Global Renewable Energy Transition - Issues and Options

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***Abstract*—The global renewable energy transition is advancing rapidly yet unevenly, with 2024–2025 witnessing record additions of 585 GW in renewable capacity—92.5% of all new power generation—driven by cost declines, technology innovation, and policy commitments, such as the 28th session of the Conference of the Parties (COP28) target to triple capacity by 2030. However, this pace remains insufficient to align with the 1.5 °C pathway, as persistent reliance on fossil fuels, grid bottlenecks, financing constraints, and policy reversals—most notably in the United States impede progress. This paper adopts a comparative policy review approach, synthesizing recent global and regional developments to highlight both structural advances and systemic barriers. China's unprecedented solar and wind deployment contrasts with under-utilization due to curtailment and storage gaps, while South Asia exhibits diverse trajectories shaped by infrastructure readiness and institutional capacity. Emerging trends, including long-duration energy storage, circular-economy energy recovery, and monetization of surplus renewables through digital economies demonstrate innovation potential but also raise governance challenges. Policy options identified include phasing out fossil subsidies, coordinating grid expansion with capacity growth, and integrating decentralized systems for equitable access. Achieving a just and resilient energy transition will require synchronized technological, financial, and policy measures to ensure benefits are globally inclusive.**

Keywords- renewable energy, energy transition, climate change, sustainability, electrification, policy, innovation, finance.

I. INTRODUCTION

The global energy landscape is at a critical juncture as rising concerns over climate change and energy security catalyze a trans-formative shift from fossil fuels to renewable energy sources. Despite record global CO2 emissions and temperatures already 1.2°C above pre-industrial levels, efforts to accelerate the adoption of solar, wind, hydropower, and modern bio-energy technologies have been notable [1][2]. In 2023, renewables accounted for 30% of electricity generation worldwide, with capacity additions reaching an unprecedented 473 GW, reflecting a 36% year-on-year growth [3]. However, this progress remains insufficient to meet the ambitious international climate goals, as fossil fuels still dominate total energy consumption and installed renewable capacity falls short of the 11.2 TW target needed by 2030 [4].

This paper addresses the critical trust deficit and gaps in the global renewable energy transition. While the expansion of renewables is undeniable, uneven regional progress and persistent reliance on traditional energy sources reveal structural challenges that must be overcome [5]. For instance, shifts in policy such as recent US reversion towards coal [6], and natural gas contrast with leadership from Europe and China, underscoring divergent political commitments worldwide [7]. Specifically, the emerging economies of Southeast Asia, including Pakistan, Bangladesh, Nepal, Thailand, and Indonesia, face unique hurdles in aligning energy development with sustainability [8].

Against this backdrop, the study asks how structural and policy gaps continue to restrict the global renewable energy transition, in what ways geopolitical and economic dynamics shape divergent regional pathways, and which innovative and inclusive strategies emerging economies can adopt to accelerate their transition while ensuring energy security.

This paper reviews global renewable energy trends, policy frameworks, and technological innovations while critically examining barriers to the transition, such as insufficient progress despite record growth and persistent regional disparities. It analyzes policy and investment shortcomings, diverse strategies shaped by geopolitics and economics, and technological pathways for scaling renewables, with a focus on inclusive approaches for emerging economies. By highlighting the need for integrated efforts that combine innovation, investment, policy support, and broad societal engagement, the study seeks to bridge knowledge and implementation gaps and provide strategic insights for aligning global climate action with energy security and accelerating the transition to a sustainable energy future.

Methodologically, the paper adopts a comparative policy review approach, drawing on survey, peer-reviewed literature, Institutional reports from the International Renewable Energy Agency (IRENA), International Energy Agency (IEA), Intergovernmental Panel on Climate Change (IPCC), the World Bank were reviewed, and policy documents from 2023–2025. Regional cases cover both advanced economies and emerging markets, This cross-regional synthesis highlights systemic barriers, uneven progress, and actionable pathways toward a just and coherent global energy transition.

The rest of the paper is structured as follows. Section II presents current global renewable energy trends and capacity developments. Section III discusses key transition challenges, focusing on policy and investment gaps. Section IV examines diverse transition strategies shaped by geopolitical and economic factors. Section V highlights innovative technologies driving renewable scale-up. Section VI addresses regional disparities and inclusive strategies for emerging economies. Finally, Section VII concludes with recommendations and future directions for global climate and energy security.

II. TRENDS IN RENEWABLE ENERGY DEVELOPMENTS

Regional trajectories in renewable energy deployment reveal both rapid expansions and persistent structural constraints, with sharp contrasts across leading economies. From 2012 to 2022, the renewable electricity shares exhibited growth across all major regions as shown in Figure 1 below, with Europe leading the transition by increasing its share from 30% to 42%, a gain of 12 %. North America and the Asia-Pacific regions both saw significant rises of 10 %, reaching 25% and 28%, respectively. Africa's renewable share grew from 17% to 24% with increase of 7 %, while Latin America and the Caribbean experienced a modest increase from 56% to 61% with 5% increment [9]. The Middle East and North Africa (MENA) region showed the smallest growth, from 2% to 5%, adding 3 %. This data illustrates a widespread global shift towards renewable energy, with Europe making the most substantial progress in increasing its renewable electricity share over the decade.

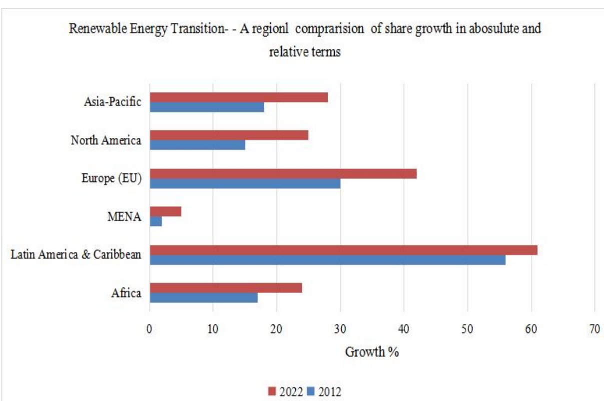

Figure 1. Regional Growth in Renewable Electricity (2012–2022).

China continued its unprecedented expansion of renewable energy in 2024 and early 2025, installing a record-breaking 277 GW of new solar capacity—a 45.2% increase that brought total solar capacity to 887 GW—alongside an 80 GW (18%) increase in wind power, pushing total wind capacity to nearly 521 GW [10]. This rapid growth has dramatically reshaped the country's energy profile, with solar power generation tripling in just five years, rising from 4.1% of total electricity generation in April 2020 to 12.4% by April 2025. For the first time in early 2025, China's combined wind and solar capacity surpassed coal and gas capacity, contributing nearly 23–26% of national electricity consumption [11]. However, the remarkable expansion in installed capacity has not been matched by proportional generation due to grid congestion, curtailment, and limited energy storage, while coal remains the backbone of China's baseload power supply [12]. This growing gap between capacity and actual generation underscores the complexities of managing such a large-scale energy transition and emphasizes the urgent need for grid modernization, power market reforms, and enhanced storage infrastructure to fully realize the benefits of clean energy investments.

European renewable energy deployment continued its steady progression in 2024, with the region increasing renewable electricity supply by 3.4% while coal-based generation declined by 10–14% [13]. This dual trend reflects Europe's continued commitment to energy transition despite economic uncertainties. Several European nations achieved particularly notable renewable energy shares in 2024: Denmark (≈88.4%), Portugal (≈87.5%), Croatia (≈73.7%), and Germany, which added 15.9 GW of solar capacity and generated 72.2 TWh of solar electricity—its first full year without nuclear power, with renewable supplying over 60% of electricity generation [14].

South Asian countries are pursuing diverse renewable energy pathways shaped by national priorities, institutional capacities, and energy needs. India awarded a record-breaking 59 GW of renewable capacity in 2024, more than double the previous year, bringing installed capacity to 209 GW toward its 2030 target of 500 GW. However, around 40 GW remain stalled due to transmission constraints and PPA delays [15][16]. Pakistan, while still heavily reliant on fossil fuels, diversified its energy mix: by 2024, low-carbon sources comprised about 47% of electricity generation, with 117,807 net-metering installations generating 1,822 MW of solar; the country targets 62% renewable by 2031 [17]. In contrast, Bangladesh remains in early stages, with just 1.56 GW (~4.5%) of capacity as of 2025, but targets 20% by 2030 and 30% by 2040, supported by over 6 million solar home systems [18].

Beyond South Asia, Southeast Asian countries exhibit a broad spectrum of renewable progress. Nepal stands out, deriving over 95% of its electricity from hydro power , with 3,000 MW installed and projects like Arun-3 and Upper Trishuli-1 aiming for 28,500 MW by 2035 [19]. Thailand installed more than 4 GW of solar in 2024 and is piloting floating solar and biomass co-firing under its Alternative Energy Development Plan, targeting 30% renewable by 2037 [20]. Vietnam scaled solar from under 1 GW in 2018 to nearly 19 GW by 2024, although limited grid infrastructure has led to high curtailment rates [21]. Indonesia, with vast renewable potential, remains heavily coal-dependent, with only 12.3% renewable in its 2024 mix, but its $20 billion Just Energy Transition Partnership (JETP) aims to reverse this through coal phase-down and renewable investment [22]. The Philippines has achieved 22% renewable generation, aided by the Green Energy Option Program, while Malaysia targets 31% renewable by 2025 under its National Energy Transition Road map [23].

The renewable energy profiles of selected countries and regions reveal notable differences in energy sources and growth trends. Table 1 summarizes these patterns, highlighting country-specific renewable mixes and recent

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developments. The United States and the European Union (EU) feature strong wind and solar sectors, with the EU also making significant advances in biomass energy. Southeast Asian countries exhibit a diverse renewable energy mix, including hydropower, solar, biomass, and geothermal sources, reflecting their resource availability. In contrast, India and China have experienced rapid renewable growth, powered primarily by aggressive expansions in solar and wind energy.

TABLE 1. THE GLOBAL ENERGY LANDSCAPE 2005-2025

Country/ Region	***Renewable Energy Share (%) 2005***	***Renewable Energy Share (%) 2015***	***Renewable Energy Share (%) (ets) 2025***	***Main Renewable Subsectors Driving Growth***	***Source***
Pakistan	17	30	41.6	Hydropower	[24], [25], [26]
India	10-15	22.5	35-40 %	Solar, Wind, Small Hyro	[27], [25], [28]
China	10-5	20-25	30-35	Wind , Solar , Large Hydro	[27], [25], [28]
United Sates	7-8	10-12	20-25	Solar	[24], [27], [28]
European Union	15-20	25-30	35-40	Wind, Solar, Biomass	[24], [27], [28]
Bangladesh	1-2	3-5	10	Solar, Biomass	[25], [28]
Ghana	5-7	8-10	10-15	Biomass, Solar	[25], [28]
Thailand	5-7	10-15	15-20	Biomas, Solar	[25], [28]
Indonesia	4-5	10-12	20-25	Geothermal, Hydropower, Biomass	[25], [28]
Bhutan	90	100	100	Hydropower	[27], [25], [24]

Pakistan's renewable electricity is predominantly supported by hydropower, alongside increasing solar installations, while Bhutan's renewable energy share, nearing 100%, is driven almost exclusively by hydropower. These growth patterns and projections are based on recent trends and analyses from global renewable energy status reports and energy outlooks.

III. CORE ISSUES AND OPTIONS IN THE GLOBAL RENEWABLE ENERGY TRANSITION

A. Uneven Global Distribution and Regional Disparities

Despite this progress, the world remains off track to meet international climate goals. The current installation pace is insufficient to achieve the global target of tripling renewable energy capacity by 2030, an objective that would require total installed capacity of 11.2 TW [29]. To align with the 1.5°C pathway outlined in the Paris Agreement [30], annual renewable installations must more than double, reaching approximately 1,043 GW per year through 2030 [31].

The renewable energy transition exhibits marked unevenness across regions and energy systems. While Europe achieved a record 44% renewable share in electricity generation in 2023 [32], major developing economies maintain heavy fossil fuel dependence. China, despite leading global renewable capacity additions, still relies on coal and other fossil fuels for the majority of electricity generation. Countries like India and Bangladesh maintain fossil fuel dependencies exceeding 75% and 90% respectively, highlighting persistent inequities in the global energy transition.

B. US Policy Reversals Might Affect Global Trend

More recently, the United States energy transition entered a period of significant uncertainty as in early 2025, the United States underwent a major policy reversal marked by President Trump's "Unleashing American Energy" Executive Order, which rolled back key clean energy regulations and incentives. The new policy framework prioritizes fossil fuel expansion, specifically oil, gas, coal, hydro-power, and nuclear, while phasing out federal support for electric vehicles and renewable energy, including tax credits for wind and solar. Additional executive actions suspended clean energy projects on federal lands and offshore zones, and the U.S. formally withdrew from the Paris Agreement. These sweeping changes have created significant regulatory uncertainty and disrupted momentum in the country's renewable energy development pipeline [33].

C. Grid Integration and Infrastructure Constraints

China's renewable energy expansion illustrates the critical challenge of grid integration and infrastructure limitations. Despite installing a remarkable 277 GW of new solar capacity in 2024 (representing a 45.2% increase) and expanding wind power capacity by 80 GW, this capacity expansion has not translated proportionally into electricity generation due to systemic constraints [34]. Grid integration challenges limit full utilization of renewable capacity, highlighting the complexity of transitioning large-scale energy systems beyond simple capacity installation.

D. Structural Challenges in Developing Countries

South Asian and Southeast Asian countries demonstrate diverse but persistent structural challenges in renewable energy adoption. India, despite conducting record-breaking renewable energy auctions that awarded 59 GW of capacity in 2024, faces systemic obstacles including transmission bottlenecks and delayed power sale agreements that currently stall approximately 40 GW of projects [35].

For example, Bangladesh represents early-stage transition challenges, with only 1.56 GW of installed renewable energy capacity comprising about 4.5% of total power capacity [36]. Despite ambitious policy targets of 20% renewables by 2030 and 30% by 2040, the country maintains over 90% fossil fuel dependence in electricity generation, primarily from natural gas (57%) and coal (20%). Indonesia continues to lag with renewables comprising only 12.3% of the energy mix while coal maintains over 60% of electricity generation, despite abundant renewable potential [37].

IV. DEEPER DIVE INTO KEY ENERGY POLICIES

A. U.S. Renewable Energy Policy Setbacks

The Trump administration's 2025 policy overhaul reverses momentum from the Inflation Reduction Act (IRA) and Infrastructure Law, repealing major tax incentives for wind and solar, pausing federal leasing, and revoking Electric Vehicle (EV) mandates [38][39]. The result: investor uncertainty and paused or canceled project pipelines (bisected clean-energy capacity by 2035). The repeal of the Environmental Protection Agency's (EPA) Greenhouse Gas (GHG) "endangerment finding" adds regulatory uncertainty, potentially stalling long-term emissions reductions and prompting legal challenges from states and stakeholders [40].

Over $14 billion in planned clean-energy investments have been delayed or canceled, threatening jobs and undermining U.S. competitiveness in Artificial Intelligence (AI) and green innovation by discouraging essential infrastructure deployment. The policy narrative frames renewable as "unreliable" and emphasizes securing energy independence, but critics argue these shifts still undermine long-term energy security and grid modernization even as electricity demand grows with AI expansion.

Options include accelerating domestic clean manufacturing with targeted incentives to strengthen U.S. supply chains and reduce dependence on Chinese inputs [41]; leveraging state and local leadership; and clarifying and extending subsidy timelines to support grid resilience while expanding renewables.

B. China – Supply Chain Dominance and Strategic Expansion

China dominates global EV and clean energy supply chains, producing the majority of lithium-ion batteries and leading in rare earth refining and component manufacturing. This creates challenges for the US and others seeking to expand their EV industries or shift to renewables. Export restrictions in 2025 have disrupted supply, impacting automakers, energy firms, and defense sectors [42]. Dependence on China reduces strategic autonomy and raises geopolitical tensions. Options include diversifying supply chains, investing in green innovation, and forming strategic alliances, such as the US exploring collaboration with Pakistan.

C. Off-Grid and Decentralized Renewable Deployment Issues

Many countries need off-grid decentralization systems. In South Asia and Africa, off-grid solar, mini-grids, and waste-to-energy remain important but are limited by scalability and investment issues. Projects in Bangladesh, Nepal, and Ghana face regulatory, financing, and land challenges. To address these, options include strengthening institutional frameworks, scaling pilots with blended finance, leveraging public-private partnerships to reduce investment risk, and involving local stakeholders for lasting impact.

D. Grid Transmission Under-Investment

In 2024, India awarded 59 GW in renewable energy auctions, but 40 GW remains delayed due to transmission issues, pending Power Purchase Agreements (PPA), and land acquisition setbacks [43]. Globally, expanding auction capacity without simultaneous grid upgrades has resulted in high energy curtailment. Policy recommendations include: coordinating grid expansion with generation auctions, investing in infrastructure before adding new capacity, implementing smart grid and demand-response solutions, and streamlining regulations for land acquisition and PPA signings to minimize delays.

E. Hydropower Excellence and Circular Economy Innovation

Nepal exemplifies successful renewable energy development in challenging geographic conditions, with over 95% of electricity generation coming from hydropower, totaling more than 3,000 MW in installed capacity. The country has evolved from energy importer to regional supplier, exporting power to India and Bangladesh in 2024–2025 . Major projects include the 900 MW Arun-3 and 216 MW Upper Trishuli-1, part of Nepal's ambitious plan to increase hydropower capacity to 28,500 MW by 2035 [44].

Beyond hydropower, Nepal demonstrates innovative circular economy approaches to energy. The Dharan waste-to-energy plant converts 30 tonnes of municipal waste daily into 1,200 kg of bio-CNG for local transport, while over 300,000 household biogas units reflect a culture of energy recovery from organic waste. Off-grid solutions have reached over 3.6 million people through solar mini-grids and micro-hydro systems, with targets of 12 MW additional off-grid solar capacity by 2030 [45].

V. INNOVATIVE STORIES IN ENERGY TRANSITION

A. Energy and Environment Partnership Mekong Programme (EEP Mekong Programme)

Across Cambodia, Laos, Thailand, Myanmar and Vietnam, the EEP Mekong programme has catalyzed 55 pilot and demonstration projects in renewable and waste-to-energy technologies, reaching more than 190,000 rural residents and reducing approximately 141,800 tCO_2-equivalent across Phase II (2014–2019) [46]. In Vietnam's Mekong Delta, biodigesters installed in hundreds of households have transformed livestock waste into cooking gas and organic fertilizer, developing micro-entrepreneurship while substantially cutting methane emissions. In Chiang Mai, Thailand, community-level production of solid "bisquets" from agricultural residues has enabled forest conservation and lower carbon and particulate emissions, all through locally-managed circular-economy fuel systems. Finally, in Lao PDR, an industrial biogas project treating starch-factory wastewater, backed by EEP Mekong and developed with Thai Biogas Energy Co., replaces coal with on-site methane, cutting up to 60,000 tons of CO_2 emissions per year and offering a scalable model for industry–community energy reuse [47].

B. Pumped-Storage Hydro (PSH)

The long-duration storage landscape is evolving fast, offering critical flexibility for grids based on highly variable renewables. Pumped-Storage Hydro (PSH) itself remains the foundation of grid-scale energy buffering, and China continues to lead globally, installing 7.75 GW in 2024 to reach 58.69 GW of total capacity, with over 200 GW under construction, accounting for roughly one-third of the world's PHS pipeline [48]. At the same time, innovation is reshaping how PSH can be deployed, RheEnergise's 500 kW "high-density" pilot near Plymouth uses a fluid 2.5× denser than water to slash infrastructure requirements and enable site locations off low hillsides, increasing global applicability [49]. Complementing this, next-generation batteries are diversifying beyond lithium-ion: Form Energy's iron-air battery broke ground in August 2024 on a 1.5 MW/150 MWh pilot in Minnesota capable of up to 100 hours of continuous storage [50]; Alsym Energy's metal-oxide battery uses a non-flammable, water-based electrolyte and abundant materials for safe, low-cost long-duration applications in hot climates; no lithium or cobalt needed. The field is also breaking out of the chemical shell: in December 2023, Energy Vault's 25 MW/100 MWh gravity storage system came online in Rudong (China), using stacked blocks to store potential energy tied directly to a wind farm and feeding it into the grid on demand [51]; meanwhile solid-state hydrogen storage, notably via metal-hydride systems like LAVO's hydrogen pilot testing in the UK, is emerging for seasonal renewable smoothing and clean fuel generation; and Compressed-Air Energy Storage (CAES), long used at cavern scale to store surplus wind or solar power for later release, remains a promising route for grid flexibility where geologic conditions allow. These innovations—mechanical, chemical, and hybrid—form an increasingly rich portfolio of storage options tailored to specific climates and deployment contexts, underpinning an energy transition that demands balancing across timescales from minutes to days.

C. Data Centers and Energy Demand

As the global demand for Artificial Intelligence (AI) accelerates, so too does the energy required to power it, posing a significant challenge to current energy systems. Global electricity demand from data centers worldwide is projected to more than double by 2030, with AI as the main driver [52]. A Forbes-cited example: Meta's CEO announced a $65 billion investment to scale AI operations including a 2,500-acre site in Louisiana, this single campus is expected to require approximately 2.23 GW of electricity, enough to power about 2 million homes. While an exact location-specific source was not located, this aligns with broad investment trends in AI infrastructure.

D. Excess Energy and Bitcoin Mining

Countries rich in low-cost renewables are increasingly converting excess power into economic value via cryptocurrency mining and AI data centres, turning curtailed energy into revenue streams. Bhutan, leveraging 100% hydropower, has quietly mined over 13,000 BTC (Bitcoin), equivalent to roughly 30–40% of its GDP, since 2019. Its sovereign wealth fund (Druk Holding and Investments) has used crypto profits to fund public salaries, reduce brain drain, and label its initiatives "green crypto" due to carbon-neutral mining [53][54]; Pakistan is now pursuing a similar path, officially allocating 2,000 megawatts of surplus electricity to Bitcoin mining and AI data centres under its Pakistan Crypto Council strategy.

Bitcoin mining is relevant to renewable energy and electricity management because it utilizes excess or stranded energy, turning idle electricity into economic value. In Pakistan, surplus capacity from fossil-fuel-based Independent Power Producers (IPPs)—exacerbated by oil price spikes, creates financial burdens. Allocating this excess energy to Bitcoin mining and AI data centres monetizes idle power, improves generation efficiency, attracts investment, and supports digital industries. Similarly, Bhutan and Paraguay have shown that regulated crypto-mining can fund public initiatives and enhance energy system efficiency, making it a strategic tool for energy policy and economic diversification.

VI. Conclusion and Future Work

The global renewable transition is technically possible and accelerating, in 2024 alone, the world added 585 GW of renewable capacity (92.5 % of all new power), boosting total renewables to 4,448 GW. Yet this falls short of the 11.2 TW needed by 2030 to follow a 1.5 °C path; at a 15.1 % growth rate, installation must rise to 16.6 % annually to stay on track . Most additions flowed into Asia are led by China while regions like Africa remain marginal contributors, revealing a glaring equity gap . In the U.S., recent policy reversals, including the rapid phase-out of wind/solar tax credits, revocation of federal EV mandates, and suspension of clean energy land leases have shaken investor confidence, imperiling $ 8 billion+ of manufacturing and causing projected slowdowns of 17–20 % in solar and wind rollouts over the next decade . Meanwhile, China is doubling down on both production and grid resiliency: in 2024 it added 7.75 GW of pumped hydro storage, bringing total to 58.7 GW and establishing a 200 GW pipeline,underpinning flexibility at scale. Emerging technologies are delivering longer-duration storage: gravity blocks in China, high-density pumped hydro, and especially iron-air batteries,like the 1.5 MW/150 MWh Minnesota pilot that stores for 100 hours at significantly lower cost than lithium-ion batteries, are shifting the paradigm.

Innovative economic uses of excess renewables are also emerging. Bhutan, powered entirely by glacier-fed hydropower, has mined over 12,000 BTC valued at ~30 % of GDP, and directed proceeds to public salaries, healthcare, and environmental programmes, demonstrating small-country monetization of green surplus electricity . Similar circular economy pilots across Southeast Asia, upcycling biowaste into fuel and fertilizer, are delivering community health, income, and environmental dividends.

In short, while renewables are broadly scalable, realizing their full benefits hinges on stable policies, robust financing, next-gen storage and grid infrastructure, and deliberate innovation deployment. The technology is ready, but without

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coordinated strategy and equity-focused investment, the 1.5 °C ceiling remains unachievable, and the gains may fail to spread globally.

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