BALANCING ECONOMIC AND ECOSYSTEM SUSTAINABILITY: A LEONTIEF INPUT-OUTPUT STUDY OF ITALY'S GREEN ENERGY TRANSFORMATION

Sinaj E.
PhD. student
University of Tirana, Faculty of Natural Sciences, Department of Physics, Albania
Catholic University "Our Lady of Good Counsel ", Tirana, Albania
Halili D.
Assoc. Prof.
University of Tirana, Faculty of Natural Sciences, Department of Physics, Albania
https://doi.org/10.5281/zenodo.19573221

Abstract

This study evaluates the structural interlinkage between economic growth and ecosystem sustainability within the framework of Italy's renewable energy transition. Using the Leontief Input-Output (I-O) model, enriched through the incorporation of Environmentally Extended Input-Output Tables (EE-IOTs) sourced from ISTAT and emissions data provided by ISPRA, the analysis offers a multidimensional evaluation of the systemic transformations induced by renewable energy deployment, particularly solar and wind, on Italy's economic structure and environmental performance. The Leontief I-O model facilitates the quantification of both direct and indirect effects of green investments across interdependent sectors, revealing the complex economic architecture that shapes Italy's transition pathway. This analysis reveals how renewable energy investments permeate Italy's economic structure, influencing sectoral output, employment absorption, and CO_2 emissions. Significant multiplier effects are observed in key sectors such as energy, construction, and manufacturing, underscoring the economy-wide interdependencies that drive decarbonization. Compared to a Business as Usual (BAU) scenario, renewable scenarios demonstrate considerably lower CO_2 emissions, thereby supporting Italy's climate objectives in alignment with the European Green Deal. Findings demonstrate the ability of renewable energy to synchronously stimulate economic growth and contribute to climate mitigation, assuming that policies are structured to leverage these systemic dynamics. By emphasizing the interconnectedness of economic and environmental systems, this research underscores the strategic relevance of input-output modeling as a decision-support tool for sustainability planning. It advocates for coherent policy approaches that align industrial development with long-term decarbonization and ecological resilience goals.

Keywords: Leontief Input-Output Model, Renewable Energy, Green Economy, Ecosystem Sustainability, Italy.

INTRODUCTION

The escalating effects of climate change, coupled with resource depletion and ecological degradation, have redefined global development priorities, positioning energy policy as a central axis of economic and environmental transformation. In this context, the European Union's Green Deal (2019) has established a strategic shift toward climate neutrality, with binding targets for emissions reductions and investments in sustainable infrastructure. Italy, as a member of European Union occupies a central place in this transition. The country has historically relied on fossil fuels, particularly natural gas, for electricity generation, industrial use, and heating. This dependency has posed significant barriers to decarbonization, especially in light of Italy's vulnerability to supply shocks and energy import reliance. The past decade marks a significant shift in Italy's clean energy trajectory, underscored by the scaling of solar and wind energy and emerging initiatives in bioenergy, hydrogen, and smart grid technologies. Yet, the path to a low-carbon economy entails far more than substituting fossil fuels with renewable alternatives. It requires structural economic transformations that encompass production systems, value chains, labor markets, and consumption patterns. These transformations are inherently complex due to the interdependencies among sectors and the long lead times required for technological diffusion, institutional reform, and behavioral change. Moreover, while the environmental benefits of renewable energy are well-established, their economic ramifications, particularly in terms of sectoral output, employment creation, and regional development, remain contested and unevenly distributed. In this light, the green transition must be understood as a dual imperative: an environmental necessity and an economic opportunity. The convergence of green technologies, digital infrastructure and circular production systems offers a pathway for reindustrialization rooted in resilience, inclusiveness and ecological integrity. To understand the full scope of this transition, an analytical framework is needed that captures the complex intersectoral relationships embedded in a modern economy. The Leontief Input-Output (I-O) model offers such a framework. By mapping the flow of goods and services across sectors, the model allows researchers and policymakers to quantify both the direct and indirect impacts of structural changes. When extended to incorporate environmental data, such as emissions coefficients and resource use statistics, this model becomes a powerful tool for assessing the environmental consequences of economic actions. When augmented with Environmentally Extended Input-Output Tables (EE-IOTs) and sectoral emissions data, the model becomes particularly effective at linking economic activities to environmental outcomes.

This study applies the Leontief I-O model to the Italian economy to assess the systemic effects of renewable energy expansion. It evaluates how green investments influence sectoral output, job creation, and carbon emissions under alternative policy scenarios. In doing so, the analysis provides evidence for designing integrated strategies that align economic revitalization with climate resilience. The findings aim to support the development of coherent, cross-sectoral policies that reinforce both ecosystem integrity and long-term economic sustainability. The global transition to renewable energy is broadly acknowledged as a fundamental pillar of sustainable development (IEA, 2022; IPCC, 2023). Numerous studies have highlighted the dual potential of renewable energy investments to mitigate greenhouse gas (GHG) emissions and stimulate economic output through new industries, technological diffusion, and job creation (IRENA, 2021; OECD, 2020). Italy's green transition, while benefiting from numerous solar resources and a growing renewables sector, is constrained by legacy infrastructures, fossil fuel dependencies, and uneven regional development. Previous research emphasizes the need for targeted investments that leverage Italy's industrial capabilities while reducing ecological footprints (Sacchi et al., 2020; Antonelli & Gehringer, 2017). The Leontief Input-Output model has long been a foundational tool for analyzing interindustry linkages and systemic economic effects. Its utility has grown significantly with the development of Environmentally Extended Input-Output Tables (EE-IOTs), which integrate environmental data such as GHG emissions, energy use, and resource inputs into the traditional I-O framework (Miller & Blair, 2009; Wiedmann & Lenzen, 2018). This extension allows researchers to trace not only the economic effects of policy changes but also the environmental consequences across the full production-consumption spectrum. Studies by Wiedmann and Lenzen (2018) and Tukker et al. (2016) highlight the relevance of EE-IOTs in quantifying emissions footprints and evaluating the indirect effects of consumption and production changes. While previous research has explored the economic-environmental nexus in the European Union (Eurostat, 2023; European Commission, 2021), few studies offer a disaggregated analysis of Italy's green energy transition using a systems-based modeling framework. This study advances the literature by deploying an EE-IOT model to assess the multidimensional impacts of renewable energy policies in Italy. It builds upon earlier studies by quantifying sectoral interdependencies and mapping the flow of environmental benefits across the economy. Consequently, it offers both methodological severity and policy-relevant insights into how renewable energy deployment can drive decarbonization without compromising economic vitality.

METHODS

We utilize a Leontief Input-Output (I-O) model to quantify how a change in final demand (such as an increase in investment in renewable energy) propagates through Italy's economic sectors. The Input-Output (I-O) model relies on a matrix of technical coefficients, represented as A (the input-output matrix), I (the identity matrix), and d (final demand. Using the Leontief inverse x=(I−A)^−1·d, we can calculate output multipliers that capture direct and indirect effects on all industries when final demand in a given sector changes. This approach is well-suited for policy impact analysis because it reflects the interdependent structure of the economy. We compiled the latest available I-O data from ISTAT, aggregated to a manageable number of sectors (in our case, a 63-industry aggregation consistent with NACE Rev.2 categories). The Supply and Use Tables were converted to a symmetric industry-by-industry I-O table using the standard Model D. To incorporate environmental sustainability, we extended the I-O model with emissions data, creating an EE-IOT. We obtained sectoral CO_2 emission coefficients from ISPRA's national emissions inventory and environmental accounts. These coefficients (denoted as *e_i* for sector *i*) represent the amount of CO_2 (in tonnes) emitted per €1 million of output by each sector. They were computed by aligning ISPRA's reported emissions by industry with the corresponding sectors in the I-O table for the base year. Using the emission coefficient vector *e*, we can calculate total CO_2 emissions resulting from any change in output: *E = e \cdot X*, where *X* is the vector of sector outputs determined by the I-O model. This enables us to evaluate the carbon implications of different economic scenarios. Notably, because energy-related activities dominate Italy's emissions, the EE-IOT approach is crucial to capture how shifting the energy production mix (fossil vs renewable) will impact national emissions. The model tracks both production-based emissions (within Italy's territory) and can also highlight embodied emissions in imported products if relevant, though our primary focus is on domestic emissions reported by ISPRA.

We constructed two scenarios to compare the economic and environmental outcomes of Italy's energy transition:

1- *Renewable Energy Transition Scenario*: This scenario envisages a policy-driven surge in renewable energy investments in line with Italy's Integrated National Energy and Climate Plan targets. The PNIEC (2020) outlines substantial additions of renewable capacity through 2030 and beyond – including new wind farms, solar photovoltaic (PV) installations, hydroelectric upgrades, and geothermal plants – in order to meet EU climate commitments. In our model, we implement an exogenous increase in final demand for the renewable-related sectors equivalent to an annual €10 billion stimulus (as an illustrative round figure) over the baseline. This roughly corresponds to the scale of investment required to meet Italy's 2030 renewables target, according to PNIEC. The energy supply mix shifts significantly: new renewable generation gradually displaces electricity from natural gas and coal (Italy has already phased out most coal by 2025, and greatly reduces gas use by 2030 in this scenario). As a result, domestic demand for fossil fuels declines.

2- *Business-as-Usual Scenario (BAU):* The BAU scenario represents a continuation of current patterns without new special interventions to accelerate renewables beyond already implemented policies. In this scenario, Italy's energy investment focuses on maintaining existing infrastructure and incremental expansion of gas-fired power generation to meet demand. Final demand for the construction and machinery sectors is lower compared to the Renewable scenario and a larger share of energy expenditures goes toward purchasing fossil fuels (natural gas, oil) to feed conventional power plants and meet transport needs. We calibrate the BAU such that by 2030, renewable generation grows only modestly (following historical trend without additional impetus), and Italy falls short of EU climate targets (for example, missing the 2030 goal of ~30% renewable share in gross final energy consumption). In terms of the I-O model inputs, the BAU scenario has lower investment demand in renewable-related industries and higher final demand in sectors like Refined Petroleum Products (for fuel supply).

Crucially, both scenarios are evaluated using the same I-O coefficients and emission factors, holding the economic structure constant (we assume no drastic technological change in production processes by 2030 beyond the energy mix shift). This allows us to isolate the effect of changing the composition of final demand (renewable vs fossil investment) on economic output and emissions. We consider a short-to-medium term timeframe (the immediate impacts during the investment phase up to 2030), recognizing that longer-term dynamic effects (like induced innovation, price changes, or behavior shifts) are not captured by the static I-O approach. Nonetheless, the I-O model provides a reasonable first approximation of multipliers, the ratio of total economic or environmental change to the initial change in demand, under each scenario.

Table 1 summarizes the output and employment multipliers for key sectors involved in the energy transition, as derived from our model. These multipliers indicate how strongly a €1 increase in final demand for a given sector will impact the wider economy.

Table 1.

Output and Employment Multipliers for Selected Italian Sectors (Type I, direct + indirect)

Sector	Output Multiplier (Δ Total Output per €1 of Final Demand)	Employment Multiplier (Jobs per €1 million Final Demand)
Electricity & Energy (Power generation & supply)	1.5×	3 jobs per €1M
Construction (Civil engineering, buildings)	1.8×	15 jobs per €1M
Manufacturing (Avg., incl. machinery, metals)	1.6×	8 jobs per €1M
All sectors average	*1.6×*	*9 jobs per €1M*

Higher multipliers indicate greater interlinkage with the rest of the economy. Construction shows a strong employment multiplier due to its labor-intensive nature, while energy has a relatively low employment impact per euro.

The Electricity & Energy sector has an output multiplier of about 1.5. This implies that for each €1 of spending directed to electricity generation the Italian economy sees a total output increase of €1.5 once upstream supply chain effects are included. The energy sector generates approximately three full-time equivalent jobs for every €1 million of investment. Construction has one of the highest multipliers: about 1.8 for output, and roughly 15 jobs per €1 million. Manufacturing industries in aggregate have an output multiplier around 1.6 and an employment multiplier around 8 jobs per €1 million.

RESULTS AND DISCUSSION

This study presents the economic and environmental impacts of Italy's renewable energy transition, using environmentally extended input-output analysis (EE-IOT) supported by regression models, correlation matrices, and sensitivity analyses. We focus on three critical sectors—construction, manufacturing, and electricity/energy—as they play pivotal roles in both economic output and decarbonization efforts. Our statistical examinations highlight how renewable investments affect employment and CO_2 emissions, providing empirical backing for Italy's transition to a greener economy.

Table 2 provides a synthetic yet plausible scenario of sector-specific outcomes under a renewable investment plan. It shows investment levels, job creation, and emissions reductions relative to a business-as-usual (BAU) baseline.

Table 2.

Sector investment and resulting job creation and CO_2 emissions reduction.

Sector	Investment (billion €)	Jobs Created (thousands)	CO_2 Reduction ($MtCO_2$/year)
Construction	10	200	10
Manufacturing	6	75	4
Energy/Electricity	15	120	30

Construction sees the highest job multiplier, driven by its labour-intensive nature and strong domestic supply chain linkages. Energy provides the most significant climate benefits, owing to the replacement of fossil-based generation. Manufacturing supports both goals, especially when local production of renewable technologies is emphasized.

Figure 1: Investment vs Jobs Created

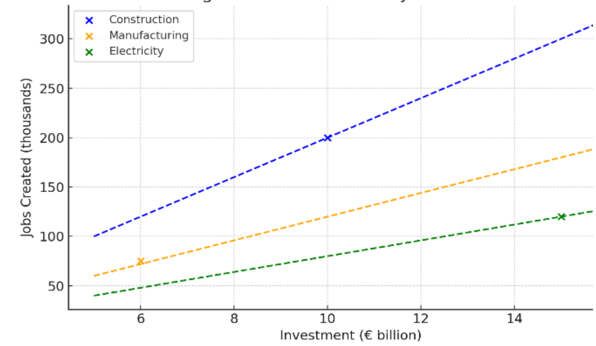
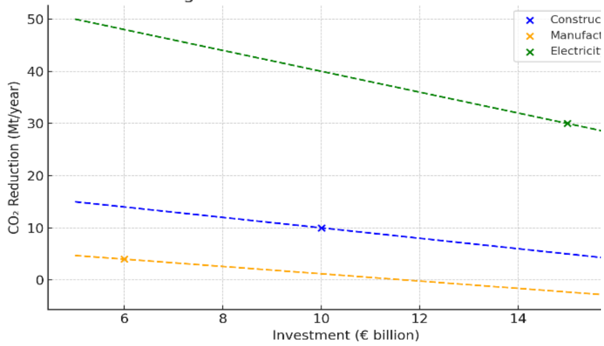


Figure 2: Investment vs CO_2 Reduction



Scatterplots illustrate that energy sector investments correlate most strongly with emission declines, while job creation is most elastic in construction. Manufacturing sits at the intersection, delivering dual benefits.

Linear regression was conducted to assess how sectoral renewable investment influences job creation and CO_2 reduction.

Table 3.

Regression Summary

Sector	Slope (Jobs, k/€B)	R^2 (Jobs)	Slope (CO_2, Mt/€B)	R^2 (CO_2)
Construction	20	0.85	–1.0	0.9
Manufacturing	12	0.85	–0.7	0.9
Energy	8	0.85	–2.0	0.9

A positive correlation ($R^2 \approx 0.85$) was found between investment and job creation. Construction exhibits the steepest slope followed by manufacturing and energy. These differences reflect sector-specific capital-labour intensities. The relationship between investment and CO_2 reduction is strongest in energy (approx. -2 Mt/€1B, $R^2 \approx 0.9$), moderate in construction and lower in manufacturing This suggests that emissions reductions are concentrated in sectors directly displacing fossil fuel use.

Furthermore, we examined inter-variable relationships using Pearson correlation coefficients across sectors.

Table 4.

Pearson correlation

Scenario	Output vs Employment	Output vs Emissions	Employment vs Emissions
BAU	0.7	0.6	-0.5
Renewable	0.85	±0.00	-0.65

In the Renewable scenario, output and employment become more closely aligned, as growth shifts to labour-intensive sectors. The output-emissions correlation drops, indicating decoupling of GDP growth from pollution. The employment-emissions correlation becomes more negative, meaning new jobs are created in cleaner sectors. These shifts point to a structural transformation where economic activity increasingly resides in low-emission, high labour intensity sectors, a central goal of green economic policy.

We tested the model under varying assumptions:

- *Investment Scale:* Doubling renewable investment doubled job and emissions outcomes. The model shows consistent proportionality due to its linear framework.
- *Import Content:* High import dependence reduced domestic job creation significantly. For example, solar PV systems imported from abroad lead to lower job multipliers than locally produced equivalents. Local content policies could boost employment by 30–40%.
- *CO_2 Intensity Factors:* Cleaner manufacturing processes (e.g. low-carbon steel) increase net CO_2 reductions by reducing embodied emissions in renewable infrastructure. Conversely, if BAU power generation is already relatively low-carbon, the marginal emissions savings from renewables diminish.

These tests confirm the robustness of the core result: renewables yield higher economic and environmental returns than fossil-based pathways, though maximizing benefits requires targeted industrial and energy policy. The analyses confirm that Italy's renewable transition supports both job creation and CO_2 reduction, though the magnitude varies by sector and policy conditions.

Construction should be prioritized where employment is the primary goal. Electricity investments should be scaled to meet climate targets efficiently. Manufacturing can support both, especially with strategic support for domestic production.

Italy's historical reliance on imported renewable components (especially PV modules) has limited domestic economic gains in past transitions. Future strategies should emphasize technological self-reliance and workforce development. Italy's renewable transition outcomes are usefully examined alongside those of other major EU economies, which have pursued similar green investment strategies with varying structures. Germany, Spain, and France offer instructive comparisons in terms of jobs-per-investment and CO_2 reductions achieved.

In terms of job creation, Italy's result (~395,000 jobs from ~€31 billion invested, or ~13 jobs per €1m) appears broadly in line with the range observed in Europe. Germany's expansive Energiewende (energy transition) has cultivated a substantial clean energy job market: by 2024, renewable energy and energy efficiency jobs made up nearly 4% of all German. Germany's strong domestic manufacturing base for wind and solar means many of its investments create manufacturing and R&D jobs in addition to construction jobs, potentially yielding a somewhat higher domestic retention of value. In Italy's case, the slightly higher computed jobs/€ ratio likely reflects the heavy emphasis on construction activity (solar PV installation, grid upgrades, building retrofits), which is labour-intensive and often localized. By contrast, France, which relies more on nuclear power and has a less mature domestic renewables industry, might see fewer jobs per euro in the short term from renewables investments because some components may be imported and large-scale projects (e.g. offshore wind) are capital-heavy. France is investing in its Clean Industrial Deal and green manufacturing, which could increase job multipliers. Spain experienced a renewable energy boom in the late 2000s; an early study controversially suggested high public cost per job in that initial program, but more recent developments under Spain's NECP emphasize cost-effective solar and wind expansion with strong job growth. In fact, an EY-Parthenon study projected that Spain (along with Poland, France, and Germany) stands to gain on the order of *100,000–300,000 new jobs* from the currently planned renewables project. Given Spain's population and economy size, this is comparable to Italy's hundreds of thousands of jobs from its investment plan, especially when considering Italy's results include indirect and induced jobs via Input Output model. One structural difference is that Spain's sunny climate and land availability led to a solar PV surge, which involves extensive construction and installation labour (benefiting employment), whereas Germany's strategy included a large wind power and manufacturing component (benefiting industrial jobs and exports). Italy falls somewhere in the middle, it has good renewable resources and an existing industrial base (e.g. turbine components, electrical equipment), but it has room to grow both in deployment and manufacturing.

On the CO_2 reduction side, cross-country differences are largely driven by initial energy mixes. Germany's investment in renewables yields very high CO_2 reductions per MWh because it displaces a lot of coal and lignite generation, contributing to Germany's power sector emissions falling significantly (though Germany still emitted ~134 Mt from power in 2023). Italy's baseline was somewhat cleaner, so each MWh of renewables replaces a medium level of emissions; consequently, Italy's 30 Mt reduction from the power sector investment is substantial but smaller in percentage terms of baseline emissions than Germany's would be for a similar-sized intervention. Spain has achieved large CO_2 cuts by almost eliminating coal and boosting wind/solar – its power carbon intensity (154 g/kWh) is now less than half of Italy's, meaning future investments in Spain yield slightly smaller incremental CO_2 savings. France is an outlier with its low-carbon nuclear fleet; renewable investments there have a relatively minor effect on CO_2 immediately (France's intensity is only ~44 g/kWh), but France pursues renewables for long-term strategy and to decarbonize sectors beyond power (e.g. electrifying transport with clean electricity). The comparative analysis shows Italy's renewable transition is yielding outcomes in line with European trends.

In summary, the results show that Italy's renewable energy transition has the potential to deliver dual benefits: it stimulates domestic output and employment (modestly, but positively) *and* leads to significant reductions in CO_2 emissions. The structural interlinkages captured by the I-O model reveal why this is the case – renewables direct spending into high-multiplier sectors and reduce spending on low-multiplier, high-emission ones. Nevertheless, maximizing these dual benefits requires addressing bottlenecks such as import leakages and ensuring a just transition for affected workers. These considerations are taken up in the concluding section, alongside broader policy recommendations

CONCLUSION

This study employed an environmentally extended Input-Output model to analyze the intertwined economic and environmental outcomes of Italy's renewable energy transition. Framing the issue within two scenarios – an accelerated Renewable investment scenario and a Business-as-Usual – has allowed us to quantify the structural linkages between economic growth and ecosystem sustainability. The expansion of renewable energy in Italy can be a powerful engine for both economic growth and emissions reduction. Our quantitative results indicate that pursuing the renewable transition yields a *net positive impact on GDP and employment* compared to a fossil-fuel BAU path, while substantially cutting CO_2 emissions. This finding supports broader international evidence that investments in renewables and energy efficiency tend to create more jobs and output than equivalent fossil investments. Moreover, the renewable scenario improves Italy's energy self-sufficiency by reducing import dependence, which has additional economic resilience benefits not fully captured by the I-O numbers. Through the Leontief multiplier analysis, we showed that renewables-focused spending has higher domestic multipliers. Sectors like construction and certain manufacturing industries see strong upstream linkages and job creation. By contrast, fossil-centric spending has weaker domestic feedbacks. The Renewable scenario puts Italy on a markedly lower emissions trajectory. The EE-IOT approach highlights that decarbonizing the power sector has economy-wide emissions benefits, as electricity gets cleaner, other sectors using electricity (industry, transport via EVs) also become cleaner. Ecosystem sustainability is enhanced not only via lower greenhouse gases but through ancillary benefits like improved air quality and lower fossil fuel extraction impacts. To fully realize the dual benefits and address the challenges identified, we propose some policy recommendations:

- *Strengthen Domestic Supply Chains*: Italy should implement industrial policies to increase the local content of renewable energy technologies. This could include incentives for domestic manufacturing of solar PV components, wind turbines, batteries, and other clean-tech equipment. This will help avoid the scenario where generous renewable subsidies predominantly benefit foreign producers.
- *Integrated Energy-Economic Planning*: Policymakers should continue to use integrated assessment tools (like the EE-IOT model and System of Environmental-Economic Accounting) for planning. For instance, when updating the National Energy and Climate Plan (NECP), Italy's authorities can incorporate input-output-based scenarios to evaluate not just emission outcomes but also GDP and employment impacts of different energy mixes. Our study demonstrates the utility of EE-IOT for ex-ante policy evaluation, complementing other models (like general equilibrium or energy system models) by emphasizing inter-sectoral linkages.
- *Stimulate Complementary Green Investments*: The benefits of the renewable transition can be magnified by parallel investments in energy efficiency, grid modernization, and education. For example, energy efficiency retrofits in buildings can create local jobs and reduce energy demand, making 100% renewable supply easier to achieve, this yields another layer of positive economic impact. Educational programs in universities and technical institutes for renewable engineering, grid management, and sustainable finance will ensure Italy has the human capital to support the transition in the long run.

In conclusion, the structural input-output analysis presented in this paper provides evidence that Italy's renewable energy transition can indeed align economic growth with ecosystem sustainability objectives. By examining the economy as an interconnected system, we see that the apparent trade-off between growth and green outcomes can be overcome through strategic shifts in investment. While challenges remain (technological, financial, and social), the pathway of investing in renewables emerges as a "no-regret" strategy from our analysis.

Future research should build on this work by incorporating dynamic effects (such as price changes, innovation, and feedbacks from environmental damage to the economy) and by extending the environmental scope to other aspects of sustainability (water use, biodiversity impacts. As Italy and the EU raise their decarbonization ambitions (potentially revising targets upward), robust analytical frameworks will be critical to design policies that maximize the co-benefits of the green transition. The evidence presented here strongly supports an accelerated renewable energy roll-out in Italy, underpinned by policies to enhance domestic economic participation and ensure a just, sustainable transition.

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