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WELCOME TO ICSD 2025

On behalf of the organizing committee, we are pleased to announce that the **11th** International Conference on Sustainable Development **(ICSD-2025)** will be held on **October 22-26, 2025 in Sarajevo, Bosnia and Herzegovina. ICSD 2025** provides an ideal academic platform for researchers to present the latest research findings and describe emerging technologies, and directions in Sustainable Development issues. The conference seeks to contribute to presenting novel research results in all aspects of Sustainable Development. The conference aims to bring together leading academic scientists, researchers and research scholars to exchange and share their experiences and research results about all aspects of Sustainable Development. It also provides the premier interdisciplinary forum for scientists, engineers, and practitioners to present their latest research results, ideas, developments, and applications in all areas of Engineering and Natural Sciences. The conference will bring together leading academic scientists, researchers and scholars in the domain of interest from around the world. **ICSD 2025** is the oncoming event of the successful conference series focusing on Sustainable Development. The scientific program focuses on current advances in the research, production and use of Engineering and Natural Sciences with particular focus on their role in maintaining academic level in Engineering and Applied Sciences and elevating the science level. The conference's goals are to provide a scientific forum for all international prestige scholars around the world and enable the interactive exchange of state-of-the-art knowledge. The conference will focus on evidence-based benefits proven in clinical trials and scientific experiments.

Best regards,

Prof. Dr. Özer ÇINAR

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Sustainability Value Segmentation at Music Festivals

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Abstract:

Existing research has already identified that music festivals are clear victims of littering and poor sustainable behaviours and that there is a need to address attendee behaviours in order to minimise the amount of waste that is produced to ensure longevity of this particular event sector. Not only is this an obvious issue in terms of environmental repercussions, but it also compromises the future of the music festival industry. This research project explores the behaviours, attitudes and values of attendees towards littering and sustainability whilst at music festivals, which has resulted in the development of a value segmentation framework. This will aid the design of sustainability interventions by allowing music festival organisers to target specific groups based upon values rather than a blanket intervention for everyone.

Ethnographic research at music festivals was collected over five separate music festival events during the summer of 2023, which included interviews on site, observations and a diary kept by the researcher. Five themes were identified through thematic analysis, including:

- Community/herd mentality
- Education
- Forced sustainability (limited resources)
- Existing interventions
- Environment

Five value segments were also developed, drawing upon the attitudes and values of music festival attendees who participated in the data collection. These are:

- Green herd leaders
- The followers
- Keen greens
- Fair weathered recyclers
- The hungover

This value segmentation framework will support music festival organisers and sustainability teams with the design of interventions drawing upon the identified segments. For example, it was identified that sustainability messaging was less noticed as the festival went on, and so by the end of the event, attendees were often more focused on leaving site and therefore left tents and waste behind. This research aims to support with the introduction of new interventions that can help target these issues.

Keywords: Sustainability, Behaviour Change, Music Festivals, Segmentation

Probiotics in Aquaculture: A Pathway to Sustainability

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Abstract:

The increasing demand for sustainable and efficient aquaculture practices has driven the exploration of probiotics as a viable alternative to antibiotics and chemical treatments. Probiotics, defined as live microorganisms that confer health benefits to the host when administered in adequate amounts, have shown significant promise in marine aquaculture. Their functions include enhancing immune responses, improving nutrient absorption, modulating gut microbiota, and maintaining water quality—key factors in promoting the health and productivity of aquatic species.

This presentation highlights the historical development of probiotics, their mechanisms of action, and their application in aquaculture systems. It emphasizes the importance of selecting well-characterized strains that meet strict biosafety and efficacy criteria, both in vitro and in vivo. Among the various candidates, Bacillus velezensis D-18 has emerged as a particularly effective probiotic strain for European sea bass (Dicentrarchus labrax). Experimental trials demonstrated its ability to adhere to intestinal mucus, tolerate bile and pH variations, and significantly reduce the adhesion of pathogenic Vibrio anguillarum. Moreover, dietary supplementation with B. velezensis D-18 enhanced innate immune responses, including lysozyme activity, nitric oxide production, and phagocytosis, while also modulating the expression of pro-inflammatory genes.

The use of B. velezensis D-18 led to a marked increase in survival rates in fish challenged with V. anguillarum, confirming its protective effect. These findings support the integration of targeted probiotics into aquaculture health management strategies. However, challenges remain, including regulatory gaps, variability in field performance, and the need for standardized application protocols.

In conclusion, probiotics such as B. velezensis D-18 represent a powerful tool for advancing sustainable aquaculture. Continued research and collaboration between academia, industry, and regulatory bodies are essential to fully unlock their potential and ensure their effective implementation in commercial settings.

Keywords: Aquaculture, Seaabass, Probiotic, Sustainability

Diagnosing Co-Housing: A New Evaluation Model (Chdsm) Across Global North And South Contexts

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Abstract:

This study investigates co-housing as a socio-cultural response to urban sustainability challenges through selected case studies from diverse geographical and cultural contexts. Drawing upon principles of participatory design, social equity, and ecological responsibility, the paper analyzes co-housing models that promote collective living and resource sharing while addressing social isolation, housing affordability, and environmental degradation.

Internationally, the study examines well-established examples including Trudeslund Co-Housing (Denmark), EcoVillage at Ithaca (USA), Quartier Vauban (Germany), and La Borda Cooperative (Spain). These communities exemplify diverse co-housing approaches grounded in democratic governance, ecological architecture, and strong social cohesion. Each case shows how co-housing fosters sustainable lifestyles by blending private spaces with communal facilities, promoting active citizenship and reinforcing local cultures.

In Turkey, where institutionalized co-housing practices are still emerging, the research explores grassroots initiatives and ecologically driven cooperative projects such as the Yeryuzu Ecological Collective and the developing Gediz Ecological Living Cooperative in Izmir. Although these models do not yet fully reflect conventional co-housing frameworks, they indicate a growing interest in alternative living arrangements that challenge mainstream urbanization patterns and revive communal traditions.

The originality of this study lies in its focus on socio-cultural sustainability in underrepresented Global South contexts, particularly Turkey, and in its development of a multidimensional evaluation framework. The proposed Co-Housing for Socio-cultural and Sustainability Diagnostics Model (CHDSM) enables comparative assessment across four main dimensions: spatial-ecological design, socio-cultural dynamics, participatory governance, and contextual adaptability. By applying this model to both international and Turkish cases, the study provides a structured understanding of how co-housing practices vary and what conditions are necessary for successful adaptation in different urban and cultural settings.

Ultimately, the research underscores the transformative potential of co-housing in creating inclusive, resilient, and culturally rooted urban environments, while offering insight into the policy and structural barriers hindering wider implementation.

Keywords: Co-Housing, Socio-Cultural Sustainability, Participatory Urban Living, Comunity-Based Housing Models, Global South Urbanism

Sustainability Goal Adoption in Global Transport Sector

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Abstract:

Objective. We measure how Sustainable Development Goal (SDG) adoption evolved in the global transport sector and how it varies by industry, region, and firm fundamentals.

Data. Panel of 2,262 firm-years (2019–2024) covering five GICS industries (Air Freight & Logistics, Ground Transportation, Marine Transportation, Passenger Airlines, Transportation Infrastructure) across five world regions. Seventeen SDG indicators are coded binary (0/1) at the firm-year level, plus an SDG index (mean of 17).

Methods. Descriptives, Kruskal–Wallis tests, and Dunn post-hoc comparisons for year, industry, and region; paired 2019 vs 2024 changes for firms observed in both years using McNemar tests, and Spearman correlations between SDG index and firm financials.

Results. Year effects are large for many SDGs. Among matched firms, adoption jumped most for SDG 8 (Decent Work) and SDG 13 (Climate Action), with similarly large gains for SDG 3, 5, 9, 12, 16, and 17.

Across all firm-years, the most adopted goals are SDG 8 and SDG 13, followed by SDG 3/9/12/5; the least adopted are SDG 2, SDG 1, and SDG 6.

Industry differences are modest. Effects are generally small, except SDG 14 (Life Below Water), which shows a moderate industry effect, with Marine and Infrastructure.

Region effects are small to moderate. Dunn tests show North America and the Caribbean significantly lower than Europe, Asia-Pacific, Latin America, the Middle East, and Africa.

The SDG index correlates positively with assets, net income, and weakly with leverage, indicating that larger firms adopt more SDGs.

Conclusion. SDG adoption in transport has risen rapidly since 2019, with time dominating industry and regional effects. Differences that remain are intuitive, and regions outside North America lead. Results suggest that sector-wide momentum, scale, and capability—rather than structural industry mix—are now the primary drivers of SDG uptake, with implications for benchmarking, engagement priorities, and policy targeting.

Keywords: SDG Adoption, Transport Industry, Regional Patterns, Corporate Sustainability

FULL-TEXT ARTICLES

Spatiotemporal Assessment of Desertification Dynamics in Anbar, Iraq Using Remote Sensing and Time Series Modeling

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Abstract

Desertification poses a critical environmental threat in Iraq, especially in western provinces like Al-Anbar. The region's arid climate, declining Euphrates River flow, and rapid urban expansion have intensified ecological stress, resulting in vegetation loss, soil degradation, and increased drought vulnerability. Despite its severity, Al-Anbar remains underrepresented in desertification research, with limited long-term spatial analysis. This study evaluates the spatiotemporal dynamics of desertification in Al-Anbar from 2005 to 2023 and forecasts trends through 2035. A composite Desertification Index (DI) was developed by integrating four satellite-derived indicators: Soil-Adjusted Vegetation Index (SAVI), Modified Normalized Difference Water Index (MNDWI), Topsoil Grain Size Index (TGSI), and surface albedo. Each index was normalized on a fuzzy scale, where vegetation and moisture loss contribute negatively and soil exposure and reflectance contribute positively. Annual DI rasters were generated at 250-meter resolution in GRID format. Future desertification was modeled using pixel-wise ARIMA time series applied to the DI stack, producing forecasts for 2024–2035. Analysis was conducted using R and Google Earth Engine to ensure reproducibility and spatial precision. Validation employed MODIS-derived land surface temperature anomalies and known drought periods. Expected outcomes include identifying desertification hotspots, trend acceleration zones, and areas with ecological restoration potential. This research offers a scalable framework for desertification monitoring in Iraq's drylands and supports evidence-based land use planning. It contributes to national efforts toward land degradation neutrality and provides a replicable model for other arid regions facing similar environmental challenges.

Keywords: Al-Anbar Governorate, ARIMA Modeling, Desertification Index (DI), Remote Sensing

1. INTRODUCTION

Desertification is one of the most pressing environmental challenges facing Iraq, particularly in its western provinces such as Al-Anbar. Defined by the United Nations Convention to Combat Desertification (UNCCD) as the persistent degradation of dryland ecosystems due to climatic variations and human activities, desertification threatens ecological stability, agricultural productivity, and socio-economic resilience (Al-Obaidi et al., 2022). Al-Anbar Governorate, Iraq's largest province by land area, spans vast arid and semi-arid terrain. Its fragile ecosystems are increasingly exposed to prolonged droughts, declining water availability from the Euphrates River, and rapid urban expansion—especially around Ramadi, Fallujah, and Al-Qaim (Adamo et al., 2022; Meklef et al., 2020). The region's vulnerability is compounded by climatic conditions such as high temperatures, erratic rainfall, and frequent dust storms. According to Iraq's Ministry of Agriculture, over 50% of the country is at risk of desertification, with Al-Anbar among the most affected zones (Shafaq News, 2025). Key indicators of desertification—loss of vegetation cover, soil exposure, and increased surface reflectance—require systematic monitoring to inform land management and climate adaptation strategies. Remote sensing has emerged as a powerful tool for quantifying desertification processes across space and time, especially in regions where field-based ecological monitoring is constrained by logistical, political, or security challenges (Al-Timimi, 2021; Abbas & Mahdi, 2019). Spectral indices derived from satellite imagery—such as the Soil-Adjusted Vegetation Index (SAVI), Modified Normalized Difference Water Index (MNDWI), Topsoil Grain Size Index (TGSI), and surface albedo—offer critical insights into vegetation health, moisture availability, and soil radiative properties. When integrated into a composite Desertification Index (DI), these metrics enable pixel-level assessment of ecological stress and land degradation. Recent studies in Iran's Isfahan Province have demonstrated the efficacy of combining MODIS-derived Aerosol Optical Depth (AOD) data with machine learning algorithms to zone dust-prone areas (Afshari & Vali, 2023). Models such as Random Forest (RF), Boosted Regression Trees (BRT), Support Vector Machines (SVM), and Classification and Regression Trees (CART) have shown

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high predictive accuracy, with RF outperforming others (AUC = 0.86). These approaches underscore the importance of integrating climatic variables—rainfall, temperature, wind speed—with spectral indices to model desertification susceptibility. In Iraq, similar methodologies have been applied to regions such as Al-Muthanna, Basra, and Salah Al-Din, revealing significant land cover changes and the expansion of sand dunes over the past three decades (Rasheed & Al-Ramahi, 2021; Hashim et al., 2025). For instance, studies using Landsat imagery and GIS techniques have documented a 34.8% reduction in vegetation cover between 1990 and 2019 in central Iraq, alongside a 22.9% increase in severe desertification zones (Al-Timimi, 2021). These findings highlight the urgent need for localized models that account for ecological gradients, land use transitions, and climatic variability. The relationship between vegetation and land surface temperature (LST) is central to understanding desertification dynamics. Vegetated areas typically exhibit lower LST due to evapotranspiration and shading effects, whereas barren or degraded lands absorb and re-radiate more solar energy, resulting in thermal amplification. However, in arid environments such as Al-Anbar, this relationship becomes nonlinear and context-dependent. Moisture stress limits the cooling capacity of vegetation, and even green patches may fail to significantly reduce surface temperatures (Mzuri et al., 2022; Abbas et al., 2019). This complexity underscores the need for localized, multi-index models that can capture the nuanced interplay between vegetation, soil, and climate. Despite its ecological significance, Al-Anbar remains underrepresented in Iraq's remote sensing literature. Most existing studies focus on urban centers or agricultural zones in central and southern Iraq, leaving western provinces like Al-Anbar relatively unexplored. Moreover, the lack of consistent ground-truth data and historical land cover records has hindered long-term ecological assessments. Recent advances in cloud-based platforms such as Google Earth Engine (GEE), combined with open-access satellite archives from MODIS, Landsat, and Sentinel missions, now offer unprecedented opportunities to monitor desertification trends at high spatial and temporal resolution (Omdena Iraq Chapter, 2022). This study aims to fill a critical knowledge gap by conducting a spatiotemporal analysis of desertification in Al-Anbar using a multi-index approach. By integrating SAVI, MNDWI, TGSI, and albedo into a unified DI framework, and applying time series modeling techniques such as ARIMA, the research provides a comprehensive view of ecological stress evolution from 2005 to 2023, with forecasts extending to 2035. The pixel-level modeling enables identification of desertification hotspots, trend acceleration zones, and potential areas for ecological restoration. Ultimately, the findings support evidence-based decision-making for land use planning, climate resilience, and sustainable development in western Iraq. Several studies have explored desertification in Iraq using remote sensing and GIS techniques. Al-Timimi (2021) evaluated vegetation loss and sand dune expansion in central Iraq, reporting a 34.8% decline in vegetation cover and a 22.9% increase in severe desertification zones. Rasheed and Al-Ramahi (2021) applied supervised classification to assess sand dune encroachment in Salah Al-Din, linking desertification to climatic shifts and land use changes. In southern Iraq, Hashim et al. (2025) analyzed LST and NDVI correlations, revealing thermal amplification in degraded areas. In Al-Muthanna, Aldabbagh et al. (2022) integrated 3D convolutional neural networks and cellular automata to simulate desertification patterns, achieving high accuracy (OA = 91.5%). Their model incorporated NDVI, soil type, elevation, and proximity to water bodies. Similarly, Abbas and Mahdi (2019) used Landsat imagery to assess vegetation dynamics and LST in Basra, highlighting the role of urbanization in exacerbating land degradation. Internationally, Afshari and Vali (2023) demonstrated the utility of MODIS AOD data and RF models in dust zone mapping in Iran. Their methodology informed the current study's multi-index approach. Mzuri et al. (2022) examined the nonlinear relationship between vegetation and LST in Duhok, Iraq, emphasizing the limitations of NDVI alone in arid contexts.

Compared to these studies, the present research introduces several innovations:

- Focus on Al-Anbar, a critically vulnerable yet understudied region.

- Integration of four spectral indices (SAVI, MNDWI, TGSI, albedo) into a composite DI.

- Application of ARIMA modeling for temporal forecasting to 2035.

- Pixel-level analysis using GEE for high-resolution spatial mapping.

This approach addresses the limitations of previous studies by combining ecological, climatic, and spectral dimensions into a unified framework tailored to Iraq's western drylands.

2. MATERIALS AND METHODS

This study employs a quantitative geospatial framework to assess desertification dynamics across Anbar Governorate using satellite-derived indices and time series modeling. The workflow integrates remote sensing preprocessing, index construction, temporal stacking, and pixel-wise forecasting to ensure analytical rigor and spatial specificity.

2.1. Study Area and Scope

The analysis focuses on Anbar Governorate, located in western Iraq, encompassing vast desert plains, intermittent river corridors, and scattered agricultural patches. The temporal scope spans from 2005 to 2023 for historical assessment, with projections extending to 2035. The study operates at a pixel resolution of 1000 meters, enabling fine-scale ecological monitoring.

2.2. Data Sources

Table.1. Data Source

Index	Source	Format	Spatial Resolution
SAVI	MODIS/Sentinel-derived	GRID	1000 m
MNDWI	MODIS/Sentinel-derived	GRID	1000 m
TGSI	Custom-calculated	GRID	1000 m
Albedo	MODIS surface reflectance	GRID	1000 m

All data were preprocessed and stored in GRID format within the directory G:/Iraq, with subfolders for each index and year (e.g., savi_ir_2005). The Desertification Index (DI) was computed annually and stored in G:/Iraq/DIIndex.

2.3. Index Construction

Each index was normalized to a fuzzy scale ranging from 0 (low ecological quality) to 1 (high ecological quality).

This formulation ensures that vegetation and moisture indices contribute negatively to desertification, while soil exposure and surface reflectance contribute positively.

2.4. Annual Raster Generation

For each year from 2005 to 2022:

- SAVI, MNDWI, TGSI, and Albedo were loaded from their respective GRID folders

- DI was computed pixel-wise using the formula above

- Output rasters were saved as GeoTIFF files in G:/Iraq/DIIndex with filenames DI2005.tif to DI2023.tif

2.5. Time Series Modeling with ARIMA

To forecast desertification trends:

- A raster stack of DI2005–DI2022 was constructed

- A pixel-wise ARIMA model was applied using the auto.arima() function from the R forecast package

- For each pixel, the model predicted DI values for 13 future years (2022–2035)

- Forecasted rasters were saved as DI2022.tif to DI2035.tif in the same directory

This approach captures localized temporal dynamics and allows for spatially explicit forecasting of ecological stress.

2.6. Tools and Platforms

- R programming language for raster processing and time series modeling

- Google Earth Engine (GEE) for initial data access and preprocessing

- MODIS and Sentinel datasets for consistent long-term monitoring

- GeoTIFF format for compatibility with GIS platforms and spatial analysis

3. RESULTS AND DISCUSSION

The findings of this study, based on spatiotemporal analysis of the Desertification Index (DI)fig.1& fig.2 and Local Moran's I clustering fig.3. in Al-Anbar Province, Iraq, reveal a concerning trajectory of intensifying and spatially converging desertification. The analysis documents both the severity of land degradation from 2005 to 2023 and forecasts future patterns through 2035 using ARIMA modeling and spatial statistics.
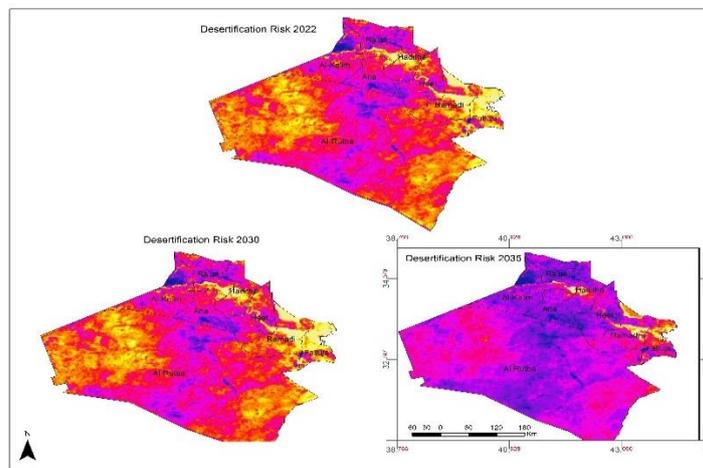

Figure 1.Spatial and Temporal changes in desertification Al_Anbar
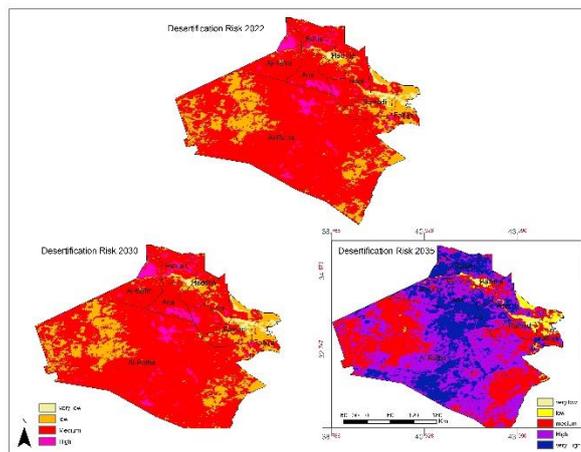

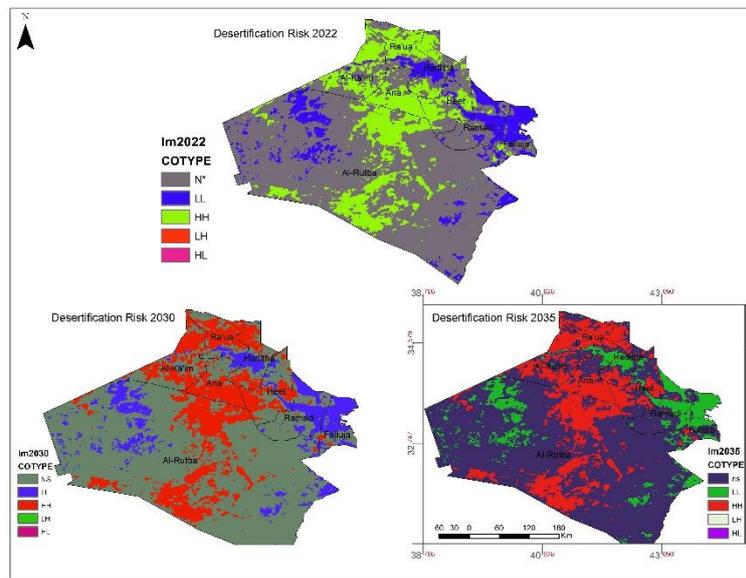Figure.2.Spatial and temporal desertification risk assessment

Figure.3. Local Moran's I clustering

3.1. DI Trend Analysis: From Fragmentation to Convergence

The DI trend map shows that desertification in Al-Anbar has evolved from a scattered and localized pattern in the first decade (2005–2015) to a more convergent and regional pattern in the second decade (2015–2023). In the early years, areas with increasing DI values were primarily located in the western and southern parts of the province, especially around Al-Qa'im, Ar-Rutbah, and desert fringes. These zones experienced vegetation loss, elevated land surface temperatures, and declining soil moisture. After 2015, the pace of desertification accelerated, extending into the central parts of the province, including the surroundings of Ramadi, Heet, and Haditha. These changes coincided with urban expansion, reduced Euphrates River flow, and intensified resource extraction. The trend map highlights areas with steep positive slopes in DI—particularly in the west and south—as having crossed ecological thresholds, making them increasingly difficult to restore without targeted intervention.

3.2. Local Moran's I Analysis: Identifying Spatial Clusters

The Local Moran's I maps for 2022, 2030, and 2035 reveal statistically significant spatial clusters of desertification. Each pixel is categorized into five types of spatial association: High-High (HH), Low-Low (LL), High-Low (HL), Low-High (LH), and Not Significant (NS).

In 2022, HH clusters were concentrated in the central and western zones, particularly around Ramadi, Heet, and Haditha. These areas exhibit high desertification surrounded by similarly high-risk neighbors, indicating systemic ecological stress. LL clusters appeared in the northeast, especially near Falluja and along the Euphrates, suggesting relative ecological stability.By 2030, HH clusters expanded significantly, covering broader areas in the west and south. This expansion reflects intensifying soil degradation, vegetation loss, and rising surface temperatures. Simultaneously, LL clusters became smaller and more fragmented, indicating weakening ecological resilience. HL and LH outliers increased near urban fringes such as Ana and Heet, signaling transitional zones or early warning areas. In 2035, HH clusters consolidated into a contiguous belt across the western half of the province. This spatial convergence suggests that desertification has become entrenched and systemic. LL clusters were confined to small pockets in the northeast, while HL and LH zones were absorbed into larger HH areas, indicating a loss of spatial heterogeneity and the dominance of uniform degradation.

3.3. Integrating Trend and Cluster Analysis: A Spatiotemporal Desertification Model

The integration of DI trend maps with Local Moran's I clustering reveals a dual pattern of intensification and spatial coherence. HH zones align with areas showing steep positive DI trends, confirming that both severity and spatial autocorrelation are increasing. These zones should be prioritized for restoration, water resource management, and erosion control. Conversely, LL zones correspond to areas with stable or declining DI trends and represent ecological refugia. Preserving these zones is critical for maintaining landscape resilience. HL and LH zones serve as transitional areas and should be closely monitored to prevent their conversion into HH clusters. This spatiotemporal model provides a robust framework for identifying critical zones, assessing ecological thresholds, and guiding geographically targeted interventions.

3.4. Policy Implications

The findings indicate that desertification in Al-Anbar has entered a critical phase. The spatial convergence and temporal acceleration of land degradation demand urgent, data-driven, and geographically tailored responses. The framework developed in this study enables the identification of high-risk, stable, and transitional zones and can inform national strategies for Land Degradation Neutrality (LDN), natural resource management, and land use planning.

The spatiotemporal assessment of desertification dynamics in Al-Anbar Province offers critical insights into the ecological transformations unfolding in Iraq's western drylands. By integrating multi-spectral indices into a composite Desertification Index (DI) and applying pixel-level ARIMA modeling alongside Local Moran's I spatial clustering, this study provides a nuanced understanding of both the intensity and spatial coherence of land degradation processes. The findings confirm that desertification in Al-Anbar is not only accelerating but also becoming increasingly spatially consolidated, with high-risk zones expanding and stabilizing over time.These results align with broader regional trends observed in central and southern Iraq, where vegetation loss and thermal amplification have been documented over the past three decades (Al-Timimi, 2021; Rasheed & Al-Ramahi, 2021). However, the present study advances the literature by focusing on Al-Anbar—a province largely underrepresented in remote sensing research—and by employing a multi-index approach that captures the complex interplay between vegetation, moisture, soil texture, and surface reflectance. Unlike studies that rely solely on NDVI or LST, the inclusion of SAVI, MNDWI, TGSI, and albedo enables a more ecologically grounded and context-sensitive assessment of desertification.The observed expansion of High-High (HH) clusters in the Local Moran's I maps, particularly between 2022 and 2035, suggests that desertification in Al-Anbar is transitioning from a fragmented phenomenon to a systemic pattern of ecological collapse. This spatial convergence is especially pronounced in the western and central corridors, where declining water availability from the Euphrates River, urban encroachment, and prolonged droughts have compounded ecological stress. These findings corroborate earlier studies in Iran and Iraq that emphasize the role of climatic variability and land use transitions in driving desertification (Afshari & Vali, 2023; Abbas & Mahdi, 2019).Importantly, the study reveals that even areas with residual vegetation cover—such as the northeastern riverbanks—are not immune to degradation. The shrinking Low-Low (LL) clusters and the emergence of transitional zones (HL and LH) near urban fringes indicate that ecological resilience is eroding, and that formerly stable zones may soon enter high-risk trajectories. This underscores the nonlinear and context-dependent nature of desertification in arid environments, where vegetation may fail to mitigate surface temperatures due to moisture stress and soil exposure (Mzuri et al., 2022). The use of ARIMA modeling for temporal forecasting adds a predictive dimension to the analysis, enabling the identification of trend acceleration zones and future hotspots. While machine learning models such as Random Forest and SVM have shown high accuracy in dust zone mapping (Afshari & Vali, 2023), the ARIMA approach offers transparency, interpretability, and suitability for time series data with seasonal and trend components. Its application at the pixel level ensures that spatial heterogeneity is preserved, allowing for localized intervention planning. From a policy perspective, the findings have significant implications for land use planning, climate adaptation, and sustainable development in western Iraq. The identification of HH clusters as priority zones for restoration, LL clusters as ecological refugia, and HL/LH zones as early warning indicators provides a spatially explicit framework for decision-making. Moreover, the study demonstrates the utility of cloud-based platforms such as Google Earth Engine in overcoming data scarcity and enabling reproducible, high-resolution monitoring in conflict-affected regions. The methodological framework developed here is scalable and transferable to other arid provinces in Iraq and the broader Middle East. By combining ecological, climatic, and spectral dimensions into a unified model, the research addresses key limitations in previous studies and contributes to Iraq's national efforts toward Land Degradation Neutrality (LDN). Future research could enhance this framework by incorporating socio-economic variables, ground-truth validation campaigns, and participatory mapping with local communities. In conclusion, desertification in Al-Anbar is a spatially structured and temporally accelerating process that demands urgent, evidence-based intervention. The integration of remote sensing, time series modeling, and spatial statistics offers a powerful toolkit for understanding and mitigating land degradation in Iraq's vulnerable drylands.

4. CONCLUSIONS

This study provides a detailed spatiotemporal analysis of desertification in Al-Anbar Province, Iraq, offering a robust framework for monitoring and forecasting land degradation in arid environments. By integrating four satellite-derived indices—SAVI, MNDWI, TGSI, and surface albedo—into a composite Desertification Index (DI), and applying pixel-level ARIMA time series modeling, the research captures both historical trends (2005–2023) and future projections (to 2035) with high spatial resolution. The use of Local Moran's I further reveals the spatial structure of desertification, identifying zones of ecological vulnerability and resilience. Findings show that desertification in Al-Anbar is intensifying and becoming spatially concentrated. Western and central regions—especially around Ramadi, Heet, Haditha, and Ar-Rutbah—have emerged as High-High (HH) clusters, marked by elevated DI values and strong spatial autocorrelation. These areas represent ecological hotspots requiring urgent intervention. In contrast, northeastern zones along the Euphrates River remain relatively stable (Low-Low clusters), though trend analysis suggests gradual erosion of their resilience. Transitional zones (High-Low and Low-High), often located near urban fringes, act as early warning areas and merit close monitoring.

This research introduces several methodological contributions:

- A focused analysis of Al-Anbar, a vulnerable and understudied region in Iraq's desertification discourse;

- Integration of four ecologically relevant spectral indices into a unified DI framework;

- Use of ARIMA modeling for pixel-level temporal forecasting;

- Implementation of Google Earth Engine for scalable and reproducible spatial analysis.

The results have practical implications for land use planning, climate adaptation, and sustainable development in western Iraq. Spatially explicit identification of high-risk and resilient zones enables targeted resource allocation, informed restoration planning, and strategic policy design. The framework also supports Iraq's commitments to Land Degradation Neutrality (LDN) and can be adapted for other arid regions across the Middle East. Given the complexity of desertification in dryland ecosystems, future research should consider integrating socio-economic variables such as migration, land tenure, and agricultural productivity with environmental indicators. Ground-truth validation and participatory mapping with local communities would enhance the reliability and relevance of remote sensing outputs. Machine learning models could further improve predictive accuracy and reveal latent spatial patterns. Additionally, evaluating the role of national and regional policies in shaping land degradation dynamics is essential for designing effective interventions. In sum, desertification in Al-Anbar is a multidimensional and accelerating phenomenon with distinct spatial patterns. This study contributes a replicable and scalable analytical framework for understanding and addressing land degradation in Iraq's drylands. By combining ecological indicators, time series forecasting, and spatial clustering, it offers a powerful tool for evidence-based decision-making and policy formulation in arid environments.

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Proposal for a World Energy Stock Balance Sheet

Michael Bosch[2]

Abstract

Considering the sharp increase in global energy demand, the question arises whether worldwide energy ressources will be sufficient to cover humankind's future energy requirements (including energy for food requirements). In addition to the urgent built up of renewable energy systems, energy-intensive processes to prevent greenhouse gases from being released into the atmosphere (Carbon Capture and Storage, CCS) or removed from there (Carbon Dioxide Removal, CDR, in particular Direct Air Capture, DAC) are required to meet the climate targets. On the basis of a comprehensive analysis of existing Systems of Environmental Economic Accounting (SEEA) and the International Recommendations for Energy Statistics (IRES), a proposal for a World Energy Stock Balance Sheet (WESBS) consistent with these systems was developed. The principle of prudent valuation, borrowed from business accounting, was also applied, which requires the inclusion of energy consumption for CCS and DAC. The assets side of the WESBS shows all fossil and renewable primary, secondary and final energy sources at the balance sheet date prudently valued with the energy unit Peta Joule (PJ). Provisions for the energy losses in PJ that would arise when the capitalized primary, secondary and final energy stocks are converted into useful energy are shown on the liability side of the WESBS, as well as provisions for the energy consumption for CCS and DAC. The respective energy consumption is calculated by first applying Life Cycle Assessment (LCA) emission factors to calculate the greenhouse gas emissions and thereafter using LCA energy consumption factors of CCS or DAC. The difference between energy assets and energy liabilities results in the energy equity in PJ, which is available for the future useful energy demand of humankind under the precondition that the climate targets are met. This paper explains the items of the proposed WESBS and the developed valuation methods in appropriate detail.

1. INTRODUCTION

Due to the following developments, humankind's energy requirements, including energy bound in food, will continue to rise sharply despite all efforts to increase energy efficiency and save energy:

First, the expected growth of the global population to almost 9.8 billion people by the middle of the century (2054) [1] and the rapid technological development, particularly in the areas of digitalization and artificial intelligence, will lead to an increase in energy and food demand.

Growing living standards and demand for more comfort will lead to larger living and usable spaces per person and thus to a further increase in land sealing which reduces the amount of land available for growing food and energy crops as well as commercial forest and biodiversity areas, which also act as greenhouse gas sinks. The same applies to the expected increase in traffic. Furthermore, the growth of "photovoltaic land sealing" makes it difficult or impossible to cultivate crops on the respective soil or use it as grazing land. Finally, climate change and other factors are leading to an increasing erosion of fertile soils and to decreasing crop yields. As a consequence, the biocapacity of the planet will continue to decline. [2], [3], [4]

The inevitable shift towards renewables requires the energy-intensive development and construction of a global renewable energy generation, storage, and transport infrastructure.

According to IPCC's Special Report 15, net zero by mid of the century cannot be acieved without energy-intensive Carbon Capture and Storage (CCS) and Direct Air Capture (DAC), especially Direct Air Carbon Capture and Storage (DACCS) [5].

Therefore, comprehensive information about the stock of fossil and renewable energy sources available worldwide for use by humankind at a certain point in time, complying with the goal of net zero, is essential in order to identify emerging shortages immediately.

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2. CRITICAL ANALYSIS OF EXISTING SYSTEMS

In principle, Environmental-Economic Accounting Systems already comprehensively record the interactions between economic activities and the environment, including mineral resources and land [6].

The Framework of the System of Environmental-Economic Accounting (SEEA), which was adopted as an international standard by the United Nations Statistical Commission, is a multipurpose conceptual framework for understanding the interactions between the economy and the environment, and for describing stocks and changes in stocks of environmental assets. As an accounting system, it enables the organization of information into tables and accounts in an integrated and conceptually coherent manner. [7]

Energy accounts data – including primary energy resources and secondary energy products – are compiled by converting physical measures of mass and volume such as tons, liters and cubic meters into a common unit representing energy content in net calorific terms. The use of the joule as a common measurement unit is recommended by the International Recommendations for Energy Statistics (IRES). [8]

A typical asset account for mineral and energy resources is defined as follows: The accounting year starts with the opening stock, before different additions (such as discoveries, upward reappraisals and reclassifications) and reductions (such as extractions, catastrophic losses, downward reappraisals and reclassifications) in stock are recorded throughout the year, resulting in the closing stock of mineral and energy resources at the end of the year [9]. However, asset accounts for renewable energies are not provided because in the accounting sense of the SEEA Central Framework and SEEA Energy, a physical stock of renewable sources of energy does not exist [10].

Usability of the fossil fuels recorded in the systems of environmental economic accounting, as well as all other energy sources requires not only primary energy resources but also appropriate primary energy extraction and conversion facilities. A prudent assessment can therefore only be ensured by determining and applying the minimum from the capacity-bottleneck of energy extraction and conversion facilities over their average remaining useful life or the resource bottleneck.

As a subsystem of the SEEA Central Framework, SEEA-Energy elaborates in greater detail the links between energy accounts and energy statistics and balances, as described in IRES, and to serve as a bridge between the statistical and energy communities. IRES contribute valuable inputs into the production of tables and accounts of SEEA-Energy, particularly support the use of harmonized definitions of energy products in accordance with the Standard International Energy Product Classification (SIEC) and offer guidance regarding data sources and data compilation. [11]

Furthermore, the SEEA classification of land use consists of the categories: agriculture, forestry, land used for aquaculture, use of built-up and related areas, land used for maintenance and restoration of environmental functions as well as other uses of land not elsewhere classified and land not in use [12].

Energy from natural inputs by type – according to a rough classification in SEEA-Energy – are: *Mineral and energy resources* (oil, natural gas, coal and peat, uranium and other nuclear fuels), *natural timber resources, inputs of energy from renewable sources* **(**solar, wind, wave and tidal, geothermal, other electricity and heat), *other natural inputs* and *energy inputs to cultivated biomass* [13].

Energy statistics and energy balances are also the main sources of data for the calculation of energy-related greenhouse gas (GHG) emissions, as the IPCC Guidelines are based on the same conceptual framework. They address emissions of direct and indirect GHGs. The direct GHGs covered by the guidelines are carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), sulphur hexafluoride (SF_6) and some others. The indirect GHGs considered in the guidelines are nitrogen oxides (NO_X), ammonia (NH_3), non-methane volatile organic compounds (NMVOC), carbon monoxide (CO) and sulphur dioxide (SO_2). [14]

Traditional energy balances in the sense of energy economics document the generation, conversion, and use of energy sources in a national economy comprehensively, detailed (by sector) and consistent in the form of a matrix [15]. Based on classical energy balances, energy flow diagrams are created that visualize the process of energy conversion from primary energy to useful energy, including energy losses [16]. An energy balance is therefore a calculation of energy flows over a period of time and not a representation of energy resources at a given point in time.

The critical analysis of existing systems can therefore be summarized as follows:

First of all, the existing systems pursue different goals. They do not reflect the requirement for prudent, bottleneck-oriented, and point-in-time-related recording of all energy stocks – including renewables – and they do not take into account energy consumption for CCS and DACCS.

Nevertheless, it makes sense to base the balance sheet items of the WESBS on the standardized terminology of the existing systems, which also enables comprehensive data compatibility. SEEA Central Framework and SEEA-Energy provide the conceptual basis and terminology for a range of asset data on fossil energy resources as well as land and marine-based biocapacity.

Even though SEEA is primarily a concept for establishing national systems of Environmental-Economic accounting, the terminology can also be used for a WESBS. Finally, the statistical data on energy conversion losses recorded in classical energy balances can contribute to the dimensioning of provisions for energy conversion losses (see below) in the WESBS.

3. CONCEPTIONAL BASICS OF A WORLD ENERGY STOCK BALANCE SHEET

The World Energy Stock Balance Sheet (WESBS) is a system for presenting global energy assets at a specific point in time, applying the principle of prudence borrowed from business accounting. WESBS also takes into account the energy consumption in the form of provisions (liabilities of uncertain timing or amount) that will be incurred for CCS and DACCS.

The assets side of the global energy stock balance sheet shows all fossil and renewable primary, secondary, and final energy stocks prudently valued in PJ at the balance sheet date. Primary energy resources are in accordance with the terminology of SEEA-Energy (see above): mineral and energy resources (oil, natural gas, coal and peat, uranium and other nuclear fuels), natural timber resources, renewable sources (solar, wind, wave tidal, geothermal, etc.), other natural inputs and cultivated biomass. Additionally, potential crop yields for food production, livestock suitable for consumption and unprotected wild animal and fish stocks are also primary energy resources capitalized on the assets side of the WESBS.

In accordance with the principle of prudence, either the primary energy extraction and conversion facilities capacity bottleneck over its remaining useful life or the resources bottleneck – each valued of course in PJ – represents the upper valuation limit of the respective energy source on the assets side. Facilities in the sense of the WESBS include e.g. gas/oil drilling rigs/equipment on land or sea, mining equipment, refineries, coal, oil, nuclear, solar, wind, geothermal, tidal and hydroelectric power plants, combined heat and power plants (CHPs), as well as sufficient harvesting equipment available at harvest times, fishing/hunting equipment and slaughterhouse capacity.

The bottleneck-oriented valuation in the WESBS – demonstrated by using the example of renewable primary energy assets (e.g., solar energy for photovoltaic electricity generation) – should be generally carried out as follows:

Because solar energy can be effectively considered as unlimited, the bottleneck is on the side of all photovoltaic systems installed worldwide and their ability to convert solar inputs into electricity over their expected remaining useful life. At the balance sheet date, the primary energy source *solar energy for power generation* is therefore recognized in the WESBS as the cumulative expected solar input in PJ over the expected remaining useful life of all photovoltaic systems installed worldwide.

Specifically, the assessment of solar energy as a primary energy source for photovoltaic power generation is calculated by multiplying the expected remaining useful life of all photovoltaic systems installed worldwide in years by the cumulative expected solar input into all photovoltaic systems installed worldwide in PJ per year. All expected values could be determined on the basis of statistical averages in the past, unless the latest findings on the balance sheet date of the WESBS indicate a higher or lower value.

Furthermore, independently from the example of solar energy for photovoltaic power generation, it could be discussed for all primary energy sources whether energy extraction and conversion facilities that have already been planned and approved but are not yet in operations should also be included in the bottleneck-oriented assessment. In this case, appropriate provisions (see below for details) for the energy consumption that will still be incurred until they are commissioned, as well as the energy consumption for neutralizing the CO_2e that will still be incurred until commissioning by CCS and DACCS would have to be recorded on the liabilities side of the WESBS. However, a strict interpretation of the principle of prudence would favor a restriction to plants that are already commissioned at the balance sheet date, especially since political, legal and economic risks could lead to a temporary or permanent construction freeze.

Furthermore, the assets side includes all fossil and renewable energy and food products in PJ that are still within the energy conversion sector on the balance sheet date as secondary energy sources. These are energy products that are in interim storages or on their way to the end consumer on the balance sheet date, e.g. heating oil, gasoline and gas stocks, nuclear fuel elements, briquettes, coking coal, waste intended for incineration in waste incineration plants, firewood, electricity stored in battery storages and food products of all kinds.

Finally, all fossil and renewable final energy and food products that are already directly available to end energy consumers for conversion into useful energy are recorded on the assets side in PJ.

Facility and equipment bottlenecks – such as an insufficient number of battery storages for renewable electricity leading to energy losses – that occur on the way from activated secondary and final energy sources to the energy consumer do not reduce their asset value in the WESBS, but are recorded as provisions for energy losses.

The liabilities side includes provisions for all estimated energy consumption and losses in PJ that are expected to arise during the conversion of capitalized primary, secondary, and final energy stocks into useful energy. This also includes the energy consumed by food production and distribution, as well as energy losses due to food waste that occur on the way from farming, livestock breeding, hunting and fishing to consumption.

In addition, liabilities have to be recognized for the energy consumption by CCS and DACCS to neutralize GHG emissions arising during conversion/use of the capitalized energy sources. Finally, a DACCS provision must also be recorded for atmospheric CO_2e, as soon as and as far as the CO_2e budget limitation in the atmosphere – intended to achieve the 1.5°C target with overwhelming probability – will be exceeded in the future.

The energy consumption for CCS and DACCS to ensure net zero is calculated using emission factors followed by the calculation of the energy consumption for CCS and DACCS. As far as facilities for CCS and DASS do not exist on the balance sheet date, their construction consumes energy and, depending on the energy sources used, also generates CO2-e, emissions. In this case, emission factors and energy consumption factors must be determined on the basis of a life cycle assessment (LCA).

However, already on the balance sheet date existing extraction, conversion, transport, storage, CCS, and DACCS infrastructures may not be included in the WESBS as provisions using LCA emission factors and LCA energy consumption factors, as the energy required to construct these infrastructures has already been consumed and is therefore no longer included in the energy assets. The same applies to the GHGs already emitted as a result of the construction of these infrastructures. Those emissions are already in the atmosphere on the balance sheet date and could lead to DACCS liabilities for atmospheric CO_2e above 1.5°C – perhaps in the nearest future – if the conditions described above are met.

The difference between energy assets and energy liabilities results in energy equity, which is available, if the 1.5°C target is met. Energy equity thus represents the net energy assets or "useful energy capital" of humankind at a given point in time. An aggregated WESBS could look like this:

Energy Assets	WESBS at Dec. 31st 2027 in PJ	Energy Liabilities
Primary Energy (PE), fossil and renewable		Provisions for energy losses from PE to Useful Energy (UE) Provisions for CCS/DACCS from PE to UE
Secondary Energy (SE), fossil and renewable		Provisions for energy losses from SE to UE Provisions for CCS/DACCS from SE to UE
Final Energy (FE), fossil and renewable		Provisions for energy losses from FE to UE Provisions for CCS/DACCS from FE to UE
		DACCS Liabilities for atmospheric CO_2e above 1.5°C
		Energy Equity
Balance Sheet Total Assets		**Balance Sheet Total Liabilities**

Overall, the following applies:

Energy Assets = Energy Equity + Energy Liabilities   (1)

Energy Equity = Energy Assets – Energy Liabilities   (2)

Of course, all primary, secondary, and final energy assets, as well as their corresponding provisions, are recorded in sufficient detail and transparency so that the contribution of each energy source or product to the energy equity can be determined.

4. CONCLUSIONS AND NEXT STEPS

In analogy to any business balance sheet, the WESBS could also be subject to an in-depth analysis.

First, it could answer the fundamental question of how long the energy equity determined on the balance sheet date could satisfy humankind's total useful energy demand and how long the useful energy output of a single energy resource (e.g. crop yields, solar energy for photovoltaic power generation, etc.) could satisfy the useful energy demand for this specific energy resource.

Furthermore, energy efficiency indicators could be determined at different levels as the relationship between energy input and useful energy output. Therefore, global energy efficiency can be calculated like:

Global Energy Efficiency = Energy Equity / Global Energy Assets (3)

Improvements in global energy efficiency – such as progress in energy saving technology or a shift to primary energy resources with a higher energy efficiency – will lead ceteris paribus to an increase in energy equity. For example, the efficiency for certain prime energy resources can be determined as follows:

Example 1: Fossil energy assets (e.g., hard coal for power generation):

$$\text{Energy Efficiency}_{Hard\_Coal} = \text{Useful Energy}_{Hard\_Coal} / \text{Primary Energy Assets}_{Hard\_Coal} \qquad (4)$$

Example 2: Renewable energy assets (e.g., photovoltaics for power generation):

$$\text{Energy Efficiency}_{Photovoltaics} = \text{Useful Energy}_{Photovoltaics} / \text{Primary Energy Assets}_{Photovoltaics} \qquad (5)$$

However, the next major challenge will be to quantify the balance sheet items. LLM-based approaches are currently being tested with ChatGPT to find relevant and up-to-date scientific studies to ensure a reliable quantification process.

In the future, it would be interesting to develop national energy stock balance sheets (NESBS) to reach the goals of a WESBS also on a national level. A consolidated aggregation of all national NESBS together with the rest of the world's energy assets and liabilities to a global WESBS could create a consistent information system about energy stocks on national, supra-national (e.g. EU) and global levels.

Furthermore, the WESBS could also serve as a starting point for simulations. For example, the macroeconomic and global effects of technological progress in terms of higher CO_2e and energy efficiency on the growth of energy equity could be simulated.

Finally, the WESBS could also contribute to the vision that energy consumption will no longer be included in the gross national product and thus no longer contribute to economic growth. Rather, the development of energy equity over time could be a significant indicator of sustainable growth.

5. ACKNOWLEDGMENT

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[17] Based on a recommendation from ChatGPT to acknowledge the use of DeepL in this context (Question for and response from ChatGPT on Sept. 27, 2025, 23:26 CEST).

BIOGRAPHY

Academic Record

Apprenticeship in Banking (Sparkasse Bad Tölz), Diplom-Kaufmann (University of Regensburg), Dr. rer. pol. (University of Regensburg, Chair for Business Informatics I: Systems Theory and Systems Simulation), Professor (Albstadt-Sigmaringen University, Life Sciences Faculty), primary research interests: systems and complexity management as well as corporate responsibility, particularly in the aerospace industry and in the construction, real estate and energy sector.

Entrepreneurial Activities

1990 Co-Founder of Immobilien Zentrum Regensburg, 1990 - 1999 Managing Director (Immobilien Zentrum), since 1999 Member of several supervisory boards, since 2014 President of the supervisory board of Immobilien Zentrum Holding AG.

Academic Career

Since 1999 Professor (Albstadt-Sigmaringen University), 2006 - 2009 President of HFH-Hamburger Fern-Hochschule, 2013 - 2018 Managing Director Institute of Executive Education and Vice President both Albstadt-Sigmaringen University.

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