KEYNOTE ADDRESS

Energy, Efficiency and Intelligence: Integrated Modelling for Sustainable Development and Resilient Energy Infrastructure

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Opening

Distinguished conference organisers, eminent scholars, colleagues, researchers, industry leaders, policymakers, students, ladies and gentlemen:

It is a great privilege to deliver this keynote address on a subject that has defined a substantial part of my research journey: the relationship between **energy, efficiency and intelligence**, and how these three dimensions can be integrated to support sustainable development and resilient infrastructure.

Energy is fundamental to development. It powers industry, supports healthcare and education, enables digital connectivity, creates employment and improves quality of life. Yet the challenge before us is no longer simply to produce more energy. We must ask deeper questions: How efficiently are we using the energy already available to us? What factors are driving changes in consumption and emissions? How do we distinguish productive energy demand from avoidable inefficiency? And increasingly, how can artificial intelligence and advanced modelling help us make better decisions in complex and changing energy systems?

These questions have shaped my work over many years and have led me to a simple proposition: **sustainable energy systems must increasingly bring together energy availability, operational efficiency and intelligent decision-making.**

From Energy Consumption to Energy Intelligence

Much of conventional energy planning has historically concentrated on supply and demand. How much energy do we need? How much can we generate? What capacity must be installed?

These remain important questions, but they are no longer sufficient.

When energy consumption increases, we need to understand **why**. Is the increase caused by economic activity? Has the structure of production changed? Has the production process become less efficient? Has the energy mix changed? Similarly, when two industries produce comparable outputs with different levels of energy consumption, we need to understand the efficiency gap between them and determine what improvement is realistically achievable.

This challenge motivated the development of an integrated modelling approach in my research using three complementary analytical techniques: **Index Decomposition Analysis, Artificial Neural Networks and Data Envelopment Analysis**, or IDA–ANN–DEA.

The strength of the framework is not found in any one technique individually, but in the way they complement one another.

Index Decomposition Analysis helps us understand the **drivers of change**. Through the Logarithmic Mean Divisia Index approach, changes in energy consumption can be separated into activity, structural and energy-intensity effects.

Artificial Neural Networks then provide a means of learning the nonlinear relationships among these variables and establishing an expected energy-consumption baseline.

Data Envelopment Analysis takes us one step further by benchmarking performance against an efficiency frontier and estimating the potential for improvement.

Put simply:

IDA explains. ANN predicts. DEA benchmarks and supports optimisation.

The progression is therefore from understanding the system, to anticipating its behaviour, to identifying opportunities for improving it.

Evidence from Industrial Energy Systems

The usefulness of this integrated approach has been demonstrated through studies conducted across significantly different industrial contexts.

In the Canadian industrial sector, the methodology was applied across 15 industrial sectors. The results demonstrated that even in a relatively mature industrial energy system, measurable efficiency gains remained available. In one of the analysed periods, approximately 1.6% improvement was required to reach the identified efficiency frontier.

At first sight, such a percentage may appear small. However, at industrial or national scale, marginal efficiency gains can translate into substantial energy, financial and environmental benefits.

The South African experience presented a different picture. The analysis of 11 energy-intensive sectors revealed a much larger potential for energy savings. Economic activity was an important contributor to changes in energy consumption, while structural and intensity effects were also significant.

The broader lesson from these comparative cases is important: **energy-efficiency interventions cannot simply be transferred from one economy to another without understanding the underlying system.**

A mature industrial economy and an emerging energy-intensive economy may face fundamentally different efficiency challenges. Effective intervention must therefore begin with evidence.

This is why I have consistently argued for moving beyond simply measuring energy consumed toward understanding the mechanisms that produce the observed consumption.

From Energy Efficiency to Carbon Mitigation

As the global sustainability challenge has evolved, energy research has necessarily expanded from efficiency to decarbonisation.

Energy consumption and greenhouse-gas emissions are closely connected, particularly in economies where fossil fuels remain dominant. My subsequent work therefore extended the integrated modelling framework from energy assessment to carbon-dioxide mitigation.

The decomposition framework was expanded to account for variables such as the energy mix, enabling the analysis to distinguish between emissions arising from activity, structural change, energy intensity and the nature of the energy sources being used.

The important implication is that decarbonisation cannot be achieved through a single intervention.

We need to ask whether emissions are increasing because more goods and services are being produced, because production structures are changing, because energy is being used inefficiently, or because the energy mix remains carbon-intensive.

The answer determines the intervention.

In some circumstances, improving energy intensity may provide the greatest benefit. In others, changing the energy mix may be more important. Frequently, both must occur simultaneously.

This systems perspective links industrial efficiency directly with the wider objectives of climate mitigation and sustainable development.

The African and Nigerian Energy Challenge

This discussion has particular significance for Africa.

Our continent must simultaneously address energy access, economic development, industrialisation, affordability, environmental sustainability and climate resilience. These objectives should not be regarded as competing agendas. They are interconnected components of the same development challenge.

Nigeria provides a particularly important illustration.

The Nigerian electricity challenge is not simply a question of insufficient generation. It is a systems problem involving generation availability, transmission constraints, distribution losses, metering, revenue recovery, infrastructure investment, affordability and reliability.

For industry, unreliable electricity creates consequences far beyond the power sector. When firms must depend extensively on self-generation, an electricity-infrastructure problem becomes a productivity and competitiveness problem. Higher energy costs affect production, investment and ultimately economic development.

The appropriate response therefore cannot consist of isolated interventions.

This is where the principles of **energy, efficiency and intelligence** become particularly relevant.

Energy requires reliable, diversified and increasingly sustainable supply.

Efficiency requires us to obtain greater economic and social value from every unit of energy delivered while reducing technical and operational losses.

Intelligence requires data-driven systems capable of forecasting demand, identifying emerging problems, benchmarking performance and supporting adaptive decisions.

The challenge is therefore to build energy systems that do not merely possess additional generation capacity, but are also **efficient, intelligent and resilient**.

The Transition to Intelligent Energy Systems

This brings me to the next stage of my research journey.

Traditional analytical models remain valuable, but contemporary energy systems are becoming more dynamic, distributed and data-intensive. Renewable generation is variable. Demand changes rapidly. Distributed energy resources are growing. Climate conditions influence supply and demand. Communities differ in their energy needs, infrastructure and socioeconomic characteristics.

Our analytical systems must therefore evolve.

This has motivated my current direction toward **Multi-Task Learning and Reinforcement Learning**, or MTL–RL, for intelligent energy planning.

The intention is to develop frameworks that can learn from different forms of information, predict energy demand and renewable-energy potential, classify the suitability of different locations or communities, and ultimately recommend appropriate hybrid energy configurations.

This represents an important change in emphasis.

We are moving from models that predominantly tell us **what happened**, toward systems that help us understand **what is happening, what is likely to happen next, and what action should be taken**.

The future of energy modelling, in my view, lies in this movement from analysis toward adaptive intelligence.

However, artificial intelligence must not become an objective in itself.

AI is valuable only when it enables better decisions.

For energy systems, this means decisions that improve reliability, reduce waste, lower emissions, increase access, strengthen resilience and ultimately improve people's lives.

Building Resilient Energy Infrastructure

Resilience requires more than constructing additional physical assets.

A resilient energy system must be able to anticipate disruption, absorb shocks, adapt to changing conditions and continue delivering essential services.

Consequently, resilient infrastructure should integrate three dimensions.

First is **physical resilience**: robust generation, transmission, distribution, storage and distributed-energy infrastructure.

Second is **operational efficiency**: ensuring that available resources are not lost through avoidable technical, commercial or process inefficiencies.

Third is **adaptive intelligence**: using data, modelling, forecasting and intelligent control to anticipate risks and continuously improve performance.

For countries such as Nigeria and for the African continent more broadly, the opportunity is not simply to reproduce legacy energy systems developed elsewhere. We have the opportunity to develop systems that combine conventional grid infrastructure with renewable energy, distributed generation, mini-grids, storage and intelligent digital technologies.

Such transformation must nevertheless be accompanied by appropriate regulation, financial sustainability, data governance, institutional capacity and human-capital development.

Technology alone will not deliver the energy transition.

From Research to Implementation

One of the responsibilities of academic research is to move beyond explanation toward impact.

Our models should ultimately help an industrial manager decide where an efficiency investment should be made. They should help an electricity utility identify where losses can be reduced. They should help a regulator compare performance objectively. They should help policymakers understand the consequences of alternative energy pathways. And they should help communities identify reliable and affordable solutions appropriate to their circumstances.

I therefore see an opportunity for stronger collaboration among **universities, government, regulators, utilities, industry, communities and development partners**.

We need shared and reliable energy datasets.

We need living laboratories where analytical models can be tested against real energy systems.

We need pilot projects that bring researchers into direct engagement with utilities, industrial facilities and communities.

And we need to develop the next generation of African researchers who can work across the traditional boundaries of engineering, artificial intelligence, economics, climate science and public policy.

Most importantly, our measurement of research success must increasingly include not only publications, but also the extent to which knowledge contributes to improved systems and better decisions.

A Future Research Agenda

Looking ahead, I see several important opportunities.

The first is the development of **real-time intelligent energy-management systems** in which industrial and infrastructure data continuously update analytical and optimisation models.

The second is greater integration of **artificial intelligence, digital twins and adaptive decision-support systems** into energy planning.

The third is continental benchmarking. Africa would benefit significantly from platforms that enable industries and energy systems to learn systematically from comparable performance data across sectors and countries.

The fourth is the integration of energy modelling with **climate resilience, social development and human-centred productivity**. The optimal energy system should not simply minimise cost or emissions. It should simultaneously consider reliability, productivity, accessibility, environmental performance and human well-being.

Finally, we must strengthen the connection between **research and policy implementation**. Sophisticated models have limited value if their findings cannot inform investment decisions, regulatory frameworks and practical interventions.

Conclusion

Ladies and gentlemen, the energy challenge before us is complex, but there is also enormous opportunity.

My research journey has progressively moved from understanding the drivers of energy consumption, to predicting expected performance, to benchmarking efficiency, to mitigating emissions, and now toward intelligent and adaptive energy systems.

Across this journey, one principle has remained consistent:

We cannot effectively optimise what we do not understand.

If we can explain why energy systems behave as they do, predict how they are likely to behave, benchmark their performance against what is achievable, and intelligently adapt our decisions, then we can begin to transform those systems.

Our energy future must therefore be built around three interconnected ideas:

Energy. Efficiency. Intelligence.

Energy must become more reliable and sustainable.

Efficiency must ensure that every available resource creates greater value.

Intelligence must transform increasing volumes of data into timely, transparent and effective decisions.

For Africa, and particularly for countries confronting significant energy constraints, this is more than an academic challenge. It is central to industrial development, economic competitiveness, environmental sustainability and quality of life.

The task before researchers, policymakers and industry is therefore not simply to develop more sophisticated models. It is to ensure that our models become instruments of transformation.

The question should no longer be merely, **“How much energy can we produce?”**

We should also ask:

How intelligently can we manage it?

How efficiently can we use it?

How resiliently can we deliver it?

And ultimately:

How effectively can we translate energy innovation into sustainable development for society?

If we can **explain, predict, benchmark and adapt**, we can act.

And if we act on the evidence, we can move from energy crisis to energy transformation, from inefficiency to resilience, and from modelling systems to improving the lives of the people those systems are intended to serve.

Thank you.