



Carbon-Emission Minimization in Nigerian Thermal Generation: Station-Level Drivers and Cost-Emission Trade-offs under Alternative Dispatch Priorities

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ABSTRACT :

Reducing the environmental burden of thermal generation requires dispatch decisions that account explicitly for unit-specific emission characteristics rather than treating emissions as a by-product of least-cost scheduling. This paper extracts and analyses the carbon-emission evidence from a Nigerian economic-emission dispatch dataset containing twenty-one thermal stations and a stated 2,500 MW demand. Three reported schedules are examined: economic emphasis ($\omega=1$), emission emphasis ($\omega=0$) and equal economic-emission weighting ($\omega=0.5$). Carbon dioxide decreases from 120,480 kg/h in the economic schedule to 114,930 kg/h in the emission-oriented schedule, a reduction of 4.607%, while reported fuel cost increases by 4.483%. The equal-weight case reports 117,960 kg/h of CO₂ and occupies an intermediate cost-emission position. The emissions are highly concentrated: in the combined case, Geregu contributes 35.75% of total CO₂ and Geregu NIPP contributes 12.77%; together they account for 48.52%. Olorunsogo and Sapele steam station raise the four-station cumulative share to about 66.58%. Emission reduction is achieved through substantial redispatch, including a 342.5722 MW reduction at Geregu and large increases at Egbin, Okpai and Omotosho. The results demonstrate that environmental dispatch changes the generation merit order and that system-wide conclusions depend disproportionately on the quality of data for a small number of high-impact units. Because the coefficient headings, source equation and station-to-bus mapping are incomplete, the paper treats reported emission totals as empirical outputs rather than independently reconstructed stack emissions. The study concludes that credible Nigerian carbon-aware OPF requires verified pollutant definitions, station measurements and AC network-feasibility checks.

Keywords: carbon dioxide; emission dispatch; Nigerian thermal generation; economic-emission trade-off; environmental dispatch; optimal power flow; power-system emissions

1. Introduction

Thermal generation decisions have an environmental dimension as well as an economic one. The amount of carbon dioxide released over an operating hour depends on which units are dispatched, how heavily they are loaded, the fuels they consume and the efficiency of converting fuel energy into electricity. A least-cost schedule may therefore differ substantially from a lower-emission schedule, even when both meet the same nominal demand. In power-system optimization, the environmental objective is often introduced through a polynomial or polynomial-plus-exponential emission function. The exact function is meaningful only when its pollutant, coefficients and units are known. Carbon dioxide, nitrogen oxides, sulphur oxides and particulate matter are physically different quantities and should not be combined arbitrarily. For this reason, transparent coefficient provenance is as important as the optimization algorithm itself.

The Nigerian research work underlying this paper considers fuel cost, active transmission loss and generating-unit emissions within a multi-objective AC optimal power-flow framework. The available empirical data include twenty-one thermal stations, three reported dispatch schedules and hourly totals for CO₂, NO_x, SO₂ and particulate matter. They provide a useful basis for studying how an environmental priority changes the generation mix. At the same time, the carbon-coefficient table lacks explicit headings for its five numerical coefficient columns and contains values whose interpretation depends on the original emission equation.

This paper therefore focuses on what the reported emissions can support directly. It quantifies the change in system-level CO₂ under alternative priorities, identifies the stations that dominate the combined-case carbon total, links the change in emissions to generator redispatch and evaluates the associated increase in fuel cost. It does not reconstruct the emission function from ambiguous coefficients or claim that the schedules are IWDO outputs, because neither conclusion is supported by the available execution records.

The contribution is a station-level environmental reading of the dispatch evidence, combined with a data-quality argument for future Nigerian carbon-aware OPF studies. The paper is deliberately framed around carbon dioxide while retaining the other pollutants as supporting indicators.

2. Background and Related Studies

Economic-emission dispatch emerged from the recognition that least-cost generation may carry a higher pollution burden. The problem may be formulated through price-penalty factors, weighted normalized objectives or Pareto optimization. A scalar weight is straightforward to implement but embeds the decision-maker's preference before the search and can conceal non-convex trade-offs. Pareto methods instead retain cost and emissions as separate objectives and generate a family of non-dominated schedules.

Jevtić et al. (2018) used adaptive Wind Driven Optimization for combined economic-emission dispatch, illustrating the suitability of population-based search for non-convex objective functions. Broader OPF studies by Ghasemi et al. (2014), Islam et al. (2020), Khunkitti et al. (2021), Huy et al. (2022) and Kahraman et al. (2022) incorporated emissions alongside cost, losses, voltage deviation or stability measures. These studies demonstrate that environmental performance should be assessed together with network feasibility and competing objectives.

Wind Driven Optimization itself was introduced by Bayraktar and Komurcu (2010) and later expanded into a full velocity-position technique by Bayraktar et al. (2013). Adaptive, multi-objective and hybrid variants have since appeared, while Tang et al. (2022) and Mao et al. (2024) document efforts to address diversity loss and premature convergence. The existence of these variants means that an environmental application alone does not establish algorithmic novelty.

Nigerian transmission studies have largely concentrated on voltage, losses, renewable integration and FACTS devices. The environmental dimension is less consistently tied to a traceable AC network model. This creates two linked needs: better station-specific emission data and a clear mapping from physical generating stations to network injection buses. Without both, an emission objective may be mathematically precise but physically ambiguous.

The present paper addresses the first need partially by organizing and interpreting the available station-level emissions, while explicitly documenting the limits of the coefficient information.

3. Data and Methods

The empirical basis is a twenty-one-station dispatch dataset at a stated 2,500 MW demand. Three schedules are available: economic emphasis ($\omega=1$), emission emphasis ($\omega=0$) and equal weighting ($\omega=0.5$). The research work reports total fuel cost and hourly totals for CO₂, NO_x, SO₂ and particulate matter under each scenario. A separate table gives hourly station-level pollutant contributions for the combined case, and active-power limits are available for the twenty-one units.

The system-level carbon change between scenarios is calculated as

$$\Delta E_{CO_2}(\%) = (E_s - E_c)/E_c \times 100, \quad (1)$$

where E_c is the economic-case CO₂ total and E_s is the comparison scenario. Station contribution is calculated as

$$Si(\%) = E_i/\Sigma E_i \times 100 \quad (2)$$

The supplied research work already provides the leading contribution percentages; they are reproduced here and used to assess concentration.

The analysis also examines the output changes that accompany the lower-emission schedule. For each generator, the emission-case output is compared with the economic-case output. This reveals which units are displaced and which units replace them as the environmental priority increases.

A descriptive cost-per-kilogram trade-off is calculated from the change in reported fuel cost divided by the change in CO₂ between two schedules. As in the companion fuel-cost analysis, this ratio is not a market carbon price. It represents the slope between discrete operating points and omits start-up, reserve, contractual and network-security costs.

The carbon-coefficient appendix is not used to reconstruct emissions independently because its five numerical columns are not labelled in the current file and some values require the original formula for correct interpretation. The reported hourly totals are therefore treated as primary empirical outputs, while coefficient-level reimplementation is deferred until provenance and units are verified.

Network feasibility is also outside the present evidence. The twenty-one stations are not mapped to the twelve generator-connected buses in the supplied Nigerian 54-bus case. Consequently, the environmental schedules cannot yet be associated with solved voltages, reactive-power flows, branch loading or AC transmission losses.

Scenario	CO ₂ (kg/h)	NO _x (kg/h)	SO ₂ (kg/h)	PM (kg/h)
Economic	120,480	293.7548	21.6968	14.0275
Emission	114,930	280.2163	20.6968	13.3810
Combined	117,960	287.5928	21.2416	13.7333

4. Results

The emission-oriented schedule reduces all four reported pollutants relative to the economic case. Carbon dioxide falls from 120,480 kg/h to 114,930 kg/h, a reduction of 5,550 kg/h or 4.607%. NO_x decreases from 293.7548 to 280.2163 kg/h, SO₂ from 21.6968 to 20.6968 kg/h and particulate matter from 14.0275 to 13.3810 kg/h. The percentage changes are almost identical across the pollutants, suggesting a strong proportional relationship in the underlying source calculations. Because the original pollutant conversion method is not documented in the research work, the reason for that proportionality is not asserted as fact.

The reduction in CO₂ has a clear economic consequence. Fuel cost rises from ₦3,096,200/h in the economic case to ₦3,235,000/h in the emission-priority

case, a 4.483% increase. Thus, the environmental benefit is not obtained without an operating-cost trade-off. The descriptive slope between the two schedules is approximately ₦25.01 of additional hourly cost per kilogram of CO₂ reduction.

The equal-weight schedule lies between the two extremes in total emissions, reporting 117,960 kg/h of CO₂. Relative to the economic schedule, it reduces carbon by 2,520 kg/h or 2.092% while increasing fuel cost by ₦75,800/h or 2.448%. Relative to the emission-oriented schedule, it saves ₦63,000/h but releases 3,030 kg/h more CO₂. This is a genuine compromise in objective totals, although it is only one weighted point rather than evidence of an entire Pareto frontier.

Emission reduction is driven by major changes in generator allocation. Geregu drops from 436.7304 MW in the economic schedule to 94.1582 MW under emission priority, a reduction of 342.5722 MW. AES falls by 105.8439 MW. In contrast, Egbin increases by 178.3931 MW, Okpai by 139.3754 MW and Omotosho by 134.4892 MW. Delta IV and Olorunsogo NIPP also increase. The environmental objective therefore changes the effective generation merit order substantially.

Station-level carbon output is highly concentrated in the supplied combined case. Geregu contributes 42,171 kg/h, corresponding to 35.75% of total CO₂. Geregu NIPP contributes 15,061 kg/h or 12.77%. Together they account for 48.52% of the reported total. Olorunsogo contributes 9.34% and Sapele steam station 8.72%, so the four largest contributors account for approximately 66.58%. Egbin contributes 6.42%, while Afam IV, Okpai and Omotosho each contribute between about 4.7% and 5.7%.

This concentration has an important modelling consequence. An error in the emission coefficient, availability status or dispatch limit of one high-impact unit can alter the system total disproportionately. It also means that carbon reduction may be achieved efficiently by changing the outputs of a relatively small set of dominant emitters, provided the replacement generation is technically feasible.

The combined schedule illustrates the interaction between emissions and active-power limits. Geregu is at its stated 450 MW maximum in the equal-weight schedule, Sapele steam station is within roughly 0.5% of its maximum, Geregu NIPP is near its maximum and Olorunsogo NIPP is at its stated minimum. These binding decisions imply that small changes in weights, load or network constraints could produce a different compromise. The system therefore cannot be represented by a smooth unconstrained trade-off alone.

Scenario	CO ₂ (kg/h)	Change vs economic	Fuel cost (₦/h)	Cost change vs economic
Economic	120,480	Baseline	3,096,200	Baseline
Emission	114,930	-4.607%	3,235,000	+4.483%
Combined	117,960	-2.092%	3,172,000	+2.448%

Station	CO ₂ (kg/h)	Share of total CO ₂	Cumulative significance
Geregu	42,171	35.75%	Largest single contributor
Geregu NIPP	15,061	12.77%	Top two = 48.52%
Olorunsogo	11,014	9.34%	Top three = 57.86%
Sapele (ST)	10,290	8.72%	Top four = 66.58%
Egbin ST(GAS)	7,569	6.42%	Fifth largest contributor
Afam IV	6,748	5.72%	Sixth largest contributor
Okpai	5,596	4.74%	Seventh largest contributor
Omotosho	5,508	4.67%	Eighth largest contributor

Station	Economic dispatch	Emission dispatch	Change
GEREGU	436.7304 MW	94.1582 MW	-342.5722 MW
EGBIN ST(GAS)	125.3582 MW	303.7513 MW	+178.3931 MW
OKPAI	329.7748 MW	469.1502 MW	+139.3754 MW
OMOTOSHO	30.1313 MW	164.6205 MW	+134.4892 MW
AES	177.4065 MW	71.5626 MW	-105.8439 MW
DELTA IV	128.6891 MW	208.8580 MW	+80.1689 MW
OLORUNSOGO NIPP	31.0035 MW	94.0427 MW	+63.0392 MW

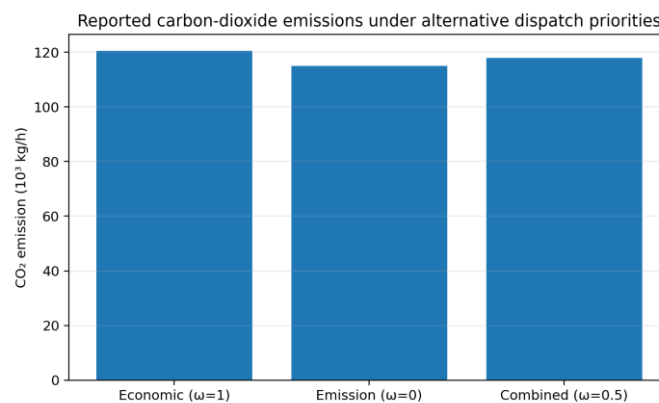


Figure 1. Reported carbon-dioxide emissions under the three dispatch priorities.

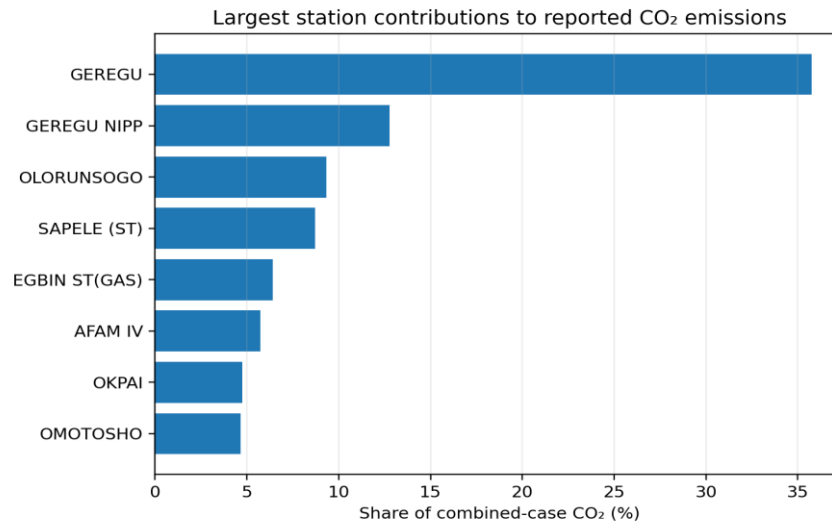


Figure 2. Largest station contributions to combined-case CO₂ emissions.

5. Discussion

The results demonstrate that environmental dispatch is fundamentally a redispatch problem. Lower CO₂ is achieved by moving generation away from some units and toward others; the aggregate emission total is the consequence of those physical allocation decisions. The large reduction at Geregu and increased use of Egbina, Okpai and Omotosho illustrate how strongly the merit order can change when emissions become a primary criterion.

The concentration of carbon at a few stations is arguably the most important station-level finding. Nearly half of the combined-case CO₂ is associated with Geregu and Geregu NIPP, while four stations account for about two-thirds. This creates both an opportunity and a vulnerability. Targeted improvement at high-impact units could reduce the system total materially, but poor coefficient quality at the same units can distort the entire optimization. For this reason, future environmental OPF studies should distinguish measured emission factors from generic benchmark coefficients. Stack measurements, fuel composition, heat-rate curves and unit technology should be aligned to the same data period as the network model. Where benchmark coefficients are used, the resulting objective should be labelled a model-based emission index rather than a measured national-grid emission inventory.

The cost increase observed here is consistent with the economic-emission literature, in which the environmental extreme typically sacrifices some economic performance. However, the three available schedules are insufficient to describe the shape of the trade-off frontier. A Pareto-based optimization could reveal whether similar CO₂ reductions are available at lower cost or whether the equal-weight schedule lies far from a knee point.

Network location is another unresolved dimension. A cleaner generator may be electrically remote from a load center, and increasing its output may raise transmission current and losses. Conversely, a high-emission station located near a major load may reduce network loss. The environmental objective should therefore be evaluated together with active loss and AC constraints, which was the rationale for the larger tri-objective thesis.

The present twenty-one-station dataset cannot yet be attached to the twelve generator buses of the 54-bus network. That incompatibility should be resolved through documented aggregation rather than arbitrary assignment. If several stations inject at one bus, equivalent emission functions must preserve the physical contribution of the individual units or the optimization may select a mathematically attractive but unrepresentative schedule.

From a policy standpoint, the reported cost-emission slope should be interpreted cautiously. It is useful evidence that environmental preference has an operating-cost consequence, but it is not a basis for setting a carbon levy. A policy price would require a broader marginal analysis, current fuel data, market rules, demand scenarios, reliability constraints and preferably measured emission coefficients.

Environmental indicator	Economic case	Emission case	Direction
CO ₂	120,480 kg/h	114,930 kg/h	Lower
Nox	293.7548 kg/h	280.2163 kg/h	Lower
SO ₂	21.6968 kg/h	20.6968 kg/h	Lower
PM	14.0275 kg/h	13.3810 kg/h	Lower
Fuel cost	₦3,096,200/h	₦3,235,000/h	Higher

6. Implications for Carbon-Aware AC Optimal Power Flow

A carbon-aware AC OPF for the Nigerian network should retain CO₂ as a separate objective rather than combining it with other pollutants whose units and health impacts differ. NO_x, SO₂ and particulate matter can be reported as supporting indicators or optimized separately if validated coefficients are available. This preserves physical interpretability.

The optimization should begin with a validated base load flow, then solve single-objective cost, loss and CO₂ cases to establish the extreme points. A multi-objective method can subsequently generate non-dominated schedules. A compromise should be selected from the feasible archive using a declared decision rule rather than assuming that equal scalar weights represent the preferred operating point.

Algorithmic performance should be assessed with repeated runs, feasibility rates, convergence and diversity indicators. If an improved WDO is used, its

contribution should be demonstrated through comparison with standard WDO and recognised benchmarks under equal evaluation budgets. Environmental claims should remain secondary to feasibility: a low-emission schedule that violates voltage or branch limits is not an acceptable operating solution.

7. Limitations

The carbon analysis is bounded by the supplied data. The coefficient table lacks explicit column headings, source equation, units and complete bibliographic provenance, so this paper does not independently reconstruct emission totals. The twenty-one thermal stations are also not mapped to the twelve generator buses of the 54-bus network. AC voltage, reactive-power and branch-flow feasibility are therefore unknown.

Only three preference scenarios are available, and no stochastic run register identifies the algorithm that generated them. The paper cannot assess convergence robustness, Pareto quality or statistical significance. The station-level contribution table used here is the reported combined-case output and should not be interpreted as a current national emissions inventory.

Finally, the study is a steady-state single-period analysis. It does not include start-up emissions, minimum up/down times, renewable uncertainty, fuel-supply constraints or unit commitment, all of which can influence real operational carbon performance.

8. Conclusion

The carbon-emission strand of the Nigerian dispatch study provides clear evidence that environmental priorities change both aggregate emissions and the physical generation mix. Moving from the economic to the emission-oriented schedule lowers reported CO₂ by 4.607% but raises fuel cost by 4.483%. The equal-weight case produces an intermediate outcome, confirming the existence of a meaningful economic-environmental trade-off in the supplied 2,500 MW dispatch model.

The station analysis further shows that emissions are concentrated. Geregu alone accounts for 35.75% of combined-case CO₂, and Geregu together with Geregu NIPP contributes 48.52%. This concentration makes station-specific data quality central to any credible carbon optimisation. Future work should recover the original coefficient definitions, map the thermal stations to network injection buses, validate the AC operating state and then generate a full Pareto set that includes active loss and network constraints. Until then, the present findings are best interpreted as robust dispatch-level evidence of the cost and allocation consequences of carbon-aware generation scheduling.

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