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Global Energy Investment Trends and the Clean Energy Transition: A Comparative Assessment of Capital Flows from 2015 to 2024

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اتجاهات الاستثمار في الطاقة العالمية والتحول إلى الطاقة النظيفة: تقييم مقارن لتدفقات رأس المال من عام 2015 إلى عام 2024

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Abstract:
Global energy investment has entered a period of structural change in which capital increasingly favors clean technologies, electricity networks, storage, electrification, and efficiency. This article assesses the evolution and composition of global energy capital flows between 2015 and 2024 using a descriptive and comparative review of the International Energy Agency's World Energy Investment 2024 dataset and analysis. The assessment compares clean energy and fossil-fuel investment, examines technology-level shifts, evaluates regional disparities, and reviews the changing sources of investment and finance. Global energy investment is expected to exceed USD 3 trillion in 2024, of which approximately USD 2 trillion is directed toward clean energy technologies and infrastructure. Solar photovoltaic investment alone is projected to exceed USD 500 billion, while grid expenditure is expected to reach about USD 400 billion. Nevertheless, the transition remains highly uneven. Emerging market and developing economies outside China account for only around 15% of global clean energy spending, and battery-storage investment is particularly concentrated in advanced economies and China. Fossil-fuel capital also remains substantial, including approximately USD 570 billion in upstream oil and gas investment in 2024. The findings indicate that the transition is progressing in aggregate but remains constrained by grid bottlenecks, high financing costs, unequal access to capital, weak investment in low-emission fuels, and geographic concentration. A credible transition therefore requires accelerated network and storage investment, lower financing costs in developing economies, stronger development-finance participation, and policy frameworks that align private capital with energy security, affordability, and climate objectives.

Keywords: Energy Investment; Clean Energy Transition; Capital Flows; Renewable Energy; Fossil Fuels; Energy Finance; Emerging Economies.

الملخص:
دخل الاستثمار العالمي في الطاقة مرحلةً من التحول الهيكلي، تتجه فيها رؤوس الأموال بصورة متزايدة نحو التقنيات النظيفة، وشبكات الكهرباء، وتخزين الطاقة، والكهربة، وكفاءة استخدام الطاقة. تقيّم هذه المقالة تطور تدفقات رؤوس الأموال العالمية في قطاع الطاقة وهيكلها خلال الفترة من 2015 إلى 2024، من خلال مراجعة وصفية ومقارنة لبيانات وتحليلات تقرير «الاستثمار العالمي في الطاقة 2024» الصادر عن وكالة الطاقة الدولية. وتقارن الدراسة بين الاستثمارات في الطاقة النظيفة والوقود الأحفوري، وتبحث التحولات على مستوى التقنيات، وتقيّم التفاوتات الإقليمية، كما تستعرض

التغيرات في مصادر الاستثمار والتمويل. من المتوقع أن يتجاوز الاستثمار العالمي في الطاقة 3 تريليونات دولار أمريكي عام 2024، يُوجَّه منها نحو تريليوني دولار إلى تقنيات الطاقة النظيفة وبنيتها التحتية. ومن المتوقع أن يتجاوز الاستثمار في الطاقة الشمسية الكهروضوئية وحدها 500 مليار دولار، في حين يُرجّح أن يصل الإنفاق على شبكات الكهرباء إلى نحو 400 مليار دولار. ومع ذلك، لا يزال التحول متفاوتًا بدرجة كبيرة؛ إذ لا تستحوذ الأسواق الناشئة والاقتصادات النامية خارج الصين إلا على نحو 15% من إجمالي الإنفاق العالمي على الطاقة النظيفة، بينما تتركز استثمارات تخزين الطاقة بالبطاريات بصورة خاصة في الاقتصادات المتقدمة والصين .وفي الوقت نفسه، لا تزال الاستثمارات في الوقود الأحفوري كبيرة، بما في ذلك نحو 570 مليار دولار من الاستثمارات في أنشطة النفط والغاز في المراحل الأولية خلال عام 2024. وتشير النتائج إلى أن التحول يتقدم على المستوى الإجمالي، لكنه لا يزال مقيدًا باختناقات شبكات الكهرباء، وارتفاع تكاليف التمويل، وعدم تكافؤ فرص الوصول إلى رأس المال، وضعف الاستثمار في أنواع الوقود منخفضة الانبعاثات، والتركيز الجغرافي للاستثمارات. ولذلك، يتطلب تحقيق تحول موثوق ومستدام تسريع الاستثمار في الشبكات وأنظمة التخزين، وخفض تكاليف التمويل في الاقتصادات النامية، وتعزيز مشاركة مؤسسات تمويل التنمية، ووضع أطر سياسية توائم بين رؤوس الأموال الخاصة وأهداف أمن الطاقة، والقدرة على تحمل التكاليف، والعمل المناخي.

الكلمات المفتاحية: الاستثمار في الطاقة؛ التحول إلى الطاقة النظيفة؛ تدفقات رأس المال؛ الطاقة المتجددة؛ الوقود الأحفوري؛ تمويل الطاقة؛ الاقتصادات الناشئة.

1. Introduction

Investment is one of the clearest indicators of the future direction of the energy system. Whereas production and consumption data describe the system currently in operation, capital expenditure reveals which technologies, fuels, networks, and end-use assets are likely to shape supply and demand over coming decades [1-3]. The period from 2015 to 2024 is especially important because it begins with the adoption of the Paris Agreement and extends through a decade marked by rapid declines in renewable-energy costs, accelerating electrification, major supply-chain disruptions, an international energy crisis, rising interest rates, and increasingly assertive industrial policies [4-6].

The International Energy Agency (IEA) estimates that global energy investment will exceed USD 3 trillion for the first time in 2024, with approximately USD 2 trillion directed toward clean energy technologies and infrastructure [7-10]. This aggregate result signals a major reorientation of capital. The world now invests almost twice as much in clean energy as in fossil fuels, while expenditure on renewable power, grids, and storage exceeds total spending on oil, natural gas, and coal. The ratio of clean-power investment to investment in unabated fossil-fuel power has risen from about 2:1 in 2015 to an estimated 10:1 in 2024 [11-13]. These figures demonstrate that clean technologies have moved from a supplementary role toward the center of the global energy investment landscape.

The headline expansion, however, does not imply that the transition is balanced or sufficient. Capital is concentrated geographically, with China, the European Union, and the United States accounting for a large proportion of clean energy spending. Emerging market and developing economies (EMDE) outside China receive only around 15% of global clean energy investment, despite their rapidly growing demand, large populations, and significant renewable-resource potential [14-18]. Technology allocation is also uneven. Solar photovoltaic (PV) deployment attracts exceptional investment [19-23], but spending on grids, storage, energy efficiency, low-emission fuels, and enabling infrastructure does not always expand at the pace needed to integrate new generation [24-29]. Meanwhile, upstream oil and gas investment continues to grow, and new liquefied natural gas (LNG) capacity is progressing in response to energy-security and market considerations.

In [30], the study highlighted the unprecedented expansion of renewable energy in 2023, with 510 GW added to global capacity, representing a 50% year-on-year increase. Solar PV accounted for approximately three-quarters of this growth, while wind energy also recorded substantial gains. China was identified as the leading contributor, installing more solar PV capacity in 2023 than the entire world did in 2022. Record capacity additions were also reported in the United States, Brazil, Germany, and Canada. By the end of 2023, renewable sources represented 43% of global installed electricity capacity, while the sector employed an estimated 6.5 million people worldwide.

Hu et al., [31], examined two key dimensions of the energy transition, fossil-fuel phase-out and renewable energy development, while distinguishing between supply-side and demand-side shocks. Using vector autoregressive (VAR) models and impulse-response analysis, it assessed their medium- and long-term effects on China. The findings showed that supply-side renewable energy development and fossil-fuel withdrawal initially had opposing effects on energy security, although their combined positive impact persisted for approximately a decade. Global renewable energy development improved market stability and system resilience by about 7% but increased risks in the crude oil market.

Renewable energy produced similar positive effects on consumption indicators and demand-side shocks, whereas the negative effect of fossil-fuel withdrawal was stronger on the supply side.
According to [32], the study analyzed a balanced panel dataset covering 16 European Union countries from 1975 to 2021 using panel-data estimation techniques. It incorporated control variables, including per capita income and globalization, to evaluate their effects alongside the Green Energy Mix Quality Index. The results showed that all examined variables played important roles in shaping the clean energy transition across the selected countries. In particular, the Green Energy Mix Quality Index significantly contributed to reducing CO_2 emissions, highlighting the importance of improving energy quality and promoting technological innovation.

Amoah et al. [33] reported that developing countries in sub-Saharan Africa (SSA), despite being major recipients of climate finance intended to support the transition toward cleaner energy systems, experienced an overall decline in renewable energy transitions. Using secondary panel data from 36 SSA countries covering 2000–2022, the authors applied a Generalized Method of Moments (GMM) Panel Vector Autoregressive (PVAR) model to examine the relationship between climate finance and renewable energy transitions across the region.

This article provides a comparative assessment of global capital flows from 2015 to 2024. It addresses four questions: How has the balance between clean energy and fossil-fuel investment changed? Which technologies have attracted the largest flows? How are investments distributed across regions? And how have the sources of investment and finance evolved? By integrating these dimensions, the article identifies the principal achievements, imbalances, and policy priorities shaping the next phase of the clean energy transition.

2. Materials and Methods

The study applies a descriptive, comparative, and policy-oriented review design. Its principal source is the IEA's World Energy Investment 2024 report, which provides historical investment estimates, a full assessment of 2023, and initial estimates for 2024. The study covers electricity generation, grids, storage, fuel supply, energy efficiency, end-use electrification, critical minerals, research and development, technology innovation, and energy finance. Monetary values are reported primarily in constant 2023 US dollars at market exchange rates, enabling more meaningful comparison across years than nominal expenditure.

The analytical period is 2015-2024. The year 2015 serves as a useful reference point because it coincides with the Paris Agreement and precedes the recent acceleration of solar PV, battery storage, electric vehicles, and clean-technology industrial policy. Values for 2024 are estimates and are therefore interpreted as indications of direction and scale rather than finalized observations. The assessment organizes the available evidence into four comparative dimensions: the clean energy-fossil fuel balance; the distribution of investment across power, grids, storage, efficiency, end use, and fuel supply; regional allocation; and sources of investment and finance.

The analysis does not reproduce an independent global investment database or estimate causal effects. Instead, it synthesizes reported investment levels, ratios, growth patterns, and institutional characteristics to identify structural changes. Comparisons are interpreted cautiously because investment categories differ in capital intensity, construction time, operating lifetime, and the quantity of energy services delivered. Falling technology costs may also allow greater physical deployment without a proportional increase in spending. Therefore, lower or slower capital expenditure does not necessarily indicate weaker deployment, while higher expenditure can partly reflect inflation or financing costs. The article uses the IEA's definitions to maintain consistency and avoids combining incompatible indicators.

3. Results and Discussion

3.1 Structural Shift in Global Energy Capital

The most significant development over 2015-2024 is the widening gap between clean energy and fossil-fuel investment. In 2024, clean energy investment is expected to reach approximately USD 2 trillion, compared with roughly USD 1 trillion for fossil fuels and related supply [34]. Clean energy investment has accelerated particularly strongly since 2020, supported by emissions-reduction commitments, heightened concern about energy security, technological progress, and policies designed to expand domestic clean-technology manufacturing. This pattern suggests that the transition is no longer driven solely by climate policy; it is increasingly linked to industrial competitiveness, price stability, technological leadership, and reduced exposure to imported fuels [35-39].

The changing allocation within the power sector is even more pronounced. The ratio of clean-power investment to unabated fossil-fuel power investment increased from approximately 2:1 in 2015 to an expected 10:1 in 2024 [40,41]. This represents a fundamental shift in the pipeline of future generating assets. It does not mean that fossil fuels have disappeared from the investment landscape, but it does indicate that most new power-sector capital is now directed toward low-emission sources. Nuclear investment is also projected to reach around USD 80 billion in 2024, nearly twice its 2018 level, increasing its role within the clean-power portfolio [42,43].

Cost trends have reinforced this reallocation. Solar-module prices fell by about 30% over the two years preceding the 2024 assessment, while prices for several transition-critical minerals and battery metals also declined [44,45]. The productivity of capital has improved: in 2023, one dollar invested in wind and solar PV produced approximately 2.5 times as much energy output as an equivalent dollar invested in these technologies a decade earlier. Consequently, expenditure data alone understate the scale of physical clean-power deployment. At the same time, higher interest rates have raised financing costs, particularly for capital-intensive technologies whose expenses are concentrated at the beginning of the project life cycle.

3.2 Solar PV Leadership and the Need for System Integration

Solar PV has become the leading destination for generation investment. Annual investment in solar PV is projected to exceed USD 500 billion in 2024, surpassing investment in all other electricity-generation technologies combined [46-48]. Several factors explain this position: modular project design, relatively short construction periods, broad geographic applicability, declining equipment prices, mature supply chains, and the ability to deploy systems at utility, commercial, and household scales. Solar PV has therefore attracted investment from utilities, independent power producers, companies, public entities, and households.

Rapid solar and wind expansion creates a parallel requirement for system flexibility. High variable-renewable output has reduced wholesale electricity prices in some markets and occasionally produced negative prices during periods of abundant generation [49-55]. Although lower wholesale prices can benefit consumers, they may reduce spot-market revenues for generators and expose weaknesses in market design [56-62]. Without adequate transmission, distribution, storage, demand response, and flexible generation, additional renewable capacity can face congestion, curtailment, or delayed grid connection [63-72].

Grid investment, which remained near USD 300 billion annually for much of the period after 2015, is expected to reach about USD 400 billion in 2024. The recovery is material but geographically concentrated: advanced economies and China account for approximately 80% of global grid spending [73-75]. Latin America has recently shown stronger growth, especially in Brazil, Chile, and Colombia, while investment remains inadequate in many other developing markets. Battery-storage investment is expected to exceed USD 50 billion in 2024, yet the disparity is severe. In 2023, for each dollar invested in battery storage in advanced economies and China, only about one cent was invested in other EMDE [76-78]. The investment challenge has consequently shifted from adding renewable generation alone to constructing an integrated, flexible, and digitally managed electricity system.

3.3 End-Use Investment, Efficiency, and Electrification

Investment in energy efficiency and electrification across buildings and industry has remained relatively resilient despite inflation, high borrowing costs, and pressures on household budgets. These investments include building-envelope improvements, efficient equipment, heat pumps, industrial electrification, and other measures that reduce final energy use or replace direct fossil-fuel consumption. Their strategic importance extends beyond emissions reduction: efficiency lowers consumer bills, reduces exposure to fuel-price volatility, limits peak demand, and can reduce the scale of generation and network expansion required to meet future energy-service needs [79].

Transport is the most dynamic end-use segment. Investment in the sector is expected to reach a new high in 2024, increasing by about 8% from 2023, largely because of strong electric-vehicle sales. This trend connects end-use investment with manufacturing, battery supply chains, charging infrastructure, and power-sector planning. It also illustrates the increasing role of household decisions in the transition [80,81]. Consumer-facing assets such as electric vehicles, rooftop solar systems, heat pumps, and building retrofits distribute investment decisions across millions of actors rather than concentrating them solely among utilities and energy companies.

However, reliance on households creates concerns about equity and affordability. Wealthier households are generally better able to fund the initial cost of clean technologies or obtain affordable credit. Without inclusive policy design, subsidies may disproportionately benefit consumers who would have invested even without support [82,84]. Policies should therefore combine predictable standards with targeted grants, concessional loans, on-bill finance, and support for renters and low-income households.

3.4 Persistent Fossil-Fuel Investment and Emerging Low-Emission Fuels

The expansion of clean energy investment coexists with substantial capital flows to fossil-fuel supply. Upstream oil and gas investment are projected to increase by 7% in 2024 to approximately USD 570 billion, following a 9% increase in 2023 [85,86]. Middle Eastern and Asian national oil companies are leading much of this growth and have increased their oil and gas investment by more than 50% since 2017 [87,88]. This change indicates a geographic and institutional shift in hydrocarbon investment, with national oil companies taking a larger role than in earlier periods.

A new wave of LNG investment is also developing, led mainly by projects in the United States and Qatar. Projects approved or under construction could substantially increase global liquefaction capacity during the second half of the decade. Such spending is motivated by expectations of gas demand, portfolio diversification, and the energy-security response that followed disruptions in international gas markets [89]. Nevertheless, concentrated project development may increase competition for specialized contractors and create a risk of excess capacity if demand evolves more slowly than anticipated under stronger climate policies.

Investment in low-emission fuels is growing from a very small base. It represents only about 1.4% of the amount invested in fossil fuels, compared with approximately 0.5% a decade earlier. Annual investment in hydrogen electrolysers has risen to around USD 3 billion, but uncertainty over demand and the limited availability of creditworthy off-takers continue to delay projects [90-95]. Sustainable aviation fuel investment has reached around USD 1 billion, while direct air capture attracts approximately USD 0.8 billion [96-101]. Carbon capture, utilization, and storage has a growing project pipeline, yet announced projects must still progress through final investment decisions, construction, and operation. These patterns show that policy ambition has not yet produced mature markets for many low-emission fuels and carbon-management technologies.

3.5 Regional Distribution and the Developing-Economy Financing Gap

Clean energy investment is highly concentrated. China is expected to invest almost USD 680 billion in clean energy in 2024, supported by its large domestic market and its strong position in solar cells, lithium batteries, and electric-vehicle manufacturing [102,103]. The European Union invests about USD 370 billion, influenced by decarbonization objectives, energy-security priorities, and measures adopted after the energy crisis [104,105]. United States clean energy investment is expected to exceed USD 300 billion, approximately 1.6 times its 2020 level, supported by federal incentives and industrial policy [106,107].

EMDE outside China are expected to attract approximately USD 320 billion in clean energy investment in 2024, more than 50% above 2020 [108,109]. India, Brazil, parts of Southeast Asia, and several African markets demonstrate that clear procurement systems, supportive policies, and improved grid planning can mobilize capital [110,111]. Africa's clean energy investment, at more than USD 40 billion in 2024, is almost double its 2020 level [112,113]. Nonetheless, these improvements start from a low base, and many least-developed economies continue to receive very limited investment.

The approximately 15% share of global clean energy investment received by EMDE outside China is inconsistent with their development needs and expected contribution to future energy-demand growth [114-118]. High sovereign risk, currency volatility, limited local capital markets, financially weak utilities, uncertain regulation, inadequate project pipelines, and expensive debt all raise required returns. Projects may be technically sound but financially uncompetitive because the cost of capital is substantially higher than in advanced economies. Debt-service pressures can further restrict public investment and the availability of sovereign guarantees. The result is a self-reinforcing gap: markets with the greatest need for new infrastructure often face the least favorable financing conditions.

4. Policy Implications

First, policy frameworks should treat grids, storage, flexibility, and digital control as core transition infrastructure. Renewable-generation incentives that are not coordinated with network planning can increase connection queues, congestion, and curtailment. Regulators should support anticipatory grid investment, faster permitting, transparent connection procedures, regional interconnection, storage remuneration, and demand-response participation. Electricity-market reforms should provide adequate signals for flexibility and capacity while preserving the operating-cost benefits of renewable energy.

Second, reducing the cost of capital in EMDE should become a central objective of international energy and climate policy. Increasing investment volumes requires more than announcing targets. Countries need predictable procurement, bankable contracts, cost-reflective and socially balanced tariffs, credible regulation, and stronger utility finances. International partners should expand concessional lending, currency-risk mitigation, guarantees, blended finance, and early-stage project preparation. Development finance should be evaluated partly by the amount of additional private capital mobilized and by whether it supports projects in markets that commercial finance would otherwise avoid.

Third, governments should design industrial policies that combine supply-chain resilience with competition and cost effectiveness. Domestic manufacturing incentives may deliver employment, innovation, and energy-security benefits, but fragmented subsidy competition can increase transition costs or support capacity that is not globally competitive. Policies should focus on genuine strategic vulnerabilities, workforce capabilities, infrastructure, research and development, and diversified supply rather than complete self-sufficiency in every technology.

Fourth, low-emission fuels and carbon-management projects require credible demand creation. Public procurement, contracts for difference, production incentives, carbon pricing, sector-specific mandates, and common certification systems can improve revenue certainty. Support should prioritize uses where direct electrification is difficult, including selected industrial processes, shipping, and aviation. Clear sustainability and emissions-accounting rules are essential so that public support produces verifiable lifecycle benefits.

Finally, household-centered policies must address affordability and participation. Targeted support, accessible credit, minimum performance standards, consumer protection, and programs for low-income households can prevent the transition from reinforcing existing inequality. Policy evaluation should consider energy-bill savings, access to mobility and comfort, regional employment, and exposure to energy-price volatility alongside aggregate investment and emissions outcomes.

5. Limitations and Future Research

This assessment is based on a secondary synthesis of the IEA's global investment estimates. The underlying figures combine multiple data sources and, for 2024, include preliminary estimates. Investment data measure capital allocation rather than installed capacity, energy production, emissions reduction, reliability, or social benefit. Comparisons across technologies are influenced by changing equipment prices, construction cycles, local costs, exchange rates, and financing structures. Furthermore, aggregate regional values may conceal large differences among countries and income groups.

Future studies should combine investment data with capacity additions, lifecycle emissions, energy output, employment, and affordability indicators. Econometric analysis could examine how interest rates, policy stability, utility creditworthiness, and risk-mitigation instruments affect investment flows. Country-level research is also needed to identify which combinations of auctions, contracts, grid reform, local finance, and development support have been most successful in mobilizing capital. Finally, subsequent data should be used to assess whether the estimated 2024 acceleration was sustained and whether investment became less geographically concentrated.

6. Conclusion

Between 2015 and 2024, global energy investment moved decisively toward clean technologies. Total investment is expected to exceed USD 3 trillion in 2024, with around USD 2 trillion directed to clean energy. Solar PV has become the largest single destination for generation capital, clean-power investment is expected to exceed unabated fossil-fuel power investment by a ratio of 10:1, and spending on grids, storage, nuclear power, electric vehicles, and efficiency is increasing. These trends demonstrate that the clean energy transition has acquired strong technological, commercial, security, and industrial momentum.

The transition nevertheless remains incomplete and uneven. Fossil-fuel investment is still substantial, low-emission fuels remain marginal relative to conventional fuel supply, and grid and storage investment is concentrated in advanced economies and China. EMDE outside China receive only around 15% of global clean energy spending, while the direct contribution of development finance institutions remains extremely limited. The principal challenge is therefore not simply to increase the global total, but to improve the composition, geographic distribution, affordability, and system-wide coordination of capital flows. Achieving this objective requires integrated network planning, credible long-term policies, stronger project pipelines, expanded risk mitigation, inclusive household finance, and a much larger catalytic role for public and development institutions.

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