. In Chile, the 2010 Maule earthquake disrupted ports and highways critical to the country's wine and fruit export sectors, leading to both direct product losses and reputational damage in international markets [15]. Meanwhile, in the 1999 Marmara earthquake in Turkey, damage to transport infrastructure and industrial zones in the economically vital Marmara region caused cascading effects across national production chains [16]. Yet, despite this growing body of evidence, indirect losses remain significantly underrepresented in disaster loss databases and insurance assessments, highlighting a persistent methodological and institutional blind spot.

2.3 Modeling Frameworks: From IO Tables to CGE and Econometrics

The estimation of indirect earthquake impacts requires sophisticated modeling techniques capable of capturing intersectoral linkages, substitution effects, and feedback loops. Several approaches have been developed for this purpose:

Input–Output (IO) models, based on the Leontief framework, offer a relatively straightforward way to quantify how disruptions in one sector affect others through backward and forward linkages. However, these models are inherently static and lack price dynamics, making them less suitable for capturing long-term or behavioral responses [14].

Computable General Equilibrium (CGE) models address these limitations by incorporating substitution effects, resource reallocation, and price adjustments. For example, the Shifang County study by Shi et al. employed a spatial CGE framework to simulate a hypothetical earthquake scenario, estimating a total of over US$8 billion in supply-side losses and demonstrating the resilience of economic systems through intra-regional adjustments [17].

Synthetic Control Methods, drawn from econometrics, use counterfactual comparison to estimate what a region's GDP or export levels would have been in the absence of an earthquake. This technique has been employed to great effect in quantifying long-term macroeconomic effects of earthquakes across multiple countries and time periods [2, 12, 18].

Each of these models brings distinct strengths and limitations. IO models excel in short-term, sector-specific disruption analysis, CGE models offer dynamic and policy-relevant simulations, and Synthetic Controls provide empirical validation across broader economic aggregates. The current trend in the literature suggests that hybrid approaches combining these tools may provide the most comprehensive assessments.

2.4 Research Gaps and Critical Perspectives

Despite advances in modeling and empirical analysis, several critical gaps persist in the literature on earthquake economics. First, while direct damages are generally well-documented, comprehensive and standardized assessments of indirect losses remain rare, particularly in low- and middle-income countries. This is due in part to data limitations, but also to the inherent complexity of tracing economic disruptions that often diffuse across time and geography. Many national disaster databases either exclude or inconsistently record secondary effects such as lost productivity, tourism decline, or perishables spoilage—despite their recognized impact on national GDP and livelihoods. This situation often leads to the true extent of indirect losses being systematically underreported and policymakers failing to adequately consider these effects in their risk management strategies. Furthermore, the lack of comparative international data makes it difficult to clearly analyze differences in economic vulnerability and resilience between countries.

Second, sector-specific losses (especially in logistics, agriculture, and services) have received insufficient attention. Most studies aggregate losses at the macroeconomic level or focus on manufacturing and housing, neglecting the nuanced vulnerabilities of sectors that depend on cold chains, just-in-time inventory systems, or informal labor. For instance, while food spoilage due to power outages or blocked transport routes has been reported in post-earthquake Chile and Japan, no standardized methodology exists for quantifying such losses [7, 19]. These shortcomings can lead to misallocation of resources, overlooking priority areas for intervention, and increased costs in the post-disaster recovery process.

Third, there is a lack of longitudinal analysis exploring how earthquake-induced economic shocks evolve over time. Recovery trajectories, productivity rebounds, and reconstruction-driven growth (often referred to as the "build back better" effect) are inconsistently modeled, leading to conflicting interpretations about whether earthquakes merely displace growth or cause permanent economic scars. Moreover, while some studies have shown a post-disaster boost in GDP due to infrastructure investment others argue that such effects are often overstated and benefit only certain economic strata or urban centers [8].

Finally, cross-country comparative studies remain limited, particularly those that adjust for institutional quality, resilience capacity, or disaster preparedness. Developing countries tend to experience higher relative losses, not only because of weaker infrastructure but also due to inadequate social safety nets, slower response mechanisms, and limited access to international insurance markets [2, 20, 21]. However, most global loss estimates fail to adjust for these variables, limiting the generalizability of findings.

While the literature on earthquake-induced economic losses has matured considerably, important conceptual, empirical, and methodological deficiencies remain. Future research must prioritize multidimensional loss accounting, sectoral disaggregation, and standardized methodologies that allow for global comparability. This approach aims to reveal the full extent of losses by measuring not only physical damage but also the ripple effects across sectors such as manufacturing, services, agriculture, logistics, and others. Furthermore, basing data collection, classification, and analysis processes on a common methodology will enhance the reliability of scientific studies and the feasibility of policy recommendations, enabling comparisons between countries. A more granular and integrated approach, spanning engineering, economics, and social science, will be essential to capturing the true economic burden of earthquakes and informing more equitable and resilient recovery strategies.

3. Methodology

The methodological framework for assessing the economic impact of earthquakes must reflect the multifaceted and often nonlinear ways in which seismic events disrupt economic activity. Unlike narrowly defined physical damage assessments, the economic effects of earthquakes span both visible and latent dimensions—including physical asset losses, sectoral production shocks, transportation bottlenecks, and cascading supply chain failures. In this study, a comparative case study approach is employed, integrating qualitative insights with quantitative estimations to analyze the economic impact of major earthquakes across a range of geographical, temporal, and developmental contexts. The methodological design is structured to incorporate both direct and indirect losses, drawing from multiple data sources and modeling strategies to provide a holistic and globally relevant perspective.

3.1 Case Selection and Comparative Framework

The selection of earthquake case studies is purposive, designed to capture a diversity of contexts in terms of economic structure, governance capacity, and exposure to seismic risk. The study focuses on eight major earthquakes occurring between 1995 and 2023, including events in both high-income countries (e.g., Japan, New Zealand) and lower-income economies (e.g., Nepal, Haiti). Criteria for selection include: (i) the availability of disaggregated economic data on direct and indirect losses, (ii) the representativeness of the event in terms of global seismicity, and (iii) its relevance to policy and scholarly discourse on economic resilience. The events are analyzed comparatively along dimensions such as total monetary loss, loss as a percentage of GDP, estimated recovery time, and distribution of damage across economic sectors.

3.2 Definitional and Analytical Framework

To ensure conceptual clarity, the study distinguishes between direct economic losses and indirect economic losses, following standard definitions from the United Nations Office for Disaster Risk Reduction (UNDRR) and the World Bank [22]. Direct losses are defined as the measurable monetary value of physical damage to assets such as buildings, roads, utilities, and industrial facilities. These are typically one-time, spatially concentrated losses that can be documented through structural assessments and engineering surveys. Indirect losses refer to the secondary and tertiary economic disruptions caused by the earthquake, including but not limited to lost income, decreased productivity, business interruption, elevated transportation costs, spoilage of perishable goods, and long-term effects on investment and trade. These losses are often distributed across time and space, and require modeling approaches to estimate. Both types of losses are considered essential for capturing the full economic footprint of each event. Where available, monetary values are reported in inflation-adjusted U.S. dollars to facilitate comparability.

3.3 Data Sources

The study synthesizes data from multiple sources to ensure robustness and triangulation. These include:

- Official reports from national disaster agencies (e.g., FEMA, AFAD, EQC, NDMA) and international organizations (e.g., EM-DAT, GFDRR, World Bank, UNDP)
- Peer-reviewed academic studies analyzing specific events or employing relevant modeling techniques
- Media and news archives, particularly for estimates of sectoral and short-term losses
- Scholarly databases such as ScienceDirect, Scopus, etc., for empirical and methodological literature
- Open-source encyclopedic platforms (e.g., Wikipedia), used cautiously and only for cross-verifying baseline event data (e.g., magnitude, location, affected population)

The synthesis of these heterogeneous sources allows for a multi-layered understanding of how earthquake losses are recorded, modeled, and interpreted across different institutional and national contexts.

3.4 Assumptions and Limitations

Like any interdisciplinary disaster economics study, this methodology is constrained by several assumptions and inherent limitations:

Data incompleteness and inconsistency: National and sectoral loss data vary significantly in availability and precision, especially for indirect effects. In some cases, figures are extrapolated from partial assessments or third-party estimates, introducing potential bias.

Cross-context comparability: Although monetary standardization is applied, institutional, cultural, and economic differences among case countries may affect the comparability of disaster response and loss accounting.

Model dependency: For indirect losses, reliance on CGE, IO, or econometric estimates means that findings are subject to model assumptions (such as elasticity values, substitution effects, or production function structures) that may not hold across all contexts.

Temporal variation: The impacts of earthquakes evolve over time, and many studies provide only snapshots (e.g., 6 months or 1 year post-disaster). This study captures mid-range effects (1–5 years), but not the full long-term trajectory of economic recovery or decline.

Sectoral aggregation: While every effort is made to disaggregate data, some sector-specific losses (e.g., informal labor markets, micro-enterprises) are not available in a quantifiable format and are discussed qualitatively.

Nonetheless, these limitations are mitigated by the triangulation of diverse data sources and the transparency of methodological choices. Rather than offering a deterministic model of earthquake economics, this study aims to illuminate the complex, interconnected pathways through which earthquakes affect economies, highlighting patterns and vulnerabilities that are often masked in single-event or single-country analyses.

4. Case Study Summaries

To elucidate the real-world economic implications of earthquakes, this section presents a set of comparative case studies focusing on eight major seismic events that occurred between 1995 and 2015. These cases were selected not only for their geographic and economic diversity but also for the availability of disaggregated data on both direct and indirect losses. The objective is to identify recurring patterns, sectoral vulnerabilities, and variations in economic impact across different national contexts. Each case study synthesizes damage assessments, sectoral losses, and macroeconomic consequences within a standardized framework, allowing for meaningful cross-case comparison. Emphasis is placed on housing and infrastructure damage, business and supply chain disruption, GDP impact, and recovery timelines.

4.1 The Great East Japan Earthquake (2011)

The magnitude 9.1 The Great East Japan Earthquake, followed by a massive tsunami, stands as the costliest natural disaster in recorded history, with total direct economic damages estimated at US$360 billion (adjusted for year 2023) [3, 23]. Direct damages were immense, including the destruction of over 120,000 buildings, substantial damage to critical infrastructure (including roads, ports, and the Fukushima Daiichi nuclear power plant) and widespread disruption of energy and water supply systems. Indirect losses were equally devastating: rolling blackouts, transport delays, and disruptions to automotive and electronics supply chains significantly impaired Japan's industrial output [7]. Estimates suggest that indirect economic losses reached US$150 billion, and the national GDP declined by approximately 0.43 percentage points in the fiscal year following the disaster [2]. Recovery and reconstruction efforts spanned over a decade, with significant financial stimulus allocated through the Reconstruction Agency of Japan.

4.2 Sichuan Earthquake, China (2008)

With an epicenter in Sichuan province, the earthquake caused direct economic losses of ¥845 billion (~US$130 billion), with more than 4.8 million people left homeless and widespread destruction of educational, health, and transportation infrastructure [4]. Housing damage accounted for the majority of the loss, with entire urban districts reduced to rubble. Indirect economic consequences included agricultural losses, export disruptions, and diminished industrial output in Sichuan's manufacturing hubs. Although detailed econometric evaluations are scarce, Food and Agriculture Organization (FAO) estimates put agricultural damage alone at over US$6 billion [24]. The Chinese government launched a multi-year, trillion-yuan reconstruction plan, partially offsetting longer-term macroeconomic shocks.

4.3 Canterbury Earthquake Sequence, New Zealand (2010–2011)

The series of earthquakes that struck Christchurch and its surrounding areas—most notably the February 2011 event—resulted in US$40 billion in total damages, with NZ$9 billion attributed to residential property losses alone [13]. Despite New Zealand's high level of disaster preparedness, significant disruption occurred in the Central Business District (CBD), which was cordoned off for months due to building collapse and infrastructure failure. Business interruption claims surged, and indirect losses—though difficult to quantify precisely, were estimated in the range of US$15–20 billion, encompassing tourism decline, service sector shutdowns, and reconstruction delays. Insurance penetration was high, which accelerated economic recovery but revealed new vulnerabilities in the financial underwriting of seismic risk.

4.4 Gorkha Earthquake, Nepal (2015)

The Gorkha earthquake had devastating consequences for Nepal, a low-income country with limited infrastructure resilience. Total damages were estimated at US$10 billion, equivalent to nearly 50% of the country's GDP [5]. Housing destruction was severe, with more than 500,000 homes either destroyed or damaged, particularly in remote and rural areas. Infrastructure failures hampered emergency relief and post-quake reconstruction. Indirect losses included a collapse in tourism revenues, delays in agricultural exports, and food spoilage due to blocked roads and power outages. The lack of diversified income sources and high reliance on foreign aid further prolonged the recovery process, highlighting the asymmetric burden borne by vulnerable economies.

4.5 Haiti Earthquake (2010)

The magnitude 7.0 earthquake that struck Haiti's capital region resulted in an estimated US$8.5 billion in damages, including the collapse of 250,000 residences and widespread destruction of government buildings and public services [16, 18, 25]. Indirect economic losses were difficult to quantify, due in part to the country's large informal sector and the destruction of baseline statistical infrastructure. Nevertheless, disruptions to food supply chains, imports via the damaged Port-au-Prince, and widespread displacement likely added billions in indirect economic costs. International assistance temporarily filled some economic voids, but chronic underdevelopment and political instability hindered long-term recovery, leading many to characterize the economic impact as permanently regressive.

4.6 Maule Earthquake, Chile (2010)

The Maule earthquake, registering a magnitude of 8.8, struck central Chile and caused economic damages exceeding US$30 billion, representing around 18% of the national GDP [15, 16, 26]. While the event occurred in a seismically prepared and economically middle-income country, the high intensity and widespread reach of the earthquake overwhelmed even Chile's relatively robust building codes. Direct damage included the collapse of over 370,000 homes and serious impairment to ports and road infrastructure, particularly in regions critical to Chile's wine and fruit export industries. Perishable spoilage from export delays and the temporary shutdown of cold storage and logistics hubs resulted in substantial, though poorly quantified, indirect agricultural losses. These disruptions highlighted the sensitivity of globally integrated supply chains to infrastructure vulnerability.

4.7 Marmara Earthquake, Turkey (1999)

Striking the industrial heartland of Turkey, the 1999 Marmara earthquake caused US$17.1 billion in direct damages and claimed over 17,000 lives. Much of the loss was concentrated in housing and urban infrastructure, with widespread destruction in the cities of İzmit, Adapazarı, and parts of Istanbul. Indirect losses were severe due to the disruption of the Gebze and Kocaeli industrial zones, where automotive, textile, and manufacturing plants were temporarily shut down. Transport networks were also heavily affected, with damage to highways and bridges impeding relief and commercial flows. While comprehensive CGE or IO modeling of indirect losses has not been published for this event, post-quake economic indicators suggest output in key sectors contracted sharply, and recovery required years of financial intervention and international lending [2, 16].

4.8 Kashmir Earthquake, Pakistan (2005)

The 2005 Kashmir earthquake, though smaller in absolute economic terms, had catastrophic human and fiscal impacts in Pakistan's Azad Kashmir and Khyber

Pakhtunkhwa regions. Estimated losses totaled US$5.2 billion, equivalent to roughly 5% of Pakistan's GDP [27]. The region's rugged terrain and limited infrastructure exacerbated access problems and emergency response times, inflating the economic impact. Direct damages included widespread housing collapse, school and hospital destruction, and road failures. Indirect effects included labor displacement, reduced agricultural productivity, and long-term educational discontinuity due to school closures. The humanitarian nature of the crisis attracted international aid, but systemic vulnerabilities and administrative delays undermined efficient reconstruction.

4.9 Comparisons and Insights

The comparative review of these eight case studies is listed in Table 1 and 2. Please, note that the "Economic Loss (% of GDP)" column in Table 1 includes direct and indirect losses combined and sources given in Table 1 are valid for Table 2, as well. Values given in both tables illustrates a number of important patterns. First, the magnitude of an earthquake does not alone determine its economic impact; rather, the structural vulnerabilities, economic integration, and resilience capacity of the affected region play a critical role. Countries with pre-existing economic fragility, such as Haiti or Nepal, tend to suffer disproportionately in relative GDP terms, whereas highly industrialized nations, like Japan or New Zealand, may incur higher absolute losses but often exhibit more rapid recoveries due to insurance penetration and institutional capacity.

Second, across nearly all cases, housing and infrastructure consistently emerge as the largest components of direct damage, while indirect losses, particularly related to business interruption, supply chains, and perishables, are both substantial and underreported. Where CGE or IO models are applied, such as in Japan and New Zealand, indirect losses frequently rival or exceed physical damages, indicating the need for more systematic incorporation of these elements in economic loss assessments.

Third, the tables show that sectoral dependence matters. Countries with economies heavily reliant on tourism, agriculture, or manufacturing exhibit particularly acute vulnerabilities. For example, Nepal's post-earthquake GDP contraction was driven not only by physical damage but also by plummeting tourism and remittance flows. Chile's and Japan's export sectors similarly faced multi-billion dollar losses due to port closures and logistics breakdowns, suggesting that economic globalization can amplify the reach of local disasters. These insights underscore the need for a holistic and sector-sensitive approach to earthquake economic impact assessment—one that considers not only the collapse of buildings but the complex socioeconomic systems they support.

5. Results & Analysis

The comparative evaluation of eight major earthquake events reveals a complex interplay between direct structural damages, indirect economic disruptions, and the broader macroeconomic resilience of affected regions. By analyzing both numerical data and contextual features across case studies, several critical themes emerge regarding the scale, composition, and distribution of earthquake-induced economic losses. These findings deepen our understanding of how seismic events shape not only the physical landscape but also the economic trajectories of nations and communities.

Table 1. Estimated economic impacts of major earthquakes (direct losses)

Earthquake (Year)	Country	Mag.	Direct Loss (USD, Billion)	Housing Damage	Infrastructure Damage	Deaths	Injured/Homeless	Economic Loss (% of GDP)	Sources
Tohoku (2011)	Japan	9.1	360	Severe; over 120,000 buildings destroyed	Extensive: ports, power plants, roads, nuclear disaster	19,759	~450,000 homeless	~6%	[3, 7, 23]
Sichuan (2008)	China	7.9	130	~5 million homeless	Roads, rail, dams, schools	87,000	~375,000 injured	~3%	[4, 24, 28]
Christchurch (2011)	New Zealand	6.2	40	Major in CBD and residential areas	Infrastructure and water systems	185	~50,000 homeless	~8%	[13, 29]
Gorkha (2015)	Nepal	7.8	10	Over 500,000 houses destroyed	Roads, bridges, public services	9,000	~3 million affected	~50%	[5, 29, 30]
Haiti (2010)	Haiti	7	8.5	Collapsed 250,000 residences	Government buildings, roads, port	230,000	1.5 million homeless	~120%	[18, 23, 25]
İzmit/Kocaeli (1999)	Turkey	7.4	17.1	Widespread residential collapse	Infrastructure, bridges, industrial areas	17,000	~250,000 displaced	~7%	[2, 16, 29]
Maule (2010)	Chile	8.8	30	>500,000 houses damaged	Power grid, highways, ports	525	>2 million affected	~18%	[15, 26, 29]
Kashmir (2005)	Pakistan	7.6	5.2	Over 400,000 houses	Schools, hospitals, roads	86,000	3.5 million homeless	~5%	[27, 29]

Table 2. Estimated indirect economic impacts and disruptions

Earthquake (Year)	Indirect Loss (USD, Billion)	Business Interruption	Transport Disruption	Manufacturing Halt	Perishable Goods Spoilage	Notable Supply Chain Effects
Tohoku (2011)	~150	National-scale outages, auto and electronics	Ports & roads unusable	Toyota, Sony, etc. halted production	Food, pharma losses in cold chains	Global ripple; auto/electronics shortages
Sichuan (2008)	~65	Regional factories, agriculture exports	Mountainous roads collapsed	Local mining & construction paused	Large agricultural losses (FAO)	China's cement industry delayed
Christchurch (2011)	~15–20	Downtown closed for months	Minor but persistent detours	Local retail and service sectors halted	Low, mostly local	CBD inactivity affected tourism & insurance
Nepal (2015)	~6	Tourism, trekking halted	Rural access roads blocked	Handicraft and exports delayed	Food, aid spoilage in warehouses	Remittances hit, aid logistics delayed
Haiti (2010)	~5	Almost total commerce halt in capital	Port collapsed; imports delayed	Informal sector lost income	Cold storage failure for aid & food	Relied heavily on external food imports
İzmit/Kocaeli (1999)	~8	Industrial downtime in Marmara Region	Rail and road network blocked	Major industry (Ford, Arçelik) halted	Not well documented	Long-term reduction in exports from region
Maule (2010)	~10–15	Ports closed; wine industry losses	Major roads and ports disrupted	Food processing plants stopped	Wine, fruit exports delayed/spoiled	Losses in agro-export value chains
Kashmir (2005)	~2–3	Remote villages isolated	Landslides, blocked roads	Minimal industry	Local food losses in mountains	Aid and recovery delayed by access issues

5.1 Distribution of Losses: Direct vs. Indirect

A key finding from the case analysis is the consistent dominance of housing and infrastructure losses in the direct damage category, typically comprising 50–70% of total direct losses. For instance, in the 2008 Sichuan earthquake, housing alone accounted for over half of the ¥845 billion in total losses [4] while in New Zealand's Canterbury earthquakes, residential property losses reached NZ$9 billion out of NZ$15 billion in total damages [13]. This pattern highlights the concentration of economic value in built environments and the heightened exposure of residential areas in seismic zones.

However, the data also indicate that indirect losses—particularly those associated with business interruption, supply chain breakdowns, and logistics failures can rival direct physical damage. In Japan's 2011 Tohoku earthquake, indirect losses stemming from power outages, factory shutdowns, and disrupted global supply chains were estimated at approximately US$150 billion, almost half the total economic cost [2, 7]. Similarly, indirect effects in Chile's 2010 Maule earthquake, though less well quantified, were substantial in sectors like agriculture and export logistics, where shipping delays and spoilage disrupted revenue streams for weeks.

This evidence supports the growing consensus in the literature that disaster loss accounting systems underestimate the full economic impact when indirect effects are excluded [14]. Particularly in industrialized economies with complex supply chains and service-driven sectors, indirect economic consequences are magnified by interdependencies across infrastructure networks and just-in-time production systems.

5.2 Economic Resilience and Recovery Dynamics

Another important finding concerns the variation in recovery speed and resilience across countries. High-income nations with robust institutional frameworks, insurance markets, and financial capacity (such as Japan and New Zealand) demonstrated relatively faster economic rebounds. In contrast, low-income countries like Nepal and Haiti faced prolonged reconstruction periods, dependency on external aid, and slow economic recovery, even years after the disaster.

For example, New Zealand's high insurance penetration facilitated capital inflows and rebuilding after the Canterbury earthquake, cushioning macroeconomic impacts despite the disaster's large cost relative to GDP [21]. Conversely, in Nepal, where losses reached nearly 50% of GDP, the recovery was hampered by administrative bottlenecks and limited domestic financing options [5]. Haiti's situation was even more severe; with economic losses exceeding 100% of GDP, the country became reliant on external donor financing, and the rebuilding process was mired in governance challenges and political instability.

These contrasting experiences underscore the importance of pre-existing institutional capacity, financial instruments, and governance quality in shaping the economic aftermath of earthquakes. Countries with integrated disaster risk financing strategies and efficient administrative structures tend to absorb and distribute losses more equitably and rapidly. Furthermore, strong institutional structures and financial mechanisms not only accelerate post-disaster recovery but also contribute to maintaining long-term economic stability. Conversely, in countries lacking such mechanisms, disasters can deepen economic vulnerabilities, leading to permanent setbacks in the development process.

5.3 Sectoral Sensitivities and the Role of Global Integration

The results also highlight the differential vulnerability of economic sectors to seismic shocks. Manufacturing and heavy industry often suffer immediate output losses due to damage to production facilities and logistical networks. However, sectors such as tourism, agriculture, and retail (especially those reliant on seasonal flows and perishables) face unique vulnerabilities that are frequently overlooked in aggregate economic assessments.

In Nepal, the tourism sector, a key source of foreign exchange and employment, collapsed following the 2015 earthquake, contributing to a steep decline in GDP and household income [31]. In Chile, blocked transport routes and port closures led to fruit and wine spoilage, resulting in temporary export shortfalls. Similarly, in Japan, the disruption of semiconductor and automotive parts supply chains echoed globally, temporarily halting production lines as far afield as the United States and Germany [7].

These findings point to the increasingly globalized nature of disaster impacts. In a world where supply chains span continents and industries rely on tightly scheduled deliveries, localized seismic events can generate transnational economic ripple effects. This further complicates post-disaster recovery, as firms must manage not only local reconstruction but also upstream and downstream coordination failures. Particularly in sectors integrated into the global value chain, such as high technology, automotive, and food, such disruptions make it difficult to quickly restore production capacity and increase costs. Furthermore, these disruptions in international trade flows directly affect not only the country where the disaster occurred but also other countries that are economically dependent on it.

5.4 GDP Impact and Long-Term Economic Scarring

A final dimension of analysis concerns the macroeconomic consequences of major earthquakes. As shown in the case studies, GDP losses vary significantly in both absolute and relative terms. Japan's Tohoku disaster caused a 0.43 percentage point decline in GDP growth in 2011 [2], a significant macroeconomic event in a high-income country. In contrast, the same magnitude of loss in a country like Haiti (estimated at over 100% of GDP) represented a near-complete erasure of annual economic output, with long-term effects on investment, employment, and public finances.

While some studies suggest that reconstruction efforts may produce a short-term GDP boost, this so-called "build back better" phenomenon is often overstated. Many reconstruction programs are constrained by absorptive capacity, lead to inefficient allocation of resources, or create dependency on donor funds. Furthermore, temporary growth may mask underlying structural damage, especially in labor markets and informal economies. Thus, while macroeconomic statistics may eventually return to pre-disaster levels, the distributional and sectoral scars often persist much longer. For this reason, in post-earthquake economic recovery assessments, it is crucial to consider the lasting effects on different sectors of the economy rather than focusing solely on growth figures.

5.5 Theoretical Interpretation and Implications

The empirical findings from the case studies resonate strongly with insights from disaster economics and system resilience theory. In particular, the "cascading failure" model—where damage in one subsystem (e.g., transport infrastructure) triggers failures in others (e.g., production, logistics, service delivery)—is repeatedly borne out in the observed dynamics of post-earthquake economies [32]. The extent to which these cascades lead to systemic breakdown or are absorbed and redirected depends on the structural flexibility and redundancy of the affected system.

For example, the ability of firms to reallocate production, source inputs from alternative suppliers, or switch to substitute goods and services determines the overall scale of indirect losses. This underscores the value of economic diversification and supply chain redundancy as resilience strategies. In regions with high dependence on a single sector or supplier chain, earthquakes tend to cause more sustained economic contractions.

Conversely, economies that exhibit high degrees of adaptive capacity, supported by efficient institutions, flexible labor markets, and robust monetary frameworks, are better positioned to recover.

These findings also lend empirical support to the use of Computable General Equilibrium (CGE) models in disaster planning, which emphasize substitution effects and market dynamics rather than linear propagation of losses assumed in traditional input–output models [8]. The ability of CGE frameworks to simulate behavioral responses, such as shifts in consumer spending or government investment, provides a more nuanced view of post-disaster recovery paths, particularly when combined with empirical calibration using case study data.

Finally, the variation across countries in terms of loss-to-GDP ratios, recovery timelines, and indirect loss magnitudes highlights the need for context-sensitive disaster policy frameworks. One-size-fits-all approaches fail to account for local economic structures, governance regimes, and social vulnerability profiles. The evidence suggests that countries must design tailored risk mitigation strategies, combining retrofitting and zoning policies with economic instruments such as contingent credit lines, catastrophe bonds, and business interruption insurance to enhance resilience comprehensively.

6. Discussion

The findings of this study reinforce and extend a growing body of scholarship that repositions earthquakes not solely as geophysical disturbances but as systemic economic shocks with wide-ranging consequences for development, financial stability, and social well-being. This section critically examines the implications of the empirical results through the lens of established literature on disaster economics, with particular attention to the comparative dynamics of direct and indirect losses, the mediating role of institutional and financial capacity, and the broader contours of economic resilience.

6.1 Earthquakes as Economic Shocks

Numerous scholars have emphasized that natural disasters like earthquakes should be understood not only in terms of physical destruction but as external macroeconomic shocks that disturb production functions, labor supply, and consumption [33, 34]. This study's comparative analysis supports this view, illustrating how earthquakes produce asymmetric economic consequences that depend more on institutional and sectoral configuration than on magnitude alone. For instance, although both Japan and Haiti experienced catastrophic seismic events, the economic outcomes were vastly different due to differences in GDP structure, financial systems, and governance quality.

The results align with the findings of Felbermayr and Gröschl [35], who show that large disasters can have long-term negative effects on GDP, particularly in low-income countries. In Nepal and Haiti, where the Gorkha and Port-au-Prince earthquakes respectively caused losses equivalent to half or more of annual GDP, the limited absorptive capacity of public institutions hindered both immediate response and long-term recovery. This stands in contrast to countries like New Zealand and Japan, where institutional mechanisms, including insurance frameworks and reconstruction agencies, helped buffer macroeconomic volatility and stabilize post-disaster growth trajectories [36].

The comparative data also underscores how the macroeconomic burden of earthquakes is deeply unequal across countries. As visualized in Figure 1, which shows the total economic losses as a percentage of national GDP, low-income countries such as Haiti and Nepal experienced losses equivalent to 120% and 50% of GDP, respectively, compared to 6% in Japan and just 3% in China. These extreme proportional losses indicate not only physical vulnerability but a lack of economic buffers, diversified income sources, and financial resilience.

This gradient supports finding by Noy and Felbermayr and Gröschl, who have shown that disasters impose greater proportional costs on countries with smaller, less diversified economies, despite possibly lower absolute damage [33, 35]. Thus, even modestly sized disasters can destabilize entire economies in low-income contexts.

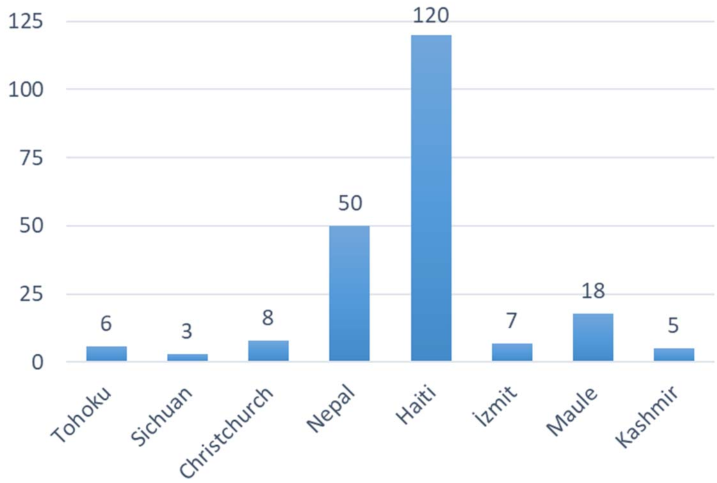

Figure 1. Total economic losses from earthquakes as % of national GDP

6.2 Balance of Direct and Indirect Losses

While direct damages to housing and infrastructure are typically well-documented in global disaster databases [37], this study confirms the literature's long-standing concern that indirect economic losses remain underrepresented in risk assessments [8, 38]. In high-income, industrialized contexts, indirect losses, such as production halts, lost wages, and disruptions to supply chains, often rivals the initial valuation of direct damage. This was especially evident in the 2011 Great East Japan Earthquake, where business interruption and global supply chain failures contributed to indirect losses estimated at nearly US$150 billion [7].

These findings are consistent with the synthetic control analysis by Cavallo et al. [34], which demonstrated that countries exposed to large earthquakes typically suffer sustained export losses and reduced industrial output unless offset by substantial reconstruction investment. The results also echo those of Koks et al. [39], who argue that traditional disaster models systematically underestimate economic risk by neglecting the compounding effects of indirect losses, particularly in interconnected systems.

To illustrate the significance of these secondary effects, Figure 2 presents the ratio of indirect to direct losses for the eight earthquake events analyzed. Across all cases, the ratio ranges between 0.42 and 0.60, with the highest ratios recorded in Nepal (0.60) and Haiti (0.59), both low-income countries with severe institutional and logistical limitations. Interestingly, even in high-income settings like Japan and New Zealand, indirect losses still comprise over 40% of total economic impact.

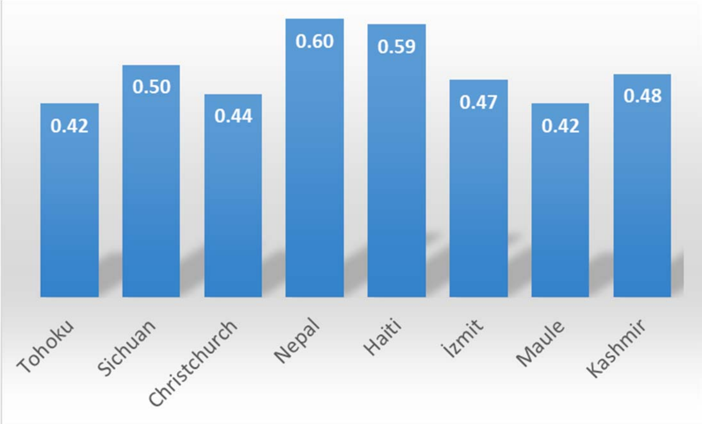

Figure 2. Ratio of indirect to direct economic losses in major earthquakes

These findings challenge the assumption that indirect losses are marginal or secondary. Rather, they are consistently comparable in scale to direct losses, regardless of national income level. This reinforces prior modeling work by Okuyama and Santos [38] and Koks et al. [39], who argue that indirect effects, especially in supply chains and services, are not residual, but co-primary components of disaster economics.

6.3 Financial Mechanisms and Institutional Capacity in Recovery

The literature strongly supports the observed correlation between insurance coverage, institutional robustness, and recovery efficacy. Studies by Cummins and Mahul [40] and Hallegatte et al. [36] have shown that countries with developed catastrophe risk financing instruments recover faster and with less social disruption. This study confirms those findings, as evidenced by New Zealand's relatively swift post-earthquake rebound, underpinned by the Earthquake Commission's insurance scheme, compared to the prolonged fiscal crisis in Haiti, where insurance coverage was negligible.

In line with Melecky and Raddatz [41], the analysis also suggests that governments in low-income countries often face a financial trap: lacking pre-disaster savings or contingent credit, they must reallocate scarce development funds for emergency response and reconstruction, thereby delaying long-term investments and compounding vulnerability. Such trade-offs underscore the urgent need for integrating financial resilience into national disaster strategies, particularly in fragile contexts.

6.4 Sectoral Vulnerability and Globalization of Risk

The study's findings reaffirm concerns raised by Henriet et al. [42] and Hallegatte [36] about the sector-specific nature of disaster exposure, particularly in supply-chain dependent and export-oriented industries. For example, the Maule earthquake's disruption of agricultural exports revealed the fragility of value chains that depend on functional ports, roads, and refrigeration infrastructure. Similarly, Japan's loss of electronic components production affected automotive manufacturing across East Asia and North America.

These effects are magnified in an era of economic globalization, where even localized disruptions can generate transnational ripple effects. Rose [32] and Santos & Haimes [43] have previously modeled such "ripple effects" in economic systems, stressing that resilience is not only a local property but one embedded in the configuration of trade, logistics, and inter-firm networks. The present study supports these insights and further argues that countries must view earthquake risk as not only a domestic challenge but a potential contributor to global economic instability.

6.5 Geography, Development, and the Type of Losses

The location of an earthquake, both in geographical and economic terms, has a profound influence on the composition of economic losses. Figure 3 illustrates the distribution of direct and indirect economic losses across the eight case studies, highlighting how the relative shares vary with development level, urbanization, and economic structure.

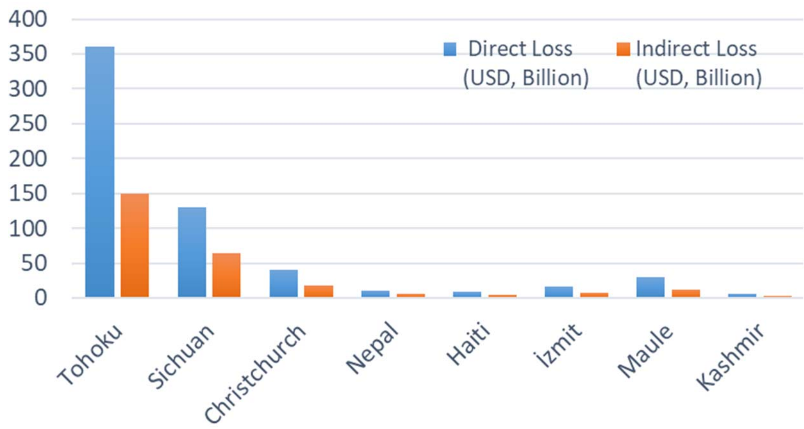

Figure 3. Comparison of direct and indirect earthquake losses by country

High-income countries such as Japan (Tohoku) and New Zealand (Christchurch) show high absolute direct losses due to the high asset value in urban environments, but they also exhibit significant indirect losses, largely attributable to tightly integrated supply chains and dense service sectors. In Japan, for example, indirect losses (US$150 billion) accounted for over 42% of the total, due to disruptions in automotive and electronics production that affected markets worldwide [7].

By contrast, in lower-income countries such as Nepal and Haiti, indirect losses are also proportionally high (59–60%), but the mechanisms differ. Here, indirect effects stem not from complex supply chains but from prolonged business closures, tourism declines, and aid delivery inefficiencies. These contexts lack logistical redundancy and functional insurance systems, which delays recovery and deepens economic scarring [34, 41].

Middle-income countries such as Turkey (İzmit) and Chile (Maule) occupy an intermediate position, where the damage is more evenly distributed. This suggests that the balance between direct and indirect losses is shaped by both economic complexity and governance capacity.

In sum, the considered cases support a geographically differentiated damage distribution of earthquake economics:

- In high-income contexts, indirect losses are driven by supply chain interdependence
- In low-income settings, indirect losses are amplified by governance and service bottlenecks
- In middle-income contexts, the composition depends on industrial density and disaster preparedness

These distinctions underscore the necessity for context-specific resilience strategies that align with local economic structures and institutional capacities.

6.6 Disaggregating Economic Losses: A Functional Typology

Understanding the full spectrum of earthquake-related economic losses requires disaggregation beyond the standard categories of “direct” and “indirect” damage. Figure 4 illustrates the conceptual composition of earthquake-induced economic losses, averaged from considered earthquake events, post-disaster studies and modeling literature [7, 15, 22, 31, 37, 38, 44, 45]. The distribution is not universally fixed but reflects common trends observed across high-profile seismic events.

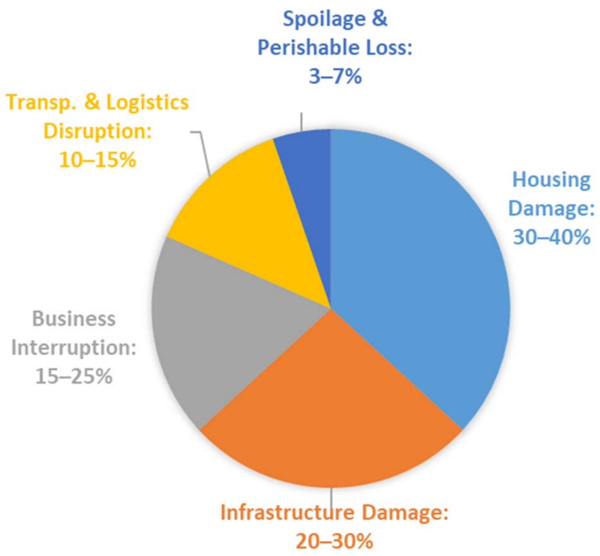

Figure 4. Average composition of earthquake-related economic losses by category

Housing Damage (30–40%)

This category includes the destruction or severe damage of private residential buildings (both owner-occupied and rented) along with temporary shelter costs and full or partial reconstruction expenditures. Housing losses are generally the largest single component of direct damages, particularly in countries with outdated building stock or poor zoning enforcement, as seen in Haiti and Nepal. Methodologies such as HAZUS-MH and GEM typically estimate these using building inventory databases and unit replacement costs.

Infrastructure Damage (20–30%)

Infrastructure losses encompass public belongings such as transport networks (roads, bridges, ports), lifeline utilities (electricity, water, sanitation), and social infrastructure (schools, hospitals). In urban or industrially dense areas like Christchurch (2011) or Tohoku (2011), infrastructure damages were particularly high due to dense asset concentration and the cascading cost of service restoration. These losses often trigger long-term economic strain on municipalities and national governments.

Business Interruption (15–25%)

This refers to the loss of revenue or productivity due to temporary or extended shutdowns in commerce, manufacturing, and services. Particularly vulnerable are SMEs, whose liquidity and risk buffers are limited. These losses are often difficult to measure directly and are estimated using input–output (IO) or computable general equilibrium (CGE) models, as well as insurance claim data. For example, in the Tohoku earthquake, halted operations in electronics and auto manufacturing accounted for billions in unrealized output [7].

Transport & Logistics Disruption (10–15%)

These losses stem from damage to key transport nodes and networks, particularly ports, rail systems, and road corridors. The impact is not limited to the immediate region; it can reverberate through global supply chains. The 2011 Japan earthquake, for instance, caused automotive production halts in the United States and Europe due to missing components.

These costs include delays, rerouting, and increased transport premiums, and are often embedded in broader business interruption metrics but deserve discrete attention.

Spoilage & Perishable Goods Loss (3–7%)

An often underreported category, this includes losses due to cold storage failures, transport delays, and distribution bottlenecks affecting food, pharmaceuticals, and agricultural exports. These are especially critical in agriculture-dependent or export-oriented economies like Chile, Turkey, and Pakistan, where produce loss directly affects trade balances and rural income. Because such losses are seldom captured in traditional damage assessments, their presence in insurance records and humanitarian logistics data serves as a proxy.

The figure 4 highlights that while housing and infrastructure consistently dominate the damage profile, indirect and functional economic effects account for at least one-third of total losses. These latter categories, business interruption, transport disruption, and spoilage, are often underestimated or omitted in official assessments, which skews policy priorities and underfunds resilience in non-structural domains. For example, investing in supply chain redundancy or cold-chain stabilization may yield high resilience returns but receives less attention than retrofitting housing.

Moreover, the distribution underscores the multisectoral nature of earthquake risk, necessitating disaster preparedness strategies that go beyond physical reconstruction. This typology encourages policymakers to view earthquake economics not only through the lens of engineering, but through systems thinking—identifying interdependencies across critical services and market functions.

6.7 Toward an Integrated Economic Resilience Paradigm

The literature increasingly promotes a shift from post-disaster response to pre-disaster resilience, and this study provides additional empirical justification for that transition. Hallegatte et al. [46] propose a systems approach to disaster resilience, wherein adaptive capacity, economic diversification, and institutional redundancy serve as core pillars. The cases analyzed in this study affirm this model, particularly in the differential outcomes observed in recovery timelines and GDP stabilization.

Importantly, resilience must be understood not only as the ability to rebuild but as the capacity to sustain economic function during and after disruption. As Rose [32] notes, economic resilience includes behavioral responses such as resource reallocation, production substitution, and market adaptation, all of which can significantly mitigate disaster impacts when institutions are capable of enabling such responses.

7. Conclusion

The economic consequences of earthquakes are far more than the sum of collapsed structures and disrupted roads. As this study has demonstrated through a comparative, cross-national analysis of eight significant seismic events, earthquakes function as systemic economic shocks, with repercussions that extend beyond immediate physical damage into the realms of production, trade, livelihoods, and long-term development. Systemic economic shocks are chain reactions and multidimensional disruptions that can affect not only the affected region but also other regions and global markets through economic networks. Such shocks serve as critical stress tests that challenge both the continuity of economic activities and the social and financial resilience of societies. The findings affirm and extend prior literature in disaster economics, suggesting that the scale and structure of a nation's economic system, rather than the seismic magnitude alone, largely determine the depth and duration of economic disruption. The findings affirm and extend prior literature in disaster economics, suggesting that the scale and structure of a nation's economic system, rather than the seismic magnitude alone, largely determine the depth and duration of economic disruption.

One of the study's key contributions lies in emphasizing the overlooked importance of indirect economic losses, echoing the arguments of Okuyama and Santos and Koks et al. [38, 39]. While direct damages, particularly to housing and infrastructure, dominate early assessments, this study shows that indirect effects such as business interruption, supply chain failures, transport disruptions, and perishables spoilage often account for 40–60% of total economic losses. As shown previously, indirect-to-direct loss ratios consistently range from 0.42 to 0.60 across varied income contexts. These findings demand a recalibration of both disaster loss accounting frameworks and financial preparedness strategies, especially in countries where traditional assessments omit economic system-level impacts. In this context, the systematic measurement of indirect losses will contribute to understanding the true economic scale of the disaster and to the more effective allocation of resources. Furthermore, such comprehensive assessments will facilitate the development of policy designs that will accelerate the post-disaster recovery process and reduce economic vulnerabilities.

Moreover, the comparative evidence reinforces the view, advanced by previous studies that earthquake impacts are highly unequal across income groups [33, 35]. While Japan's Tohoku earthquake resulted in US$510 billion in damages but only ~6% GDP loss, Haiti's earthquake caused damage exceeding 120% of its GDP. Low-income countries not only lose more in relative terms but also experience prolonged and uneven recoveries, due to limited financial space, weak insurance markets, and institutional fragility. Earthquakes in such contexts compound structural vulnerabilities and can reverse years of development progress. Furthermore, this situation systematically erodes resilience to disasters, increasing countries' vulnerability to the economic and social impacts of future shocks.

In addition to loss magnitude, the composition of losses offers insight into risk concentrations. On average, housing (30–40%) and infrastructure (20–30%) comprise the majority of direct damage, while business interruption (15–25%), transport and logistics delays (10–15%), and spoilage of perishable goods (3–7%) are considerable but often excluded from formal evaluations. The high share of non-structural losses underscores the need for broader resilience strategies that protect not just physical assets, but also the economic systems that depend on them. This situation necessitates the development of comprehensive and multi-layered resilience strategies aimed at protecting economic systems dependent on physical assets, such as manufacturing, trade, logistics, and service sectors. Such strategies should aim not only to mitigate the effects of direct damage, but also to accelerate the post-disaster recovery process and protect long-term development goals by ensuring the continuity of economic activities.

Institutional and financial capacity emerge as central mediators in this dynamic. Countries with established disaster financing instruments, catastrophe insurance, and contingency planning, such as New Zealand and Japan, tend to recover more rapidly and equitably [36, 40]. In contrast, economies dependent on unplanned aid flows or external loans taken after disasters often face delayed reconstruction processes, increased fiscal pressures, and unsustainable debt cycles. These patterns demonstrate that effective disaster resilience is not limited to the level of exposure to hazards; it is also directly related to the ability to absorb shocks, redistribute resources effectively, and sustain post-crisis recovery capacity. Therefore, strengthening institutional capacity should be a key priority in disaster risk management strategies.

These findings argue strongly for a paradigm shift in disaster risk management—from reactive, asset-focused approaches to proactive, system-wide economic resilience planning. This involves integrating seismic risk into macroeconomic and spatial policy, enforcing adaptive zoning and building codes, and expanding access to financial risk transfer tools. Moreover, it requires rethinking earthquakes not as isolated events, but as stress tests for national economic systems, capable of revealing hidden fragilities, structural weaknesses and capacity gaps under pressure.

As global supply chains grow more interdependent and urban regions concentrate increasing economic value, the risk landscape is evolving in both scale and complexity. The evidence presented in this study supports recent calls in the literature for multi-scalar, interdisciplinary approaches to resilience, grounded in empirical data, modeling, and localized knowledge systems. While earthquakes are geophysically inevitable, their economic devastation is not. With the right data infrastructure, strong institutional capacity, and effective risk governance strategies, countries can not only mitigate the effects of disasters but also move toward building lasting and sustainable economic resilience.

References

[1] Hoeppe P. Trends in weather related disasters-Consequences for insurers and society. Weather Clim Extrem. 2016; 11:70–9.

[2] Aksoy CG, Chupilkin M, Koczan Z, Plekhanov A. Working Paper No. 293: Unearthing the Economic and Social Consequences of Earthquakes. 2024 Url: https://www.ebrd.com/content/dam/ebrd_dxp/assets/pdfs/office-of-the-chief-economist/working-papers/working-papers-2024/WP-293-V1.pdf.

[3] Censky A. Japan earthquake could cost $309 billion. CNNMoney. 2011. Available from: https://money.cnn.com/2011/03/23/news/international/japan_earthquake_cost/

[4] Wikipedia. 2008 Sichuan earthquake. 2008. Available from: https://en.wikipedia.org/wiki/2008_sichuan_earthquake

[5] Qz.com. The economic damage from the Nepal earthquake is almost half of the country's GDP. 2015. Available from: https://qz.com/india/409484/the-economic-damage-from-the-nepal-earthquake-is-almost-half-of-the-countrys-gdp

[6] FEMA & USGS. HAZUS-MH: Estimated Annualized Earthquake Losses in the U.S. 2023 Url: https://www.propertycasualty360.com/2023/04/20/earthquakes-cause-14-7b-in-annualized-losses-usgs-reports/.

[7] Tokui J, Kawasaki K, Miyagawa T. The economic impact of supply chain disruptions from the Great East-Japan earthquake. Japan World Econ. 2017; 41:59–70.

[8] Rose A, Liao S-Y. Modeling regional economic resilience to disasters: A computable general equilibrium analysis of water service disruptions. J Reg Sci. 2005; 45(1):75–112.

[9] Koks EE, Carrera L, Jonkeren O, Aerts JCJH, Husby TG, Thissen M, et al. Regional disaster impact analysis: comparing input-output and computable general equilibrium models. Nat Hazards Earth Syst Sci. 2016; 16(8):1911–24.

[10] Tirasirichai C, Enke D. Case Study: Applying a Regional Cge Model for Estimation of Indirect Economic Losses Due to Damaged Highway Bridges. Eng Econ. 2007; 52(4):367–401.

[11] Shibusawa H. A dynamic spatial CGE approach to assess economic effects of a large earthquake in China. Prog Disaster Sci. 2020; 6:100081.

[12] Luo K, Kinugasa T. Do Natural Disasters Influence Long-Term Savings?: Assessing the Impact of the 2008 Sichuan Earthquake on Household Saving Rates Using Synthetic Control. China An Int J. 2020; 18(3):59–81.

[13] Beehive.govt.nz. EQC's earthquake liability revised upwards. 2012. Available from:

https://www.beehive.govt.nz/release/eqcs-earthquake-liability-revised-upwards

[14] Botzen WJW, Deschenes O, Sanders M. The Economic Impacts of Natural Disasters: A Review of Models and Empirical Studies. Rev Environ Econ Policy. 2019; 13(2):167–88.

[15] Risk Management Solutions Inc. The 2010 Maule, Chile Earthquake: Lessons and Future Challenges. 2011 Url: https://forms2.rms.com/rs/729-DJX-565/images/eq_2010_chile_eq.pdf.

[16] Erkul N. Economic damage from world's major quakes nears $1T. 2023. Available from: https://www.aa.com.tr/en/economy/economic-damage-from-worlds-major-quakes-nears-1t/2838133

[17] Shi Y, Jin S, Seeland K. Modeling business interruption impacts due to disrupted highway network of Shifang by the Wenchuan earthquake. Nat Hazards. 2015; 75(2):1731–45.

[18] Hesse J. Macroeconomic impacts of the 2010 earthquake in haiti: A replication and sensitivity analysis of synthetic control results. Dissertation. Hanken School of Economics; 2020.

[19] Hu Y, Cutler H, Mao Y. Economic Loss Assessment for Losses Due to Earthquake under an Integrated Building, Lifeline, and Transportation Nexus: A Spatial Computable General Equilibrium Approach for Shelby County, TN. Sustainability. 2023; 15(11):8610.

[20] Linnerooth-Bayer J, Mechler R, Hochrainer-Stigler S. Insurance against Losses from Natural Disasters in Developing Countries. J Integr Disaster Risk Manag. 2011; 1(1):59–81.

[21] Noy I, Kusuma A, Nguyen C. Insuring disasters: A survey of the economics of insurance programs for earthquakes and droughts. In 2017. p. 1–27.

[22] Hallegatte S, Vogt-Schilb AC, Bangalore M, Rozenberg J. Unbreakable : building the resilience of the poor in the face of natural disasters. 2024 Url: http://documents.worldbank.org/curated/en/512241480487839624.

[23] Wikipedia. Aftermath of the 2011 Tōhoku earthquake and tsunami. 2025. Available from: https://en.wikipedia.org/wiki/aftermath_of_the_2011_tōhoku_earthquake_and_tsunami

[24] Reuters. Sichuan earthquake agriculture damage $6 bln - FAO. 2008. Available from: https://www.reuters.com/article/economy/sichuan-earthquake-agriculture-damage-6-bln-fao-idusl30225591/

[25] Cavallo E, Powell A, Becerra O. Estimating the Direct Economic Damages of the Earthquake in Haiti. Econ J. 2010; 120(546):F298–312.

[26] Llera JC, Rivera F, Mitrani-Reiser J, Jünemann R, Fortuño C, Ríos M, et al. Data collection after the 2010 Maule earthquake in Chile. Bull Earthq Eng. 2017; 15(2):555–88.

[27] World Bank. Pakistan - 2005 earthquake preliminary damage and needs assessment. 2005 Url: https://documents.worldbank.org/en/publication/documents-reports/documentdetail/710481468284380489.

[28] MacInnis L. Natural disasters cost China $110 billion in 2008. 2009. Available from: https://www.reuters.com/article/economy/natural-disasters-cost-china-110-billion-in-2008-iduslm487862/

[29] Wikipedia. List of costliest earthquakes. 2025. Available from: https://en.wikipedia.org/wiki/list_of_costliest_earthquakes

[30] Gautam D, Forte G, Rodrigues H. Site effects and associated structural damage analysis in Kathmandu Valley, Nepal. Earthq Struct. 2016; 10(5).

[31] Asian Development Bank (ADB). Nepal: Disaster Risk Reduction and Management in Post-Earthquake Recovery. 2016 Url: https://www.adb.org/.

[32] Rose A. Defining and measuring economic resilience to disasters. Disaster Prev Manag An Int J. 2004; 13(4):307–14.

[33] Noy I. The macroeconomic consequences of disasters. J Dev Econ. 2009; 88(2):221–31.

[34] Cavallo E, Galiani S, Noy I, Pantano J. Catastrophic Natural Disasters and Economic Growth. Rev Econ Stat. 2013; 95(5):1549–61.

[35] Felbermayr G, Gröschl J. Naturally negative: The growth effects of natural disasters. J Dev Econ. 2014; 111:92–106.

[36] Hallegatte S. Modeling the Role of Inventories and Heterogeneity in the Assessment of the Economic Costs of Natural Disasters. Risk Anal. 2014; 34(1):152–67.

[37] EM-DAT. The international disasters database. Centre for Research on the Epidemiology of Disasters (CRED). 2023. Available from: https://www.emdat.be/

[38] Okuyama Y, Santos JR. Disaster Impact and Input–Output Analysis. Econ Syst Res. 2014; 26(1):1–12.

[39] Koks EE, Jongman B, Husby TG, Botzen WJW. Combining hazard, exposure and social vulnerability to provide lessons for flood risk management. Environ Sci Policy. 2015; 47:42–52.

[40] Cummins JD, Mahul O. *Catastrophe risk financing in developing countries: principles for public intervention*. World Bank Publications; 2009.

[41] Melecky M, Raddatz CE. How do governments respond after catastrophes? Natural-disaster shocks and the fiscal stance. Nat Shock Fisc Stance (February 1, 2011) World Bank Policy Res Work Pap. 2011;(5564).

[42] Henriet F, Hallegatte S, Tabourier L. Firm-network characteristics and economic robustness to natural disasters. J Econ Dyn Control. 2012; 36(1):150–67.

[43] Santos JR, Haimes YY. Modeling the Demand Reduction Input-Output (I-O) Inoperability Due to Terrorism of Interconnected Infrastructures*. Risk Anal. 2004; 24(6):1437–51.

[44] Inoue H, Todo Y. The propagation of economic impacts through supply chains: The case of a mega-city lockdown to prevent the spread of COVID-19. Xing L, editor. PLoS One. 2020; 15(9):e0239251.

[45] FEMA. Hazus Earthquake Model Technical Manual Hazus 6.1. 2024 Url: https://www.fema.gov/sites/default/files/documents/fema_hazus-earthquake-model-technical-manual-6-1.pdf.

[46] Hallegatte S, Rentschler J, Rozenberg J. *Lifelines: The resilient infrastructure opportunity*. World Bank Publications; 2019.

Research & Design

In This Issue

Research Group

MIM Research & Publishing