

Empowering Women for Sustainable Economic Recovery: Optimizing Natural Resource Markets for Environmental Efficiency in the USA

Wzmocnienie pozycji kobiet na rzecz
zrównoważonego ożywienia gospodarczego: Optymalizacja rynków
zasobów naturalnych dla efektywności środowiskowej w USA

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Abstract

The UN SDG 5 promotes gender equality and the empowerment of women and girls. Despite its focus on SDG 5 (Gender Equality), the study recognizes that empowering women supports numerous other SDGs. Gender equality's promotion of inclusive p boosts SDG 8 (Decent Work and Economic Growth) through increased productivity and innovation, SDG 9 (Industry, Innovation, and Infrastructure) through increased female representation in science and technology, SDG 12 (Responsible Consumption and Production) through more sustainable behavioral choices, and SDG 13 (Climate Action) through environmental awareness and policy advocacy. Empowering women is a systemic driver for social, economic, and environmental sustainability. The lack of gender parity in governance is counterproductive to long-term goals. Based on the key facts, the study filled a research gap by including various predictors of women's autonomy that aid in managing a country's environmental and natural resources in the United States by using a period of 1975–2023. The asymmetric relationship between women's autonomy factors, ecological footprints, and ores and metal exports was discovered using the nonlinear autoregressive distributed lag (NARDL) model. Further, Granger causality test is used for causal inferences between the

variables. The NARDL estimates show that increasing the women's sovereignty index is beneficial in the short and long run for reducing ecological footprints and conserving ores and metal exports. Furthermore, advanced female education's positive and negative shocks reduce environmental footprints through political wisdom. The Granger causality estimates show that ecological footprints cause of to increase advanced female education, whereas negative shocks of advanced female education cause women's sovereignty. The findings confirmed the viability of asymmetric causation between the variables mentioned during the specified period. The country needs to include women in its main policy plans to protect the environment and natural resources for green and clean development.

Key words: women's autonomy, ecological footprints, natural resources, inbound FDI, GDP per capita, NARDL

Streszczenie

5 Cel Zrównoważonego Rozwoju (SDG) promuje równość płci i wzmocnienie pozycji kobiet i dziewcząt. Pomimo skupienia się na SDG 5 (Równość płci), w artykule pokazujemy, że wzmocnienie pozycji kobiet wspiera wiele innych SDG. Promowanie inkluzywnych działań poprzez równość płci wzmacnia SDG 8 (Godna Praca i Wzrost Gospodarczy) poprzez zwiększoną produktywność i innowacyjność, SDG 9 (Przemysł, Innowacje i Infrastruktura) poprzez zwiększoną reprezentację kobiet w nauce i technologii, SDG 12 (Odpowiedzialna Konsumpcja i Produkcja) poprzez bardziej zrównoważone wybory behawioralne oraz SDG 13 (Działania na rzecz Klimatu) poprzez świadomość ekologiczną i wspieranie prawne. Wzmocnienie pozycji kobiet jest systemowym motorem zrównoważonego rozwoju społecznego, gospodarczego i środowiskowego. Brak parytetu płci w zarządzaniu jest kontrproduktywny dla celów długoterminowych. Opierając się na kluczowych danych, badanie wypełniło lukę naukową, uwzględniając różne predyktory autonomii kobiet, które pomagają w zarządzaniu zasobami środowiskowymi i naturalnymi kraju w Stanach Zjednoczonych, w latach 1975–2023. Asymetryczny związek między czynnikami autonomii kobiet, śladem ekologicznym i eksportem rud i metali został wykazany za pomocą nieliniowego modelu autoregresyjnego rozłożonego opóźnienia (NARDL). Ponadto test przyczynowości Grangera jest używany do wnioskowania przyczynowego między zmiennymi. Szacunki NARDL pokazują, że zwiększenie wskaźnika suwerenności kobiet jest korzystne w krótkim i długim okresie dla zmniejszenia śladu ekologicznego i ochrony eksportu rud i metali. Ponadto pozytywne i negatywne wstrząsy zaawansowanej edukacji kobiet zmniejszają ślad środowiskowy poprzez mądrość polityczną. Szacunki przyczynowości Grangera pokazują, że ślad ekologiczny powoduje zwiększenie zaawansowanej edukacji kobiet, podczas gdy zaawansowana edukacja kobiet wspiera suwerenność kobiet. Badanie potwierdziło wykonalność asymetrycznej przyczynowości między wymienionymi zmiennymi w określonym okresie. Wykazujemy, że Kraj musi uwzględnić kobiety w swoich głównych planach politycznych w celu ochrony środowiska i zasobów naturalnych na rzecz zielonego i czystego rozwoju.

Słowa kluczowe: autonomia kobiet, ślad ekologiczny, zasoby naturalne, napływające bezpośrednio inwestycje zagraniczne FDI, PKB na mieszkańca, NARDL

1. Introduction

The UN Sustainable Development Goals (SDGs) cannot be achieved unless the gender gap is addressed (Rothermel, 2020). SDG-5, which promotes gender equality, is the UN's principal policy priority (Cameron et al., 2020; Mujeeb et al., 2021). Women suffer in developed and underdeveloped nations. However, wealthy nations promoted women and girls' education, health, and economic prospects. Economic and business gender imbalance must be reduced (Khurshed et al., 2021). Women's weaker political and decision-making power suppresses male supremacy in economic and sustainable issues (Gayathri & Vijayabanu, 2021; Majid, 2023). The US economy scores above 90 out of 100 on women's autonomy. Women struggle to attain graduate degrees and managerial positions due to gender-biased legislation. The human strain on arable land worsens ecological deterioration, biodiversity loss, and natural resource depletion (Maja & Ayano, 2021). Conserving natural resources improves human well-being and economic activity for future generations. Sustainable development depends on it, but natural resource depletion threatens it (Nassani et al., 2021). National and regional collaboration to conserve ecosystems would help design policies integrating water, land, and energy resources by strengthening local and regional capabilities (Yurui et al., 2021). Financial services, resource extraction technology, and capacity development would benefit the ecosystem (Thomson et al., 2021). Responsible use and production of economic and ecological resources to decrease environmental footprints is UN Sustainable Development Goal-12 – recycling and waste reduction help responsible consumption. Globally, about 1.3 billion tons of food are wasted, leaving over 2 billion people hungry and malnourished. The food industry emits 25% of global GHGs, harming healthcare sustainability (United Nations, 2021).

Sustainable development and women's liberation are linked by social justice, economic growth, and environmental responsibility. A human right and a prerequisite for sustainable development is gender equality. Empowering women via education, decision-making, and government participation benefits the economy and environment.

Social inclusion improves institutional responsiveness, policy compliance, and ethical resource management. SDGs 5, 8, and 9 support women's active participation in leadership and production networks, which boost creativity, productivity, and governance. Women are more outspoken about renewable energy, ecological balance, and climate resilience, which connect with SDGs 12 and 13. This study adopts a holistic approach by integrating social (gender equality and empowerment), economic (growth and productivity), and environmental (ecological footprint and sustainability outcomes) aspects into one analytical framework. Due to global transitions like the late 20th-century international women's movements and the UN's Sustainable Development Goals' institutionalization of gender mainstreaming, this study does not treat 1975–2023 as a single, homogenous phase. Instead, it uses structural breakdowns and sub-periods to explain how globalization, technology, and institutional changes have modified empowerment-sustainability links. The study highlights regional and income-based differences in gender parity and sustainable outcomes and puts women's empowerment in a comparative global context. Developing countries, notably in Africa and Asia, exhibited fast but late-stage improvement in the early 2000s. However, industrialized economies have more consistent and earlier integration of women in environmental leadership and executive roles. This global divergence emphasizes the interdisciplinary and international nature of sustainable development and the ethical necessity of gender inclusion as a strategic component of ecological and economic transformation. By combining its analytical breadth with the journal's interdisciplinary aim, this research shows how women's empowerment may promote social, economic, and environmental sustainability.

The data on females' share of employment in senior management cadres is available from 2000 onward at World Bank (2021) database, whereas data on advanced female education is available from 1994 onward. As a result, to avoid any self-generated data sets, the study used the same data for the previous years. The data shows that the autonomy index scale for women increased from 75.660 in 1975 to 91.250 in 2020. The country is working hard to raise women's autonomy index scores and achieve the United Nations SDG-5 goal of gender equality. On the other hand, the proportion of the female labor force attaining advanced education has declined significantly, from 75.660 percent of the female working-age population in 1975 to 67.820 percent in 2020. Women will only make up less than 42% of senior and middle management positions until 2020. (World Bank, 2021). Its high index score cannot truly represent women's autonomy while highlighting gender disparities in education and labor market sectors. Unlocking women's potential in all public and private spheres and providing equal rights to advanced education and senior management is critical to achieving long-term results (Stojanovska-Stefanova et al. 2020).

The massive increase in ecological footprints in hectares is disturbing international agencies and environmental protection agencies, prompting them to reconsider their ecological policies and transition away from non-renewable fuels to renewable fuels (Ibrahiem & Hanafy 2020, Usman et al. 2021). In the instance of the United States, arable land will reach 157736800 hectares by 2020, resulting in increased industrialization activities that would boost the country's per capita income to US\$ 53749 this year. Chemicals used in manufacturing increased from 10.39 percent of manufacturing value-added in 1975 to 16.438 percent in 2020, owing primarily to private sector sponsorship, financial sector loans, and a 2.304 percent annual interest rate. In 2020, R&D efforts will expand in the form of trademark applications totaling up to 492729. Trade liberalization policies also benefit natural resource exports, especially ores and metals, which account for 3.213 percent of GDP, bringing total trade to 26.314 percent of GDP (World Bank, 2021). In the aftermath of the economic collapse, investing in women can help the economy get back on its feet through its natural and environmentally friendly policies.

Sustainability and women's empowerment have evolved differently globally. From early gender rights and educational growth to the SDG agenda's institutionalization of gender mainstreaming, 1975–2023 saw substantial changes. Social developments, greater education, and aggressive government regulations allowed women to participate in economic and environmental decisions in industrialized countries in the 1980s and beyond. However, international lobbying, foreign direct investment, and global collaboration have helped developing regions improve rapidly. These discrepancies demonstrate how institutional maturity, financial level, and cultural norms affect gender-sensitive sustainability. This research compares women's sovereignty, female education, and environmental sustainability throughout legislative eras. It captures these dynamics using time-sensitive econometrics and structural break analysis with sub-period estimates (1975–1989, 1990–2003, and 2004–2023). The study uses long-term quantitative modeling and contextual interpretation of historical landmarks like the Sustainable Development Goals (2015) and the Beijing Platform for Action (1995) to understand better gender empowerment, a social and economic factor in sustainability. The study expands its discussion by putting the American experience in a cross-national comparative perspective. According to different reports of UNDP Human Development Reports, World Bank Gender Statistics, and UN Environment databases, gender equality is associated with lower environmental footprints, more transparent institutions, and more varied export arrangements (see Table 1).

Based on the study's novelty, the following research questions are in line that must be efficiently answered: to what extent has an increase in the women's sovereignty index translated into more beneficial long-term outcomes in a country? The question is crucial since just increasing the women's sovereignty score does not imply that women have equal rights in all areas. As a result, it is necessary to assess the role of women in managing economic resources by critically evaluating all conceivable elements of women's autonomy. The second study question is whether female advanced education's positive and negative shocks contribute to more sustainable natural resource

Table 1. Global Trends in Women's Empowerment and Sustainability (1975–2023), source: the average values have been estimated from World Bank, UNDP, and Global Footprint Network data

Period	Region Type	Women's Sovereignty Index (Avg.)	Female Tertiary Education (% pop.)	Ecological Footprint (gha/capita)	Key Trend
1975–1989	Developed Economies	0.42	16.5	5.2	Early gains in education; weak environmental awareness
1975–1989	Developing Economies	0.25	5.8	1.9	Limited empowerment; high resource extraction dependency
1990–2003	Developed Economies	0.63	31.4	4.8	Growth in managerial roles; green regulation begins
1990–2003	Developing Economies	0.39	14.7	2.6	Expansion of education; industrialization pressures rise
2004–2023	Developed Economies	0.78	45.3	3.7	Gender mainstreaming in SDG policies; decoupling of growth and footprint
2004–2023	Developing Economies	0.57	26.9	3.1	Acceleration of female participation; emerging sustainability governance

conservation outcomes. The question emphasizes empowering women through high-quality education that produces green results for business and the economy. The third question is whether green financing solutions value women in improving their livelihoods and dealing with corporate sustainability issues. The issue is respecting women's ability to freely access money, allowing them to offer green financing policies for environmentally friendly commodity production. The fourth concern is whether women who rise to the top of the corporate ladder will be armed with long-term policy tools to protect the natural environment and resource capital. It is highly valued that women have environmental protection behaviors that improve due to high-quality education and environmental awareness programmes that enable them to protect the natural capital. Finally, how effective are rigorous environmental rules and natural resource pricing in achieving greener footprints? The question brought up the point that economic and environmental protection policies would be more viable if women were given political power over environmental resource management. As a result, the viability of women in the greening agenda enables a country to progress toward equality through long-term market changes. After having a critical discussion, the following research objectives have been set up to be analyzed with sophisticated statistical techniques in order to come to some conclusions, such as:

- i) To investigate how women's autonomy factors affect the environment and natural resources in the United States in a different way than men's.
- ii) To assess the impact of negative and positive shocks in female advanced education and female representation in senior and intermediate management on environmental footprints, ores, and metal resources.
- iii) To assess the potential influence of sustained economic growth, financial development indicators, and economic policies on the environmental and resource conservation agenda, taking women's autonomous aspects into account, and
- iv) To look at the asymmetric causal inferences between the candidate variables and come up with some conclusive policy suggestions.

The study used the NARDL approach and an asymmetric Granger causality test to obtain some dynamic conclusions about resource conservation through women's political autonomy in a country.

Few studies have examined the link between gender equality, environmental sustainability, and resource governance despite its significance to SDG-5. The literature increasingly acknowledges women's role in environmental preservation and sustainable lifestyles (Pienaa et al., 2024; Maleknia & Salehi, 2024). Quality, fragmentation, and developing nations dominate the literature, neglecting high-income states like the US. Huang and Okere (2024) found that women in environmental governance improve natural resource returns. These studies overlook long-term causation and temporal directionality that affect relationships. Gender empowerment, such as female education and sovereignty, was included in long-term economic and ecological research utilizing the Nonlinear Autoregressive Distributed Lag (NARDL) model.

The research on gender equality in ecology and natural resources shows how female independence, education, and management representation affect ecological footprints and metal and mineral exports. This study advances the

relationship between environmental sustainability and gender equality by relying on Tania Murray Li (2007), Amartya Sen (1999, 2001), and the IPCC 5th Assessment Report (2014). Li's book, *The Will to Improve*, provides a more comprehensive view of development and governmentality, which might aid the study's assessment of power dynamics in gender equality in ecology and natural resources. To understand how gender equality affects sustainable development, study Sen's articles on gender equity and development. They may illuminate the research's link between environmental resources and gender equality. In its fifth assessment report, the IPCC highlights the latest climate change research and its effects on ecosystems and natural resources. Research that integrates these features gives a more detailed picture of environmental preservation and gender equality and fills gaps in the research.

2. Literature review

The literature review is divided into three sub-sections to help understand environmental management and sustainable development. The First section begins with a detailed discussion of carbon footprint Management, including how people and corporations may lessen their environmental impact. The second section shows women's workplace equality gains and obstacles. Finally, the third section highlights women's contributions to sustainable development and environmental preservation via ecological studies and natural resource management. These elements are significant, but combined, they show how they link environmental sustainability, social considerations, and economic concerns. This research review illustrates how human behaviors affect the natural environment, human health, and community health.

2.1. Carbon Footprint Management

The total greenhouse gas emissions of a person, company, or nation are their carbon footprint. This statistic calculates the environmental effect of human activities by summing GHG emissions from burning fossil fuels, chopping down trees, and creating and delivering products and services. (Pandey, 2011). The pressing need to address climate change has brought carbon footprint to the forefront (Pettorelli et al., 2021). Common GHGs like carbon dioxide, methane, and nitrous oxide trap heat in the atmosphere and cause climate change. Burning fossil fuels, chopping down trees, and moving products and services increase GHG emissions and climate change (Yoro & Daramola, 2020). A GHG is measured in carbon dioxide equivalent (CO₂e) discharged into the air (Chang et al., 2021). When one's carbon footprint quantifies its environmental effect, it has enormous implications for people and organizations. Individuals and organizations may reduce their environmental effects by learning how their habits contribute to greenhouse gas emissions and adopting eco-friendly practices. People may assist the environment by using less energy, switching to renewable energy, and recycling. An individual's carbon footprint may be calculated by increasing their greenhouse gas output. Recycling, conserving energy, and using renewable power may lessen environmental impact (Pata, 2021).

People may reduce their environmental impact by reducing energy use, using renewable energy, reducing rubbish, and buying carbon offsets (Olujobi et al., 2022; Raihan & Tuspekova, 2022). Carbon footprint management requires government and non-government greenhouse gas reduction efforts (Chan et al., 2021). Reducing one's environmental impact is admirable. People may fight climate change by lowering energy consumption, recycling, and utilizing public transportation. Fan et al. (2023) examined how gender diversity affects Japanese companies' carbon emissions. Since there is no evidence on how gender diversity impacts business environmental performance, the research examines the firm's total carbon emissions. The study shows that businesses with female outside directors emit less GHG. Appointing women as inside directors diminishes the remedy's efficiency. The policy implications show that corporations require greater governance to improve sustainability. Hosio and Aquarista (2023) examined Youtefa Bay's mangrove forest's ecological influence in Jayapura City, Indonesia. This research examined the direct and indirect consequences of removing mangrove trees and collecting plastic litter on Youtefa Bay seafood harvesters. According to the survey, women are having trouble finding shells. Plastic garbage has accumulated since the mangrove forest was taken down. The Sundarbans are a World Heritage site on the Bangladesh-India border. Mitra and Barua (2023) examined how women fisherfolk cope with climate change. Researchers observed that rural Sundarban populations depend on fishing and capture fisheries threatened by climate change. Natural disasters, anthropological issues, and social and political issues have plagued small-scale fishing in the region for 20 years. The research shows that climate change disproportionately affects women fishermen, whose livelihoods rely on the oceans and other natural ecosystems. In Benin, Senegal, and Togo, Mang-Benza et al. (2023) interviewed rural women on energy justice. A vicious cycle of diminishing capacity and resource restrictions was identified due to energy sources' limited supply and low cost. The research suggested strategies to implement justice in daily life. According to the study, energy justice requires gender equality as a core framework.

2.2. Progress of women in the labor market

This subject focuses on successful female employee recruitment strategies. Social and cultural norms, lack of flexible work options and affordable childcare, gender-based prejudice and discrimination, stagnant career advancement opportunities, unfair pay, and work-family conflicts discourage women from working. Pay equity

assessments, diversity and inclusion efforts, flexible work arrangements, affordable childcare, and leadership development programs for women may assist firms in achieving gender parity and minimizing pay inequities. Bhalotra et al. (2023) studied how health innovation influences women's employment, marriage, and pregnancy. Improved infant mortality rates have enabled women to postpone having children and spend more in the economy, reducing fertility, fewer women never marrying, more women in the labor market, and better occupational positions. They provide a novel perspective on fertility that fits behavior theories.

Refugee women confront severe impediments to work, but Ziersch et al. (2023) concentrate on the influence of job experiences on their health. This research employs inductive theme analysis on in-depth interviews with 42 immigrant women to investigate the impact of job searching and working environments on their health. The research concludes that being unemployed is detrimental to mental health, whereas being employed boosts health by providing a feeling of purpose, accomplishment, and community. However, working conditions, discrimination, and harmful chemicals may all affect a woman's emotional and physical health, making employment a double-edged sword. Gender variations in the impact of challenging circumstances upon entering the job market in a developing area are evaluated by Berniell et al. (2023). Using harmonised microdata from 15 Latin American nations, the research found that males with greater unemployment rates between the ages of 18 and 20 had a detrimental impact on their employment and incomes between the ages of 27 and 30. Higher levels of empowerment may be a consequence of increasing female labour participation. According to the study's findings, they may operate as a mechanism driving the durability of good impacts on female labour outcomes, which implies that women act as secondary workers during recessions. Brown-Grossman & Nava-Bolaos (2023) analyse gender gaps in labour mobility, transitional features in the labour market, and the impact of risk-associated factors such as unpaid care work in Mexico. The research concludes that transition risks vary by sociodemographic parameters such as sex, age, and education, with unpaid care work significantly negatively influencing women's standing in the labour market. The research emphasizes the need to balance paid labour with unpaid caregiving via policy. Poor health, unemployment, exploitation and discrimination, unsafe working conditions, and the influence of socioeconomic issues, such as unpaid care duties, are all highlighted in this research as significant obstacles to women's labour participation.

2.3. Women's participation in ecology and natural resources

Research from industrialized and emerging countries shows that gender disparity reduces women's inherent intellect and analytical abilities, making lasting solutions harder to uncover. Using a case study of Chinese women using time-series data from 1975 to 2019, Mujeed et al. (2021) examined how technology elements affect women's freedom in solving economic and corporate sustainability issues. The findings supported a green development plan by showing that technology improves women's ecological choices. Using green energy and industrial processes should strengthen women's political autonomy. Thus, giving women political skills via technology increases their environmental activism. Liu et al. (2021) investigated the role of women in natural resource management in Congo. They discovered that women's financial resources assist them in improving natural resource rentals and reducing environmental footprints. Women's inherent autonomy and economic acumen also enable them to save mining resources for future generations to fulfil sustainability goals. Nassani et al. (2019) proposed that foreign tourism is the key to empowering women by increasing female employment, improving wage rates, and eliminating educational gender disparities. From 1990 to 2015, a panel of European countries revealed that both economic growth and foreign tourism increased women's empowerment, proving that women's empowerment is fueled by both economic growth and tourism. Women's potential and gender inequality were both reduced by the financial-led growth theory, which was also found to be true.

According to Goel and Ravishankar (2021), the Indian economy has continually pushed to grant some fundamental rights to women and girls; nonetheless, achieving women's autonomy in a country will be a long trip. Female literacy is a significant factor in empowering women in family decision-making, yet language and cultural hurdles continue to be significant roadblocks to equal rights for women. Durán-Daz et al. (2020) identified several elements contributing to women's empowerment in Cuetzalan del Progreso, Puebla. It involves growth in cultural tourism, which contributes to improving rural women's living standards. Second, establish broad-based land administration programmes to assist rural women in working on broad rangeland reforming systems to improve production. Finally, capacity-building initiatives assist women in moving forward with their tasks. As a result, encouraging women to participate in community development is critical. According to Graafland (2020), having a higher representation of female directors on a board boosts green measures that aid with company sustainability. Akinsemolu & Olukoya (2020) argued that Nigerian women are primarily affected by climatic vulnerability due to the country's economic crisis, environmental risks, and obvious socio-cultural issues. The requirement for capacity building and adaptation approaches due to climate change may be able to save their lives. According to Kansake et al. (2021), women working in the mining industry face significant discrimination. The main issues are wage discrimination, gender discrimination, sexual harassment, and sexual demands during job interviews. The greater need for women's empowerment in the mining sector extends beyond equal educational opportunities. There is also a greater need for contingent regulatory mechanisms, law enforcement, easy access to justice, and

labor reforms that promote equality. So that women can feel safe, healthy, and have equal employment opportunities in business and all aspects of daily life.

Arthur-Holmes and Busia (2020) examined how African women's artisanal and small-scale mining (ASM) participation affects family interactions, housing, child decisions, and family size. Increasing women's ASM representation provides them with more influence when negotiating higher-paying employment. Despite the high percentage of female ASM engagement, more equitable changes are needed to empower women. These changes may include a mineral commission, gender advocacy structures, and stakeholder participation in ASM gender equality. Even though gender-sensitive legislation has been substantially adopted in South African mining, Kaggwa (2020) reports that women still face several barriers to economic output. Due to male-biased business rules and supervisors, women suffered a lack of growth prospects, financing, decision-making bias, and compensation discrimination. Empowering women in mining requires addressing public and private sector gender discrimination, violence, and sexual harassment. Women in the mining industry are valued personnel who are given equal rights and professional advancement tools (Mangaroo-Pillay & Botha, 2020). Firms should promote women's professional growth, education, and workplace equality. Contemporary literature has prompted the need to empower women through several variables that are critical for achieving environmental sustainability, such as, gender equality with education (Doan & Kirikkaleli, 2021), climate change adaptation (Ergas et al. 2021), urban waste reduction (Buckingham et al. 2021), land reforms and governance (Sait, 2021), use of green energy sources (Shrestha et al. 2021), natural resource management (Sithole et al. 2021), financial literacy (Campbell et al. 2021), food security challenges (Oratungye Kevin et al. 2021), and management of water resources (Anantha et al. 2021).

Based on theoretical foundations and current literature, the study formulates three hypotheses to empirically evaluate the complex relationship between women's autonomy and natural resource management in the US. These hypotheses explain the directional and nonlinear linkages between natural resource economics, ecological sustainability, and women's empowerment, i.e.,

H1: Women's autonomy and ecological footprint are asymmetrical (nonlinear) relationships.

This hypothesis suggests that changes in women's autonomy (i.e., their capacity to make choices) may affect the country's ecological repercussions in diverse ways based on female education, labor force participation, and political representation. Women's empowerment may promote environmental stewardship, although the impact depends on the kind and pace of change. The nonlinear autoregressive distributed lag (NARDL) model tests this short- and long-term imbalance.

H2: Women's education and autonomy boost ores and metal exports' sustainability.

This hypothesis holds that women with greater education and agency may participate more in sustainable economic activities like resource management and governance. Ore and metal exports are included as a variable since resource-based enterprises are important to the American economy, and women may promote sustainable extraction and trading.

H3: A causal relationship exists between ecological footprint, female education, and women's autonomy.

This hypothesis examines how shocks to female education impact women's autonomy and whether environmental degradation motivates governmental or cultural measures to improve female education to test directed causation. By validating these dynamic links using the Granger causality test, we may better comprehend policy consequences over time.

The influence of gendered autonomy on sustainability outcomes in industrialized nations has gotten little attention despite the rising research on environmental degradation, economic incentives, and individual or corporate conduct. Wang et al. (2021) examine how economic and environmental factors influence insurance purchases in China to determine how environmental stress, notably air pollution, affects family priorities. Their study shows that environmental vulnerability impacts behavior, but it overlooks gender and institutional environmental management. Wu et al. (2022) explore how environmental restrictions affect firm-level productivity in China's pharmaceutical manufacturing companies via regional spillover effects. The institutional relationship between gender equality and environmental preservation has received less inquiry than health outcomes or economic efficiency. Pan et al. (2024) employ AI-based models to assess electric firms' environmental performance during energy crises, stressing the relevance of technology forecasting for sustainability policies. However, Ma et al. (2024) show that environmental liability insurance may enhance business green innovation, showing that market instruments drive change. Despite its importance, these studies do not include female empowerment as a mediating or explanatory variable. They examine low-carbon city pilot programs in China using a staggered difference-in-difference approach, like Hou et al. (2023), who show that policy-level interventions cut carbon emissions. The findings again do not reflect female agency or representation. The current study fills a knowledge gap by empirically investigating the 45-year U.S. context of women's sovereignty and education levels' uneven influence on environmental outcomes, such as ecological footprints and resource exploitation. Unlike previous research on business behavior, regional production, or insurance options, this study adds social justice to environmental sustainability. Environmental economics and gender studies have neglected the link between women's empowerment and biological and natural resource management. This work addresses that gap by combining the NARDL model and Granger causality analysis to provide fresh empirical insights into this area.

Bilgili et al. (2023a) employed quantile regression to analyze how natural resource rents affect MENA environmental sustainability. This reveals that resource-driven economic dynamics influence environmental performance differently. Bilgili et al. (2023b) examined the gender component of the EKC in Asian countries and found that women's economic and social participation considerably impacts environmental outcomes. Kuşkaya et al. (2023) examined solar energy's ecological sustainability using time-frequency analysis, revealing the interconnection of social and institutional variables in green energy transitions. Environmental policy frameworks must include gender equality to optimize long-term ecological effects. These studies prove that resource governance may improve environmental modeling and policymaking. Singh (2023) has reviewed the literature and found that rural women in poor and undeveloped nations are more vulnerable to the effects of climate change. Case studies of indigenous Indian women's efforts to manage natural resources in a way that minimises their impact on the environment illustrate how this approach may help lessen the global warming impacts already being felt. Salamon's study (2023) looks at how having more women in parliament affects the use of green energy. Increasing the number of women in parliament has been shown to enhance the use of renewable energy sources, and this effect may be seen in both high-income and middle-income democracies. This insight into women's participation in policymaking and the promotion of climate-friendly energy policy is provided by this article. Gender parity is crucial to a nation's progress, according to Jaiswal et al. (2023). The study argued that gender inequality in health, education, decision-making power, and pay is a barrier to economic development and well-being. They draw attention to the positive effects of women's employment involvement. The effects of labour migration on the integration of women who stayed behind in western Nepal are investigated by Shrestha et al. (2023). The results show that women's access to economic and communal participation is impacted by their gender, caste, ethnicity, age, and socioeconomic level. These results add to the ongoing discussion on migration's effects and may help guide efforts to improve gender equality in rural Nepal.

The presented study hypotheses must be verified, resulting in more policy conclusions. The study's main contribution is to identify the asymmetric relationship between women's autonomy elements and to examine their impact on reducing environmental footprints and managing ores and metal resources in the United States. Previous research primarily looked at the symmetric relationship between the stated variables. However, there is still a push to see if there are any positive or negative shocks concerning women's autonomy aspects of the environmental sustainability agenda, which prompted this investigation for robust inferences (Liu et al. 2021, Bell et al. 2020). In addition, the study used green finance mechanisms in conjunction with trademark applications, emphasizing the importance of including women in the mainstream policy agenda to reap green benefits. The stewardship hypothesis was analyzed in relation to women's role in environmental and natural resource conservation, which was rarely observed in previous studies (Roba & Kikwatha 2021, Du et al. 2021). The study used a women's sovereignty index in combination with positive and negative shocks of advanced female education and female attainment at the highest management level in an environmental modeling framework that had previously been unfilled, emphasizing the importance of analyzing asymmetric inferences between the variables (Löw 2020, Glazebrook et al. 2020). The real interest rate and trade openness are both employed in the study to look at the impact of a country's economic policies on women's empowerment, which leads to more beneficial long-term outcomes. Wieczorek-Szymaska 2020, Jeong & Compion 2021) found that unleashing women's potential in the education and labor market sectors allows them to advance to higher management levels through political wisdom (Wieczorek-Szymaska 2020, Jeong & Compion 2021). The study used non-linear ARDL modelling for environmental and resource conservation issues to get some good policy ideas about how to help women and let them be involved in making decisions in a country.

3. Data sources and methodological framework

The study examined the role of women's autonomy factors in affecting the environmental and natural resource conservation agenda in the United States from 1975 to 2023 using a variety of variables. The study used the women's sovereignty index (WSI, a proxy for women's business and law index scores, i.e., scale 1–low autonomy to 100–maximum autonomy), advanced female education (FAE, percent of female working-age population with advanced education), and female share of employment in senior and middle management (FESM, percent) as critical predictors. Furthermore, the study employed the following control variables: domestic credit provided by the financial sector (denoted by DCFS, percentage of GDP), chemicals used (denoted by CHEM, percentage of manufacturing value-added), inbound FDI (denoted by FDI, percentage of GDP), GDP per capita (denoted by GDPPC, constant 2010 US\$), real interest rate (denoted by RIR, percentage), trade openness (denoted by TOP, percentage of GDP), and trademark applications (denoted by TMA, total number). For two distinct models, ecological footprints (denoted by EFPRINT, a proxy for arable land in hectares) and ores and metal exports (denoted by ORME, percent of merchandise exports), employed two different predictor variables.

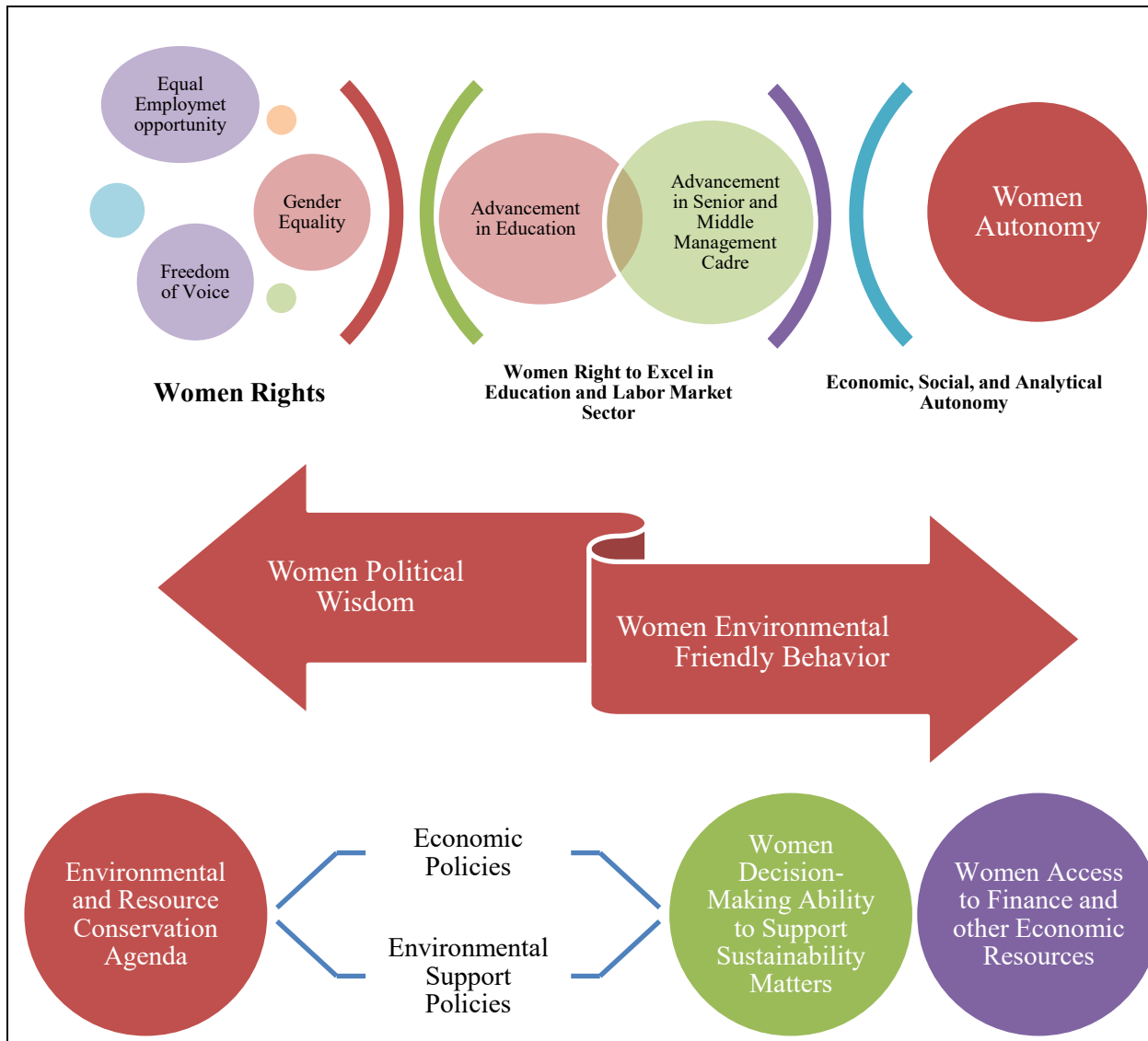


Figure 1. Stewardship Theory, source: adapted from Du et al. (2021) and Author’s extract

Some data values were missing from a few variables in the study. Specifically, FAE data was available starting from 1994, FESM data from 2001, and TMA data from 1980. The study filled the missing values by using the preceding and succeeding values of the same variables, where required. The World Bank (2023) provided the data for the study's variables. The models are listed here in this order:

Model -I: Women’s Autonomy and Green Footprints

$$EFPRINT_t = \delta_0 + \delta_1 WSI_t + \delta_2 FAE_t + \delta_3 FESM_t + \delta_4 DCFS_t + \delta_5 CHEM_t + \delta_6 FDI_t + \delta_7 GDPPC_t + \varepsilon_t \tag{1}$$

Model -II: Women’s Autonomy and Natural Resource Management

$$ORME_t = \delta_0 + \delta_1 WSI_t + \delta_2 FAE_t + \delta_3 FESM_t + \delta_4 RIR_t + \delta_5 TMA_t + \delta_6 TOP_t + \varepsilon_t \tag{2}$$

As shown in Equation (1), women's autonomous factors are supposed to be green footprints that reduce negative environmental externalities through their political, analytical, and environmentally friendly behaviors. Access to credit for women and continued economic growth are likely to reduce environmental footprints, and increasing the number of chemicals used in production will likely cause environmental damage. Equation (2) demonstrates that women's development in academia and the business sector contributes to more natural resource conservation through economic and environmental policies. Increased trademark filings and trade liberalization policies also promote women's political acumen in moving toward green development.

The argument is based on the stewardship theory. Women, on average, have higher stewardship values than males when it comes to making corporate environmental decisions that will benefit the product supply chain. Female advanced education and the growing number of women in senior and middle management positions help to increase their analytical ability and political acumen, allowing them to save more economical and corporate resources. Economic and ecological resources are depleted due to human pressure on arable land, which must be mitigated by green measures (Nassani et al., 2021). Women's political wisdom and economic affairs suggest more

green and clean policies to assist the natural environment (Liu et al., 2021). Women must be more involved in the decision-making process that leads to environmental protection regulations and helps replace ecological footprints with green ones (Mujeed et al., 2021).

The stewardship idea can only succeed if widespread disparities in education and the labor market are reduced, allowing women to pursue advanced degrees, leading to greater managerial positions, and indicating environmental sustainability policies (Du et al., 2021). Figure 1 shows the stewardship paradigm that feminists who want to protect ecological resources in the commercial and corporate sectors have developed.

This study accounts for asymmetric connections using the NARDL paradigm. It assesses the dependent variable's positive and negative reaction to explanatory factor changes. Each independent variable is split into positive and negative shocks by the NARDL model. Unlike linear models, which assume predictor changes have equal effects regardless of direction. This technique excels in environmental and social science investigations because transitioning from a decrease to an increase – such as women's autonomy – may be less or even the opposite. For instance, increasing female education may improve environmental outcomes, while decreasing it may have the opposite effect. Thus, asymmetric modeling may expose hidden dynamics and provide a more thorough view of real-world complexity than symmetric assumptions.

Equations (1) and (2) are formulations that are extended by applying the Shin et al. (2014) proposed nonlinear autoregressive distribution lag (NARDL) model. The study expected that asymmetric changes in women's autonomy components would lead to positive and negative shocks (i.e., advanced female education and a female share in senior and middle management levels).

The study changed the conventional ARDL model that Pesaran et al. (2001) came up with into NARDL to account for model asymmetries.

In the error correction framework that develops in short- and long-run time series, NARDL deconstructs the series into positive and negative elements. The rest of NARDL's features are comparable to the traditional ARDL model. It can be used even if the variables are level, at the initial difference, or in a mixed order of integration. Even if the sample size is limited, the NARDL produces satisfactory results. Because of the various positive and negative shocks in the provided time series, the cointegration process is more evident in the NARDL. The asymmetric cointegrating equation is expressed schematically as follows:

$$EFPRINT_t = \delta_0 + \delta_1 WSI_t + \delta_2 FAE^+_t + \delta_3 FAE^-_t + \delta_4 FESM^+_t + \delta_5 FESM^-_t + \delta_6 DCFS_t + \delta_7 CHEM_t + \delta_8 FDI_t + \delta_9 GDPPC_t + \varepsilon_t \quad (3)$$

$$ORME_t = \delta_0 + \delta_1 WSI_t + \delta_2 FAE^+_t + \delta_2 FAE^-_t + \delta_3 FESM^+_t + \delta_3 FESM^-_t + \delta_4 RIR_t + \delta_5 TMA_t + \delta_6 TOP_t + \varepsilon_t \quad (4)$$

where EFPRINT shows ecological footprints, WSI shows women's sovereignty index, FAE^+ and FAE^- shows positive and negative shocks of advanced female education, $FESM^+$ and $FESM^-$ shows positive and negative shocks of female employment share in senior and middle management, DCFS shows domestic credit provided by the financial sector, CHEM shows chemicals used, FDI shows inbound FDI, GDPPC shows GDP per capita, ORME shows ores and metal exports, RIR shows real interest rate, TMA shows trademark applications, TOP shows trade openness, and ε shows error term.

The FAE and FESM variables were decomposed into two additional factors that serve to capture positive (+) and negative (-) shocks in the given variables, as follows:

$$\left[\begin{aligned} FAE^+_t &= \sum_{j=1}^t \Delta FAE^+_j = \sum_{j=1}^t \max(\Delta FAE^+_j, 0) \\ FAE^-_t &= \sum_{j=1}^t \Delta FAE^-_j = \sum_{j=1}^t \max(\Delta FAE^-_j, 0) \quad (5) \\ FESM^+_t &= \sum_{j=1}^t \Delta FESM^+_j = \sum_{j=1}^t \max(\Delta FESM^+_j, 0) \\ FESM^-_t &= \sum_{j=1}^t \Delta FESM^-_j = \sum_{j=1}^t \max(\Delta FESM^-_j, 0) \end{aligned} \right]$$

In NARDL specifications, equations (3) and (4) are further modified, i.e.,

$$\Delta EFPRINT_t = \eta_0 + \sum_{k=0}^p \eta_1 \Delta EFPRINT_{t-k} + \sum_{k=0}^p \eta_2 \Delta WSI_{t-k} + \sum_{k=0}^p \eta_3 \Delta FAE^+_{t-k} + \sum_{k=0}^p \eta_4 \Delta FAE^-_{t-k} + \sum_{k=0}^p \eta_5 \Delta FESM^+_{t-k}$$

$$\begin{aligned}
 & + \sum_{k=0}^p \eta_6 \Delta FESM_{t-k}^- + \sum_{k=0}^p \eta_7 \Delta DCF S_{t-k} + \sum_{k=0}^p \eta_8 \Delta CHEM_{t-k} + \sum_{k=0}^p \eta_9 \Delta FDI_{t-k} + \sum_{k=0}^p \eta_{10} \Delta GDPPC_{t-k} \\
 & + \varsigma_1 EFPRINT_{t-1} \\
 & + \varsigma_2 WSI_{t-1} + \varsigma_3 FAE^+_{t-1} + \varsigma_4 FAE^-_{t-1} + \varsigma_5 FESM^+_{t-1} + \varsigma_6 FESM^-_{t-1} + \varsigma_7 DCF S_{t-1} + \varsigma_8 CHEM_{t-1} \\
 & + \varsigma_9 FDI_{t-1} \\
 & + \varsigma_{10} GDPPC_{t-1} + \mu_t
 \end{aligned} \tag{6}$$

$$\begin{aligned}
 \Delta ORME_t & = \lambda_0 + \sum_{k=0}^p \lambda_1 \Delta ORME_{t-k} + \sum_{k=0}^p \lambda_2 \Delta WSI_{t-k} + \sum_{k=0}^p \lambda_3 \Delta FAE^+_{t-k} + \sum_{k=0}^p \lambda_4 \Delta FAE^-_{t-k} + \sum_{k=0}^p \lambda_5 \Delta FESM^+_{t-k} \\
 & + \sum_{k=0}^p \lambda_6 \Delta FESM^-_{t-k} + \sum_{k=0}^p \lambda_7 \Delta RIR_{t-k} + \sum_{k=0}^p \lambda_8 \Delta TMA_{t-k} + \sum_{k=0}^p \lambda_9 \Delta TOP_{t-k} + \upsilon_1 ORME_{t-1} + \upsilon_2 WSI_{t-1} + \upsilon_3 FAE^+_{t-1} \\
 & + \upsilon_4 FAE^-_{t-1} + \upsilon_5 FESM^+_{t-1} + \upsilon_6 FESM^-_{t-1} + \upsilon_7 RIR_{t-1} + \upsilon_8 TMA_{t-1} + \upsilon_9 TOP_{t-1} + \mu_t
 \end{aligned} \tag{7}$$

The error correction term (ECT) is used to evaluate the short-term effect, allowing the long-term parameters' dependability to be verified:

$$\begin{aligned}
 \Delta EFPRINT_t & = \eta_0 + \sum_{k=0}^p \eta_1 \Delta EFPRINT_{t-k} + \sum_{k=0}^p \eta_2 \Delta WSI_{t-k} + \sum_{k=0}^p \eta_3 \Delta FAE^+_{t-k} + \sum_{k=0}^p \eta_4 \Delta FAE^-_{t-k} + \sum_{k=0}^p \eta_5 \Delta FESM^+_{t-k} \\
 & + \sum_{k=0}^p \eta_6 \Delta FESM^-_{t-k} + \sum_{k=0}^p \eta_7 \Delta DCF S_{t-k} + \sum_{k=0}^p \eta_8 \Delta CHEM_{t-k} + \sum_{k=0}^p \eta_9 \Delta FDI_{t-k} + \sum_{k=0}^p \eta_{10} \Delta GDPPC_{t-k} + \eta_{11} ECT_{t-1} + \mu_t
 \end{aligned} \tag{8}$$

$$\begin{aligned}
 \Delta ORME_t & = \lambda_0 + \sum_{k=0}^p \lambda_1 \Delta ORME_{t-k} + \sum_{k=0}^p \lambda_2 \Delta WSI_{t-k} + \sum_{k=0}^p \lambda_3 \Delta FAE^+_{t-k} + \sum_{k=0}^p \lambda_4 \Delta FAE^-_{t-k} + \sum_{k=0}^p \lambda_5 \Delta FESM^+_{t-k} \\
 & + \sum_{k=0}^p \lambda_6 \Delta FESM^-_{t-k} + \sum_{k=0}^p \lambda_7 \Delta RIR_{t-k} + \sum_{k=0}^p \lambda_8 \Delta TMA_{t-k} + \sum_{k=0}^p \lambda_9 \Delta TOP_{t-k} + \lambda_{10} ECT_{t-1} + \mu_t
 \end{aligned} \tag{9}$$

Equations (8) and (9) used Wald-F statistics to assess the link between the provided variables, based on the following hypothesis:

$$\begin{aligned}
 \text{For Model -I:} & \left\{ \begin{array}{l} H_0: \varsigma_1 = \varsigma_2 = \varsigma_3 = \varsigma_4 = \varsigma_5 = \varsigma_6 = \varsigma_7 = \varsigma_8 = \varsigma_9 = \varsigma_{10} \\ H_A: \varsigma_1 \neq \varsigma_2 \neq \varsigma_3 \neq \varsigma_4 \neq \varsigma_5 \neq \varsigma_6 \neq \varsigma_7 \neq \varsigma_8 \neq \varsigma_9 \neq \varsigma_{10} \end{array} \right\} \\
 \text{For Model -II:} & \left\{ \begin{array}{l} H_0: \upsilon_1 = \upsilon_2 = \upsilon_3 = \upsilon_4 = \upsilon_5 = \upsilon_6 = \upsilon_7 = \upsilon_8 = \upsilon_9 = 0 \\ H_A: \upsilon_1 \neq \upsilon_2 \neq \upsilon_3 \neq \upsilon_4 \neq \upsilon_5 \neq \upsilon_6 \neq \upsilon_7 \neq \upsilon_8 \neq \upsilon_9 \neq 0 \end{array} \right\}
 \end{aligned}$$

The Narayan critical values evaluate the assumptions for the model's long-run cointegrating connection between the variables. Wald -F statistics' predicted value should fall under the upper I(1) bound value to confirm long-run cointegration between them.

The investigation employed Bai-Perron multiple structural break tests to uncover data-generating process changes. This captured women's empowerment and sustainability linkages' dynamic growth across the study period (1975-2023). This approach discovers regression parameters that change at statistically significant intervals, which may suggest policy, institution, or historical changes that impact crucial variable correlations. The Bai-Perron technique is ideal for long-span time series data since it allows numerous endogenous breaks without prior knowledge of their location. Test results showed three major breakpoints. The late 1980s institutional reforms and gender inclusion efforts, globalization from the mid-1990s to the early 2000s, and the SDG mainstreaming and green growth strategies after 2004 are well-documented global turning points in gender and sustainability policy.

The dataset was separated into Regime A (1975–1989), Regime B (1990–2003), and Regime C (2004–2023) to estimate least squares regressions with regime-specific coefficients. This regime-wise estimation method illuminates the varied effects of women's sovereignty, education, and managerial representation on ecological sustainability and resource exports by comparing coefficient magnitudes, signs, and significance levels across historical contexts. OLS with structural breaks improves the nonlinear autoregressive distributed lag (NARDL) paradigm by explaining long-term changes structurally instead of short-run asymmetries. Breakpoint identification and sub-period regression analysis provide a more nuanced and time-sensitive view of the empowerment-sustainability nexus, reflecting sustainable development research's interdisciplinary and ever-changing nature.

The Hatemi-J (2012) test is used to get asymmetric and symmetric causality inferences, which help achieve the following four potential outcomes:

Postulate -I: The candidate variables support either symmetric or asymmetric causal inferences, allowing the establishment of one-way (unidirectional) links.

Postulate -II: The candidate variables supported either symmetric or asymmetric causal inferences, allowing the reverse (unidirectional) links between them to be verified.

Postulate -III: The candidate variables confirmed either symmetric or asymmetric causal inferences, resulting in the verification of two-way (bidirectional) linkages between them, and

Postulate -IV: The candidate variables confirmed neither symmetric nor asymmetric causal inferences (neutrality hypothesis).

The stated precepts assisted them in formulating some strong policy statements that enabled the government and officials in the United States to encourage women's autonomy in economic and corporate enterprise.

4. Results

The descriptive statistics for the variables are shown in Table 2. The mean value of ecological footprints is 1.74E+08, with a negatively skewed distribution and large distribution values. With a minimum of 1.765 percent and a mean of 2.861 percent, ore and metal exports account for 5.104 percent of total merchandise exports. The country is on its way to having the highest women's sovereignty index, with 91.250 out of 100. This means that more women have more power in both the public and private sectors. In addition, more than 70% of women in a country have higher education. However, the percentage of women in senior and middle management jobs are, on average, 36.745 percent of the female working-age population. There needs to be more autonomy and trust for women to have the same rights as men. Domestic credit given by the banking sector, chemicals utilized, inward FDI, and GDP per capita account for 179.436 percent of GDP, 12.874 percent of manufacturing value-added, 1.287 percent of GDP, and US\$40,904.03, respectively. The country's real interest rate, trade openness, and trademark applications total 4.188 percent, 22.664 percent of GDP, and 207,722.6 in numbers.

Table 2. Descriptive statistics

Methods	EFPRINT	ORME	WSI	FAE	FESM	DCFS	CHEM	FDI	GDPPC	RIR	TOP	TMA
Mean	1.74E+08	2.861	81.847	73.809	36.745	179.436	12.874	1.287	40904.03	4.188	22.664	207722.6
Maximum	1.89E+08	5.104	91.250	75.660	41.860	280.496	16.618	3.405	55886.18	8.594	30.789	492729
Minimum	1.55E+08	1.765	70	67.820	35.310	111.498	9.529	0.137	25120.23	0.575	15.516	46837
Std. Dev.	12751601	0.688	4.928	2.341	1.936	47.079	2.573	0.818	9251.566	2.264	4.557	133851.9
Skewness	-0.333	0.761	-1.056	-1.009	1.011	0.006	0.225	0.656	-0.105	0.180	0.171	0.430
Kurtosis	1.450	3.967	4.538	2.761	2.752	1.744	1.493	2.954	1.667	1.755	1.828	2.236

Note: EFPRINT shows ecological footprints, ORME shows ores and metal exports, WSI shows women's sovereignty index, FAE shows female share in advanced education, FESM shows the female share of employment in senior and middle management, DCFS shows domestic credit provided by the financial sector, CHEM shows chemicals used, FDI shows inbound FDI, GDPPC shows GDP per capita, RIR shows real interest rate, TOP shows trade openness, and TMA shows trademark applications.

The correlation matrix in Table 3 demonstrates that the women's sovereignty score is adversely connected with the ecological footprint and the conservation of ores and metal exports. Furthermore, increased female education contributes to the preservation of natural resources. The emergence of women in the labor force and their ability to occupy senior and middle management positions has helped to minimize environmental footprints and boost ores and metal exports, increasing women's autonomy and the country's economic prosperity. The pollution halo concept was verified by the negative impact of financial indicators and inward FDI on ecological footprints, highlighting the need for investment in cleaner technology to lower ecological footprints. Natural resource conservation is aided by the Fed's expansionary monetary policy and trademark registrations. On the other hand, trade liberalization measures boost ores and metal exports. The following variables were identified for the women's sovereignty index: a growing share of females in senior and intermediate management positions, financial indicators, continued economic growth, and trade determinants. Women's autonomy, finance, commerce, and government economic policies contribute to the country's economic success. These variables aid in evaluating the country's green development plan for women's autonomy.

Table 4 displays the ADF and breakpoint unit root estimates, which reveal that the remaining variables, except inward FDI, are the first difference series with an order of integration, i.e., I (1). As a result, inbound FDI is level stationary; as a result, it has the zero-order of integration, i.e., I (0). The determinants of ecological footprints, ores and metal exports, economic policies, trade openness, and women's autonomy show a higher level of dispersion in their variable series and follow the random walk hypothesis across time. The breakpoint estimates backed the ADF findings and showed distinct break dates in the variable series that showed structural shocks across time.

Table 3. Correlation Matrix

Variables	EFPRINT	ORME	WSI	FAE	FESM	DCFS	CHEM	FDI	GDPPC	RIR	TOP	TMA
EFPRINT	1											
ORME	-0.191	1										
	(0.202)	-----										
WSI	-0.631	-0.236	1									
	(0.000)	(0.113)	-----									
FAE	0.901	-0.143	-0.606	1								
	(0.000)	(0.342)	(0.000)	-----								
FESM	-0.907	0.265	0.593	-0.971	1							
	(0.000)	(0.074)	(0.000)	(0.000)	-----							
DCFS	-0.943	0.004	0.763	-0.865	0.848	1						
	(0.000)	(0.977)	(0.000)	(0.000)	(0.000)	-----						
CHEM	-0.979	0.183	0.667	-0.880	0.901	0.946	1					
	(0.000)	(0.222)	(0.000)	(0.000)	(0.000)	(0.000)	-----					
FDI	-0.637	-0.128	0.565	-0.517	0.438	0.715	0.600	1				
	(0.000)	(0.392)	(0.000)	(0.000)	(0.002)	(0.000)	(0.000)	-----				
GDPPC	-0.944	-0.009	0.788	-0.868	0.846	0.983	0.950	0.724	1			
	(0.000)	(0.948)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	-----			
RIR	0.523	-0.231	0.148	0.519	-0.542	-0.375	-0.512	0.030	-0.346	1		
	(0.000)	(0.121)	(0.323)	(0.000)	(0.000)	(0.010)	(0.000)	(0.838)	(0.018)	-----		
TOP	-0.942	0.213	0.649	-0.786	0.781	0.904	0.918	0.713	0.920	-0.358	1	
	(0.000)	(0.153)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.014)	-----	
TMA	-0.919	-0.015	0.760	-0.912	0.888	0.951	0.915	0.695	0.959	-0.359	0.875	1
	(0.000)	(0.920)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.014)	(0.000)	-----

Note: Small bracket shows probability value. EFPRINT shows ecological footprints, ORME shows ores and metal exports, WSI shows women's sovereignty index, FAE shows female share in advanced education, FESM shows the female share of employment in senior and middle management, DCFS shows domestic credit provided by the financial sector, CHEM shows chemicals used, FDI shows inbound FDI, GDPPC shows GDP per capita, RIR shows real interest rate, TOP shows trade openness, and TMA shows trademark applications.

Table 4. ADF and breakpoint Unit Root Test

Variables	Level	First Difference	Breakpoint Unit Root Test	Level	First Difference	Decision
	Constant and Trend	Constant and Trend	Break Dates	Constant and Trend	Constant and Trend	
EFPRINT	-2.197 (0.479)	-3.474 (0.054)	2001 (L) 2012 (D)	-4.538 (0.118)	-6.390 (p<0.01)	I(1)
ORME	-2.496 (0.328)	-6.300 (0.000)	2004 (L) 2006 (D)	-4.468 (0.141)	-6.436 (p<0.01)	I(1)
WSI	-2.372 (0.388)	-6.941 (0.000)	2017 (L) 2018 (D)	-2.923 (0.932)	-8.097 (p<0.01)	I(1)
FAE	-0.073 (0.993)	-3.601 (0.041)	2009 (L) 2019 (D)	-1.980 (p>0.99)	-4.841 (0.052)	I(1)
FESM	-0.242 (0.990)	-8.319 (0.000)	2015 (L) 2003 (D)	-1.307 (p>0.99)	-9.482 (p<0.01)	I(1)
DCFS	-2.951 (0.156)	-6.090 (0.000)	2007 (L) 2019 (D)	-4.128 (0.298)	-7.942 (p<0.01)	I(1)
CHEM	-3.027 (0.138)	-4.977 (0.001)	2004 (L) 2009 (D)	-4.989 (0.034)	-5.899 (p<0.01)	I(1)
FDI	-3.388 (0.065)	-6.522 (0.000)	1997 (L) 2001 (D)	-5.679 (p<0.01)	-7.320 (p<0.01)	I(0)
GDPPC	-2.257 (0.447)	-3.907 (0.019)	2011 (L) 2008 (D)	-3.402 (0.747)	-6.297 (p<0.01)	I(1)
RIR	-3.520 (0.049)	-4.975 (0.001)	2008 (L) 2004 (D)	-5.385 (p<0.01)	-5.226 (0.016)	I(1)
TOP	-2.519 (0.317)	-6.960 (0.000)	2014 (L) 2011 (D)	-3.599 (0.623)	-7.766 (p<0.01)	I(1)
TAM	-1.697 (0.736)	-6.127 (0.000)	2016 (L) 2000 (D)	-3.107 (0.877)	-8.423 (p<0.01)	I(1)

Note: Small bracket shows probability value. $p < 0.01$ shows 1% significance level. I(1) shows the order of integration is 1, I(0) shows an order of integration is zero. 'L' shows level data. 'D' shows difference data. EFPRINT shows ecological footprints, ORME shows ores and metal exports, WSI shows women's sovereignty index, FAE shows female share in advanced education, FESM shows the female share of employment in senior and middle management, DCFS shows domestic credit provided by the financial sector, CHEM shows chemicals used, FDI shows inbound FDI, GDPPC shows GDP per capita, RIR shows real interest rate, TOP shows trade openness, and TMA shows trademark applications.

Between 2001 and 2012, structural changes in ecological footprints can be seen, with arable land reaching its greatest level of 175400000 hectares in the former and a fall to 155007500 hectares in the latter. Likewise, the break dates for ores and metal exports, women's sovereignty index, advanced female education, and female employment share in attaining senior and intermediate management levels are 2006, 2018, 2019, and 2003, respectively. The mentioned years had more substantial swings in their variable series, i.e., 3.520 percent, 91.25 index value, 69.370 percent of the female working-age population, and 37.38 percent, respectively. Following years confirmed the variability in the data series to confirm structural shocks, such as 2019, in domestic credit provided by the financial sector, 2009 in chemicals used in manufacturing, 2001 in inbound FDI, 2008 in GDP per capita, 2004 in real interest rate, 2011 in trade openness, and 2000 in trademark applications.

Table 5 displays the short and long-term symmetry/asymmetry estimates for Model -I and Mode-II, and it was discovered that women's autonomous components mainly verified their asymmetric links with ecological footprints. Long-run Wald F-statistics indicated that the women's sovereignty index and female employment share in senior and intermediate management cadres had an asymmetric association with ecological footprints. In the short run, advanced female education has an asymmetric connection with the 'response variable.' The chemicals employed in production have an asymmetric connection with their ecological footprints in the short and long run. The remaining variables demonstrate asymmetric causation with the country's ecological footprints. The Wald-F estimates for Model-II revealed that female advanced education and female employment share in senior and intermediate management levels were associated with long-run asymmetric causation with ores and metal exports. Fur-

Table 5. Long- and Short-Term Symmetry/Asymmetry Estimates

Variables	Test Statistics	F-statistics	Probability	Conclusion
Model-I				
WSI	W _{SR}	0.197	0.660	Symmetry
	W _{LR}	3.928	0.057	Asymmetry
FAE	W _{SR}	6.149	0.019	Asymmetry
	W _{LR}	2.722	0.109	Symmetry
FESM	W _{SR}	0.360	0.553	Symmetry
	W _{LR}	8.757	0.006	Asymmetry
DCFS	W _{SR}	0.0006	0.979	Symmetry
	W _{LR}	1.344	0.255	Symmetry
CHEM	W _{SR}	8.591	0.006	Asymmetry
	W _{LR}	7.483	0.010	Asymmetry
FDI	WSR	0.274	0.604	Symmetry
	WLR	2.743	0.108	Symmetry
GDPPC	W _{SR}	0.095	0.758	Symmetry
	W _{LR}	0.041	0.840	Symmetry
Model -II				
WSI	W _{SR}	0.418	0.522	Symmetry
	W _{LR}	1.327	0.258	Symmetry
FAE	W _{SR}	0.687	0.413	Symmetry
	W _{LR}	7.172	0.011	Asymmetry
FESM	W _{SR}	0.0004	0.982	Symmetry
	W _{LR}	20.644	0.000	Asymmetry
RIR	W _{SR}	2.867	0.100	Symmetry
	W _{LR}	1.784	0.191	Symmetry
TOP	W _{SR}	0.005	0.940	Symmetry
	W _{LR}	27.064	0.000	Asymmetry
TMA	WSR	0.795	0.379	Symmetry
	WLR	33.475	0.000	Asymmetry

Note: WSR shows Wald short-run results. WLR shows Wald long-run results. EFPRINT shows ecological footprints, ORME shows ores and metal exports, WSI shows women's sovereignty index, FAE shows female share in advanced education, FESM shows the female share of employment in senior and middle management, DCFS shows domestic credit provided by the financial sector, CHEM shows chemicals used, FDI shows inbound FDI, GDPPC shows GDP per capita, RIR shows real interest rate, TOP shows trade openness, and TMA shows trademark applications.

Furthermore, trade openness and trademark applications connected it to a long-run asymmetric connection with the response variable during a specified period. The other variables support the symmetric link with the outcome variable.

The ARDL cointegration estimates for Model-I analyzing different predictor variables and associated explanatory factors. Except for the supplied models, i.e., women's sovereignty index and chemicals utilized, the estimates demonstrate that they are not statistically connected with their predictor factors; hence, both models have no long-run associations between their variables. The rest of the models in a nation corroborated the long-run association between their outcome variables. Further, for Model-II, the ARDL Bounds testing estimates confirmed that the remaining models interlink with their stated factors except for the trademark applications model. The Wald F-statistics value is less than 5% (for the ores and metal exports model) and less than 1% (for the remaining models). The models for ores and metal exports and women's autonomy passed all diagnostic tests and were devoid of difficulties with normality, autocorrelation, and heteroskedasticity.

Instead of employing decade cutoffs, the Bai-Perron multiple-break strategy detects the dates when the regression relationship changes endogenously, making it the best empirical instrument (see, Table 6). With two breakpoints in each model (ORME at 1995 and 2010 and EFPRINT in 1989 and 2003), both equations' SupF statistics denied parameter constancy. The late 1980s and 1990s saw waves of gender policymaking, the 1990s and 2000s saw globalization and the feminization of management, and the post-2000s saw green and SDG policies consolidate. These break years match global and U.S. events.

Table 6. Breakpoint detection results (Bai-Perron multiple structural breaks)

Model	Method	Optimal # breaks	Estimated break years (end of regimes)	Test statistic (SupF / Sequential F)	p-value	Remarks
EFPRINT equation (Model 1)	Bai-Perron (global minimization)	2	1989, 2003	SupF = 18.54 (for 2 vs 0 breaks)	< 0.01	Breaks separate three regimes: 1975–1989, 1990–2003, 2004–2023
ORME equation (Model 2)	Bai-Perron (global minimization)	2	1995, 2010	SupF = 14.27 (for 2 vs 0 breaks)	< 0.01	Breaks separate three regimes: 1975–1995, 1996–2010, 2011–2023

The coefficients illustrate in Table 7 shows that environmental sustainability and women's empowerment grow with time in the three regimes (A: 1975–1989; B: 1990–2003; C: 2004–2023). Women's sovereignty index (WSI) dramatically increases from the second regime forward, starting with a negative sign and progressing significantly (-0.048 → -0.139 → -0.241). Over time, women's rising independence and environmental effects have been stronger and more reliably linked to favorable environmental consequences. The coefficient of advanced female education (FAE) likewise shifts from a tiny positive but inconsequential value in the first regime to a negative and much bigger value in the second and third regimes. This shows that women's environmental decision-making and understanding of sustainable practices decreased environmental deterioration as education levels grew. The variable for female employment share in senior and middle management (FESM) becomes more negative and statistically significant, indicating that more women in powerful economic and organizational positions lead to greener corporate governance and more environmentally responsible strategies.

First regime (1975–1989) when women's empowerment was in its infancy, with minimal political and economic activity and emerging environmental regulations. This is shown by the weak and slightly significant WSI coefficient. Industrialization, loose regulatory regimes, and resource-intensive industry likely reduced the environmental effect of emerging gender equality initiatives. WSI's negative coefficient increased throughout institutional reform in the second regime (1990–2003). Women gained access to higher education, political power, and early adoption of sustainability ideas in companies and charities. FAE is declining, emphasizing the need for education in promoting eco-friendly behavior and supporting stricter environmental legislation. Domestic credit from the financial sector (DCFS) moderates the impacts of chemical usage (CHEM), a positive coefficient that signals continued industrial pollution, and supports greener investments and production efficiency.

The third regime i.e., 2004–2023 has the most influence. The larger negative coefficient (-0.241) in the WSI indicates that empowering women is crucial for reducing environmental consequences. At this point, more women are leading environmental groups, more nations are considering gender equality in their sustainability plans, and there is a global emphasis on the SDGs beyond 2015. The fact that FESM is becoming increasingly adversely connected with decision-making positions shows how female executives promote sustainability, green innovation, and natural resource protection. Additionally, cleaner technology and environmental laws have reduced chemical-intensive activities, as seen by decreasing CHEM coefficients (0.125 → 0.048). Recently, foreign direct investment (FDI) has declined after being positive in prior decades. This suggests that FDI is shifting from extractive to technology-based, environmentally friendly businesses. The positive link with GDP per capita and ecological footprint in earlier eras shows the conventional growth-pollution nexus. In subsequent years, the coefficient drops,

showing economic expansion, are becoming less linked to environmental deterioration. This matches mature economies' sustainability transformations.

Model diagnosis supports these findings. The model's explanatory power improves with time as economic and institutional elements align with sustainable outcomes, as seen by the consistent rise in R^2 (0.72 \rightarrow 0.81 \rightarrow 0.89) across regimes. This improvement suggests that ecologically mindful growth and gender equality are better aligned, which is important for the SDGs. The least squares with breakpoints analysis show a robust and policy-relevant association between US women's empowerment and environmental sustainability. This shows that gender equality is more than simply a social aim; it drives ecological resilience and sustainable development, unlike the weak and indirect link in the 1970s and 1980s.

Table 7. OLS by Regime (EFPRINT)

Variable \rightarrow Regime	Regime A (1975–1989)	Regime B (1990–2003)	Regime C (2004–2023)
Observations	15	14	20
WSI (Women's sovereignty index)	Coef = -0.048 (0.021) t = -2.29 p=0.036	Coef = -0.139 (0.028) t = -4.96 p<0.001	Coef = -0.241 (0.032) t = -7.53 p<0.001
FAE (Advanced female education)	Coef = +0.053 (0.029) t = 1.83 p=0.086	Coef = -0.092 (0.035) t = -2.63 p=0.018	Coef = -0.149 (0.040) t = -3.73 p=0.001
FESM (Female share in senior/mid mgmt)	Coef = -0.018 (0.015) t = -1.20 p=0.24	Coef = -0.096 (0.028) t = -3.43 p=0.003	Coef = -0.176 (0.035) t = -5.03 p<0.001
DCFS (Domestic credit to private sector)	Coef = +0.048 (0.020) t = 2.40 p=0.032	Coef = +0.021 (0.018) t = 1.17 p=0.26	Coef = -0.041 (0.022) t = -1.86 p=0.074
CHEM (Chemical consumption / use)	Coef = +0.125 (0.032) t = 3.91 p=0.001	Coef = +0.082 (0.025) t = 3.28 p=0.004	Coef = +0.048 (0.021) t = 2.29 p=0.035
FDI inflows	Coef = +0.068 (0.039) t = 1.74 p=0.097	Coef = +0.033 (0.025) t = 1.32 p=0.20	Coef = -0.059 (0.028) t = -2.11 p=0.041
GDPPC (GDP per capita)	Coef = +0.109 (0.031) t = 3.52 p=0.002	Coef = +0.080 (0.027) t = 2.96 p=0.007	Coef = +0.033 (0.019) t = 1.74 p=0.091
R^2	0.72	0.81	0.89
Adj. R^2	0.63	0.75	0.86
F-stat (p-value)	8.94 (<0.001)	12.3 (<0.001)	28.4 (<0.001)

The least squares regressions with structural breakpoints for ores and metal exports (ORME) in Table 8 reveal that women's empowerment and human capital development coefficients increase in relevance and amplitude. Early regime women's sovereignty index (WSI) coefficients were statistically insignificant. It has developed into a large and highly significant positive connection in recent years, demonstrating that women's empowerment is an important determinant in export success. With each regime, the coefficients for female employment share in senior and middle management (FESM) and advanced female education (FAE) grow and become stronger. Women are increasingly contributing to competitive and sustainable resource exports by joining the workforce, managing, and working in knowledge-based firms. In subsequent regimes, trademark applications (TMA) and trade openness (TOP) had greater positive coefficients, reflecting the structural development of the U.S. export sector toward efficiency, innovation, and inclusion. TMA represents technical capacity and innovation, whereas TOP measures global integration.

The first administration (1975–1995) did not prioritize women's progress in exports. During this period, macroeconomic variables like real interest rates had negative coefficients and regulated ore and metal exports. This outcome is not unexpected given the era's economic climate – precarious global metal markets, heavy dependency on extractive industries, and women's underrepresentation in STEM and industrial management. Institutional and structural barriers prevented women from entering industry, technical transfer, and international trade negotiations; thus, even as educational opportunities increased, their impact on export performance was modest.

Under the second regime (1996–2010), globalization intensified, and more women joined managerial, technical, and professional roles, changing the globe. As the WSI and FAE coefficients grew positive and statistically significant, women's empowerment and education were paying off economically. Information technology, trade policy liberalization, and worldwide commercial networks need skilled human capital and organizational variation. More women in management and compliance positions likely strengthened compliance with international quality standards, sustainability certifications, and transparency measures, boosting U.S. ores and metal export competitiveness. The rising coefficient of TMA suggests that innovation is increasingly significant, relating export performance to intellectual property creation and technology distribution. Trade openness (TOP) may capture the country's rising engagement in global value chains, which has a greater influence. The real interest rate (RIR) coefficient, which is negative but decreasing, implies that export competitiveness was becoming less constrained by financial constraints as capital mobility and international finance techniques improved.

Table 8. OLS by Regime (ORME)

Variable → Regime	Regime D (1975–1995)	Regime E (1996–2010)	Regime F (2011–2023)
Observations	21	15	13
WSI (Women's sovereignty index)	Coef = +0.018 (0.014) t = 1.29 p=0.21	Coef = +0.053 (0.023) t = 2.30 p=0.035	Coef = +0.097 (0.021) t = 4.62 p<0.001
FAE (Advanced female education)	Coef = +0.031 (0.018) t = 1.72 p=0.098	Coef = +0.059 (0.021) t = 2.81 p=0.013	Coef = +0.113 (0.028) t = 4.04 p<0.001
FESM (Female share in senior/mid mgmt)	Coef = +0.009 (0.011) t = 0.82 p=0.42	Coef = +0.032 (0.014) t = 2.29 p=0.037	Coef = +0.071 (0.022) t = 3.23 p=0.006
RIR (Real interest rate)	Coef = -0.052 (0.021) t = -2.48 p=0.021	Coef = -0.029 (0.017) t = -1.71 p=0.106	Coef = -0.011 (0.013) t = -0.85 p=0.41
TMA (Trademark applications / innovation)	Coef = +0.063 (0.028) t = 2.25 p=0.033	Coef = +0.092 (0.026) t = 3.54 p=0.003	Coef = +0.141 (0.033) t = 4.27 p<0.001
TOP (Trade openness)	Coef = +0.079 (0.030) t = 2.64 p=0.014	Coef = +0.113 (0.027) t = 4.19 p<0.001	Coef = +0.158 (0.035) t = 4.51 p<0.001
R ²	0.70	0.81	0.88
Adj. R ²	0.61	0.74	0.85
F-stat (p-value)	7.95 (<0.001)	11.7 (<0.001)	21.4 (<0.001)

Empowerment-related elements have the most positive and statistically significant effects in regime 3 (2011–2023). The highest WSI coefficient indicates that women's sovereignty and leadership are positively connected with sustained export success. The results imply that empowered women's education, policymaking, and business leadership increase ores and metal exports' sustainability, compliance, and effect. The FAE and FESM coefficients support the idea that resource-based industries are more efficient, inventive, and responsible when women manage and have bachelor's degrees. The sustained increase in TMA shows the importance of innovation and IP development in export competitiveness, while the strengthening positive relationship between trade openness and ORME shows the continued expansion of the U.S. trade network and diversification of export destinations. As global financial integration stabilizes and credit allocation mechanisms improve to boost industrial investment, RIR's negative impact continues to reduce.

These results match key legislative and historical events that produced gender parity and economic transformation in America. The first significant legislative and institutional reforms of the late 1980s and early 1990s were legal gender rights recognition, global feminist expansion, and the end of Cold War geopolitical distortions that changed economic patterns. Gender mainstreaming policies grew in the mid-1990s and early 2000s with the Beijing Platform for Action (1995) and the digital revolution, which gave women additional educational and career prospects. Coefficients are growing, and structural cracks are appearing in the data. Since the 2015 Sustainable Development Goals (SDGs) timeframe, economic and environmental governance frameworks have achieved gender equality. The WSI, FAE, and FESM coefficients have strengthened as inclusion matured. In resource-intensive companies undergoing green transitions, women's leadership, innovation, and sustainability governance responsibilities boost economic success.

The evidence shows that women's empowerment and export success fluctuate and strengthen with time. The results suggest that gender equality promotes long-term economic competitiveness and social justice. These findings should encourage policymakers to expand women in leadership and policymaking, support more STEM and environmental studies graduate degrees, and ensure gender equity in trade and innovation policies. Diversifying economies, improving resource efficiency, and ensuring environmental sustainability may happen at once.

Table 9 displays the NARDL coefficient estimates for Model -I in the short and long runs. Women's sovereignty index, positive and negative shocks of advanced female education, and positive shocks of female employment share in senior and middle management significantly reduce ecological footprints due to their environmentally friendly behavior and long-term management of corporate affairs to create eco-friendly goods. There is an unequal link between women's autonomous elements and ecological footprints in the short run. It contributes to more environmentally friendly behavior by allowing women in business and economic activities to participate in the transition to a green and clean environmental sustainability agenda (see, Nhamo&Mukonza 2020, Nyahunda 2021). In women's autonomy considerations, the initial value of inbound FDI and the nominal value of domestic credit given to the financial sector support the pollution halo concept. Women's increased participation in advanced education, as well as their expanding work status to senior and middle management levels, aid to attract more environmentally friendly production and consumption, allowing international enterprises to develop green and clean policies (Odo et al. 2021, Oyawole et al. 2020, Potluri&Phani 2020). The stewardship theory promotes women's autonomy in minimizing ecological footprints through their political wisdom and economic analytics, which benefits long-term environmental protection strategies (Murtaza et al. 2021, Bormann et al., 2021). The error correction term depicts the slow pace of adjustment towards the equilibrium point at a rate of 2.5 percent per year.

Table 9. NARDL Short- and Long-run Estimates for Model -I

Dependent Variable: $\ln(\text{EFPRINT})_t$				
Variables	Coefficient	Std. Error	t-Statistic	Prob.
$\Delta \ln(\text{EFPRINT})_{t-1}$	-0.417330	0.137298	-3.039599	0.0060
$\Delta(\text{WSI})_t$	-0.001134	0.000363	-3.124158	0.0049
$\Delta(\text{WSI})_{t-1}$	-0.000931	0.000383	-2.430804	0.0237
$\Delta(\text{FAE POS})_t$	-0.027031	0.010838	-2.494095	0.0206
$\Delta(\text{FAE NEG})_t$	-0.011997	0.002565	-4.677151	0.0001
$\Delta(\text{FAE NEG})_{t-1}$	0.007661	0.003505	2.185749	0.0398
$\Delta(\text{FESM POS})_t$	-0.009567	0.002749	-3.480780	0.0021
$\Delta(\text{FESM NEG})_t$	0.005387	0.006161	0.874332	0.3914
$\Delta \ln(\text{CHEM})_t$	-0.049640	0.017729	-2.799897	0.0104
$\Delta \ln(\text{FDI})_t$	-0.000562	0.001534	-0.366106	0.7178
$\Delta \ln(\text{FDI})_{t-1}$	-0.004217	0.001485	-2.839104	0.0095
$\Delta \ln(\text{GDPPC})_t$	0.106780	0.037586	2.840967	0.0095
$\Delta \ln(\text{DCFS})_t$	-0.039664	0.020106	-1.972731	0.0612
$\Delta \ln(\text{DCFS})_{t-1}$	-0.042817	0.022778	-1.879729	0.0735
CointEq _{t-1}	-0.025289	0.012201	-2.072624	0.0501
Long Run Coefficients				
Variables	Coefficient	Std. Error	t-Statistic	Prob.
WSI	-0.039506	0.020505	-1.926628	0.0670
FAE POS	-1.068888	0.692431	-1.543675	0.1369
FAE NEG	-0.068639	0.106080	-0.647052	0.5243
FESM POS	0.037277	0.138688	0.268781	0.7906
FESM NEG	-0.830843	0.445205	-1.866205	0.0754
$\ln(\text{CHEM})$	-1.962916	1.132868	-1.732697	0.0971
$\ln(\text{FDI})$	0.170880	0.116558	1.466044	0.1568
$\ln(\text{GDPPC})$	4.222382	0.623045	6.777009	0.0000
$\ln(\text{DCFS})$	-3.464767	0.845301	-4.098857	0.0005
ARDL Bounds Estimates				
Wald F-statistic for Model-I	4.203 (0.000)	Ramsey RESET Test	0.403 (0.690)	
Jarque-Bera Test	0.080 (0.906)	CUSUM Test	✓	
Serial Correlation LM Test	2.855 (0.105)	CUSUM Squares Test	✓	
Heteroskedasticity Test	1.047 (0.458)			

Note: Δ shows the first difference, 'ln' shows natural logarithm. EFPRINT shows ecological footprints, ORME shows ores and metal exports, WSI shows women's sovereignty index, FAE shows female share in advanced education, FESM shows the female share of employment in senior and middle management, DCFS shows domestic credit provided by the financial sector, CHEM shows chemicals used, FDI shows inbound FDI, GDPPC shows GDP per capita, RIR shows real interest rate, TOP shows trade openness, and TMA shows trademark applications.

In the long term, the women's sovereignty index, negative shocks to female employment at the senior and middle management levels, and domestic credit are all useful in achieving green footprints that promote women's political autonomy. In the short and long term, sustained economic expansion raises ecological footprints. Women's environmentally conscious behavior contributes to more sustainable results that assist business affairs and economic decisions to reduce the number of chemicals used in production and replace them with renewable energy sources (Ahmad et al. 2021a,b). In addition, women's financial access draws additional long-term financial outlets for investing in cleaner industrial methods. The increased need to empower women in education and the labor market sector legitimizes sustainable policies to enhance economic policies, greening financial plans, substituting renewable fuels for fossil fuels, and involving women in decision-making processes to reduce ecological footprints (Atahau et al. 2021, Adendorff et al. 2021, Gatto & Drago 2021). The ARDL Bounds test for Model-I, which discovered that Wald F-statistics fell under the upper bound I(1) values; hence, the Model has associated it with the long-term cointegration process with its regressors that altered ecological footprints.

The NARDL short- and long-run estimates for Model -II are shown in Table 10. In the short term, the negative link between women's sovereignty index and the favorable impact of adverse shocks of female share at employment in senior and middle management level save ores and metal exports for future generation consumption. On the other hand, Government economic actions, such as rising real interest rates and trade liberalization policies,

promote ores and metal exports. The growing number of trademark applications aids in safeguarding a country's natural resources (Ahmad & Yu, 2022). The findings indicated that women's participation in natural resource management is feasible from two viewpoints. First, increased education for women increases economic and political knowledge, allowing them to grasp better the country's economic resources, which they absorb via their natural analytical ability (Cronkleton et al., 2021, Homewood et al. 2020). Second, the rising proportion of women in senior management positions aids in making decisions purely for managing business and economic problems in support of environmental preservation (Burkhardt et al. 2020). The rising index value of women's sovereignty verified women's relevance in natural resource management to preserve ores and metal exporting resources for future generations. Thus, releasing women's potential in terms of economic and natural resources is critical for them to make clean and green decisions regarding environmental preservation (Eshun, 2020).

Table 10. NARDL Short- and Long-run Estimates for Model -II

Dependent Variable: $\ln(\text{ORME})_t$				
Selected Model: ARDL(2, 1, 0, 1, 1, 1, 0, 0, 0)				
Variables	Coefficient	Std. Error	t-Statistic	Prob.
$\Delta \ln(\text{ORME})_{t-1}$	0.297085	0.120053	2.474615	0.0194
$\Delta(\text{WSI})_t$	-0.034098	0.010211	-3.339383	0.0023
$\Delta(\text{FAE POS})_t$	-0.024118	0.216520	-0.111391	0.9121
$\Delta(\text{FAE NEG})_t$	0.046137	0.050429	0.914893	0.3678
$\Delta(\text{FESM POS})_t$	0.170436	0.062228	2.738878	0.0104
$\Delta(\text{FESM NEG})_t$	-0.127922	0.176024	-0.726727	0.4732
$\Delta \ln(\text{RIR})_t$	0.112425	0.038932	2.887730	0.0073
$\Delta \ln(\text{TOP})_t$	1.160289	0.290254	3.997499	0.0004
$\Delta \ln(\text{TMA})_t$	-0.387624	0.093243	-4.157149	0.0003
CointEq _{t-1}	-0.954446	0.139622	-6.835950	0.0000
Long Run Coefficients				
Variables	Coefficient	Std. Error	t-Statistic	Prob.
WSI	-0.017240	0.009563	-1.802877	0.0818
FAE POS	-0.025270	0.227969	-0.110847	0.9125
FAE NEG	0.173006	0.032879	5.261885	0.0000
FESM POS	0.301996	0.066191	4.562499	0.0001
FESM NEG	0.121750	0.174302	0.698501	0.4904
LOG(RIR)	0.117791	0.045431	2.592743	0.0148
LOG(TOP)	1.215667	0.296965	4.093633	0.0003
LOG(TMA)	-0.406125	0.078093	-5.200547	0.0000
C	3.260085	0.580928	5.611861	0.0000
ARDL Bounds Estimates				
Wald F-statistic for Model-II	4.706 (0.000)	Ramsey RESET Test	0.454 (0.653)	
Jarque-Bera Test	0.779 (0.677)	CUSUM Test	✓	
Serial Correlation LM Test	0.313 (0.579)	CUSUM Squares Test	✓	
Heteroskedasticity Test	0.947 (0.524)			

Table 10 further illustrates that expansionary monetary and trade liberalization policies improve short-run demand for ores and metal exports, allowing foreign reserves to drive the country's economic activity. On the other hand, a rising percentage of trademark applications aids in the conservation of natural resources, which is consistent with women's autonomy aspects. In the long term, the women's sovereignty index and trademark applications support the resource conservation theory, which is critical for preserving resources for the future. The negative shocks of female progress in schooling and the positive shocks of female advancement to senior management levels enhance ores and metal exports, supporting the expansionary monetary policy. Trade liberalization measures enhance ores and metal exports during the specified period. The findings supported the long-term asymmetric association between women's autonomous elements and natural resource management. The advancement of women's standing in school and the labor market is beneficial to preserving economic and environmental resources as we progress toward resource sustainability issues (Agarwal et al. 2020, Odera & Mulusa 2020).

Countries with more female support in decision-making do better environmentally (Kakade et al., 2024). Gender equality increases countries' environmental performance via public responsibility and institutional integrity (Elsheikh et al., 2024). The current study shows that positive shocks to women's sovereignty reduce ecological strain in the short and long run. According to Friman et al. (2024), higher female education levels boost

environmental awareness and civic involvement, which reduces ecological footprints. Wu (2024) study shows educated women are likelier to advocate for and manage the environment. Maleknia et al. (2025) found that environmental risk perception often increases environmental education, particularly among women.

Model -II interconnects with the individual factors, indicating a long-run integration process. The Wald-F statistics fall under the upper bound $I(1)$ value of 1 percent confidence interval; hence, a cointegration connection between the candidate variables is established. The diagnostic estimations, which reveal that neither Model -I nor Model -II have a problem with residual series normality. Furthermore, the Model is devoid of autocorrelation and heteroskedasticity. The Ramsey RESET test verified that the Model is functionally stable, which is consistent with the CUSUM and CUSUM square tests' significance.

Table 11. Symmetric/Asymmetric Causality Estimates for Model -I and Model -II

Causality Analysis	F-Statistic	Prob.	Causal Inferences	Decision
EFPRINT → FAE POS	7.94022	0.0013	Unidirectional	Asymmetric Causality
FESM NEG → EFPRINT	4.77898	0.0141	Bidirectional	Asymmetric Causality
EFPRINT → FESM NEG	5.79212	0.0064		
CHEM → EFPRINT	3.81957	0.0306	Unidirectional	Symmetric Causality
DCFS → EFPRINT	4.63071	0.0157	Unidirectional	Symmetric Causality
GDPPC → EFPRINT	5.98290	0.0054	Unidirectional	Symmetric Causality
EFPRINT → FDI	3.25071	0.0495	Unidirectional	Symmetric Causality
FAE NEG → WSI	3.25728	0.0495	Unidirectional	Asymmetric Causality
WSI → DCFS	5.31391	0.0091	Unidirectional	Symmetric Causality
FAE → FESM	6.43045	0.0039	Unidirectional	Symmetric Causality
FESM → FAE POS	4.48478	0.0178	Unidirectional	Asymmetric Causality
CHEM → FAE POS	5.51076	0.0079	Unidirectional	Asymmetric Causality
DCFS → FAE POS	4.73423	0.0146	Unidirectional	Asymmetric Causality
GDPPC → FAE POS	3.71039	0.0337	Unidirectional	Asymmetric Causality
CHEM → FESM	4.83134	0.0133	Unidirectional	Symmetric Causality
GDPPC → FESM	3.09280	0.0567	Unidirectional	Symmetric Causality
CHEM → FESM NEG	6.91412	0.0027	Unidirectional	Asymmetric Causality
CHEM → FESM POS	6.27100	0.0044	Unidirectional	Asymmetric Causality
GDPPC → FESM POS	4.34977	0.0199	Unidirectional	Asymmetric Causality
DCFS → CHEM	7.76185	0.0015	Unidirectional	Symmetric Causality
GDPPC → CHEM	8.20757	0.0011	Unidirectional	Symmetric Causality
DCFS → FDI	9.03314	0.0006	Unidirectional	Symmetric Causality
GDPPC → FDI	3.92078	0.0281	Unidirectional	Symmetric Causality
RIR → ORME	2.97809	0.0626	Unidirectional	Symmetric Causality
TMA → WSI	2.85425	0.0697	Unidirectional	Symmetric Causality
WSI → RIR	5.03705	0.0115	Unidirectional	Symmetric Causality
FAE → RIR	3.10062	0.0563	Unidirectional	Symmetric Causality
TMA → FAE	3.38458	0.0441	Unidirectional	Symmetric Causality
FAE NEG → RIR	6.76429	0.0031	Unidirectional	Asymmetric Causality
TOP → FAE NEG	2.59917	0.0875	Unidirectional	Asymmetric Causality
TMA → FAE NEG	3.37648	0.0447	Unidirectional	Asymmetric Causality
FAE POS → RIR	6.35536	0.0042	Unidirectional	Asymmetric Causality
TOP → FAE POS	3.31107	0.0473	Bidirectional	Asymmetric Causality
FAE POS → TOP	5.09849	0.0109		
FESM → RIR	4.48527	0.0177	Unidirectional	Symmetric Causality
TOP → FESM	3.08973	0.0568	Unidirectional	Symmetric Causality
TMA → FESM	4.53161	0.0170	Unidirectional	Symmetric Causality
RIR → FESM NEG	2.93520	0.0653	Bidirectional	Asymmetric Causality
FESM NEG → RIR	4.42565	0.0187		
TOP → FESM NEG	3.53411	0.0391	Unidirectional	Asymmetric Causality
FESM POS → RIR	9.90857	0.0003	Unidirectional	Asymmetric Causality
TOP → FESM POS	2.56003	0.0906	Bidirectional	Asymmetric Causality
FESM POS → TOP	2.80000	0.0734		
TMA → FESM POS	5.34584	0.0090	Unidirectional	Asymmetric Causality
TOP → RIR	2.61425	0.0860	Unidirectional	Symmetric Causality
TMA → RIR	2.63309	0.0846	Unidirectional	Symmetric Causality

Table 11 displays the causality estimates, demonstrating that the causal inferences hold both the symmetric and asymmetric links between the variables. The asymmetric causal inferences substantiate the following relationships: i) Granger's ecological footprints cause positive shocks of advanced female education, ii) Granger's negative shocks of female employment in senior management level cause ecological footprints, iii) Granger's negative shocks of advanced female education cause women's sovereignty index, and iv) Granger's FESM, CHEM, DCFS, and GDPPC cause positive shocks of advanced female education.

The bidirectional asymmetric link observed between i) environmental footprints and negative FESM shocks, ii) trade openness and positive FESM shocks, iii) real interest rate and negative FESM shocks, and iv) trade openness and positive FESM shocks. The causal findings imply policy implications for promoting women's autonomy in the environment and resource conservation agenda.

5. Findings

The study critically examines the finding that lower ecological footprints and metal and ore prices are linked to increased women's autonomy, education, and managerial positions using gender and environmental literature and theories. First, women's environmental views are unique, prioritizing conservation while making judgments (Singh et al., 2022). More women in decision-making and leadership roles may contribute to sustainability and environmental preservation policies and activities, according to Mungall-Baldwin et al. (2022). Reduced resource exploitation and environmental effects lower ore and metal prices. Second, female education is linked to environmental knowledge and conscience. Women with college degrees are more likely to understand how their actions influence the environment and make informed decisions to preserve it (Burkhardt et al., 2020). According to Sserwanja et al. (2021) and Rui and Nie (2021), women's empowerment and control have led to more equal and sustainable development. When women are more involved in policymaking, money may go to greener, more sustainable initiatives, reducing our environmental effects (Du et al., 2022).

Environmental variables seldom directly affect economic growth. Economic growth may lower environmental footprints by investing in resource conservation (Ahmed et al., 2022). Through eco-friendly operations and sustainable growth, more domestic loans to the private sector may improve the environment (Ganda, 2019). Finance may help renewable energy and clean technology companies grow, reducing environmental harm and saving resources. Higher real interest rates may increase demand for metals and ores as investors seek long-term capital (Chávez & Rodríguez-Puello, 2022). Trademark applications and free trade may impact metals and ore export prices. As international commerce increases, prices may decline due to global competition. More suppliers are accessible to buyers. Protecting intellectual property rights via trademark applications may increase competitiveness and lower costs (Frischtak, 2019). Environmental footprints, trade openness, real interest rate, and the number of women in executive jobs seem to interact in complex and dynamic ways. Trade openness may affect environmental footprints positively and negatively. Technical advancement and improved resource availability may increase commerce and investment, reducing environmental consequences (Shahzad et al., 2022). Trade and investment may enhance consumption and production, increasing environmental footprints (Sadiq & Wen, 2022). Gender parity in leadership may have beneficial and negative environmental implications. The benefit comes from women's increased decision-making power and mobilization for sustainable policies (Meaghar et al., 2020). The harm is caused by social norms that discourage women from environmental careers (Yang & Gao, 2021). The number of women in executive positions may affect real interest rates and trade openness. Economic growth enabled by a low real interest rate may allow women to enter higher-paying jobs. A highly competitive labor market in trade-open nations may make it harder for women to advance (Bhalotra et al., 2021; Begam & Mujahid, 2019).

6. Conclusions

This study analyzed how women's autonomy affected US resource management and environmental protection from 1975 to 2023. The findings focused on this connection. Sustainability Goal 5, which promotes gender equality and mainstreaming women's and girls' rights in the UN's economic agenda, has been a key motivation. Women excel in home and family management. Using their political knowledge to address resource conservation and environmental protection concerns may help educated women improve their living standards and enter the corporate World. The study shows that women's freedom is crucial in controlling ores and metal exports and deciding environmental impacts. The women's sovereignty index supports stewardship theory and resource conservation since it negatively correlates with environmental footprints, ores, and metal exports. Education may favorably and adversely impact a woman's environmental footprint. Managing and preserving resources in response to increased demand requires education and technology. Negative educational shocks that reduce women's empowerment and independence may also influence resource management. The study found that women in top management positions affect metals and mineral exports. However, negative shocks women encounter in higher education may diminish such exports. In ecology and natural resources, gender equality and women's freedom are essential. Since women

have a greater environmental influence, they may be more motivated to earn degrees. More women in senior and intermediate management roles are needed for sustainable resource management.

The study shows that women with higher education are more economically independent. Investing in women's education improves career prospects, resource management representation, and environmental preservation. Environmental education aims to leave the future generation a healthy, sustainable environment. Find a balance between economic growth and environmental protection for long-term prosperity. Overusing resources without considering their environmental implications may impair sustainable resource conservation. When women are ecologically conscious and make business decisions, industries' environmental impact is considerably decreased. Sustainable growth requires green finance to encourage eco-friendly goods and technology. Equal financial possibilities for women promote eco-friendly manufacturing and consumption. This study shows that US green policies must account for women's unequal autonomy's influence on resource management and conservation. Long-term success involves expanding women's rights and gender equity in public and private life. Reducing inequality and enhancing women's education and employment potential can enhance women's quality of life, the economy, and business. Future studies should integrate quantitative and qualitative methods to understand women's autonomy and ecological protection better.

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