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Working Papers For Keeping The Lights On

Overview: The Electric Challenge

Working Paper 1

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Electricity is different. The difference has long been ignored, but it is now at last beginning to register. Analysts still preoccupied with electricity's many immediate problems worldwide have yet to appreciate the profound and far-reaching long-term implications of the electric difference. Over time the distinctive difference of electricity is going to alter fundamentally the way we think about energy, the way we use energy, and the way we pay for it.

For more than a century we have treated electricity as though it were a fuel. The word 'fuel', from old French 'fouaille' and Latin 'focale', means 'material for a fire'. We have regarded electricity as a substance like coal or oil, as a commodity, bought and sold by the unit. By the early 1990s, when governments were liberalizing their electricity systems, they proceeded accordingly. Electricity 'markets' all over the world have been set up to trade in electricity as a quasi-commodity. The price of a unit of electricity is the focus of attention for buyers and sellers, for governments and regulators. But electricity liberalization coincided with a wave of technical innovation that is continuing, and gaining momentum. Innovative electricity technologies are already beginning to affect the structure and function of electricity systems in many places. As the process continues, it will gradually alter the role and nature of electricity in human energy systems. In so doing, it may also reveal new ways to tackle crucial global problems. But the transition may be disturbing and disruptive. Even as electricity policy grapples with pressing short-term issues, it must prepare to meet a challenge more severe than ever before.

The author's book *Transforming Electricity* (Royal Institute of International Affairs/Earthscan 1999) set out the background to these developments. As the book discusses in detail, traditional electricity is based on a common technical model, replicated all over the world throughout most of the last century. In this model large, remotely sited central stations generate electricity and send it out as synchronized alternating current, over a network including long high voltage transmission lines. The system has a monopoly franchise, granted by the relevant government; in the franchise area no one else is allowed to generate electricity for sale. However, traditional electricity based on this model is already in trouble. Its key technologies - large dams, large coal-fired and nuclear steam-cycle stations, and overhead transmission lines - all face financial and environmental problems that may become insuperable. Moreover traditional electricity has failed to reach some two billion people - one-third of humanity. As traditional electricity struggles with its mounting problems, an innovative alternative is now emerging. As yet the manifestations of this electric alternative are limited; but its potential impact is extraordinary.

Governments that liberalized their electricity systems by restructuring, selling off the assets and introducing competition appeared to believe that nothing else would change - that the systems would continue to look much the same, and function technically in much the same way. But introducing competition shifted major risks away from the captive customers of the monopoly onto the shareholders and bankers of the liberalized system. Electricity cannot be stored. Nevertheless, on systems thus far liberalized, the market is based on transactions in ephemeral units of electricity. An asset to produce or deliver electricity earns revenue only when it is functioning and participating both instantaneously and continuously in the process. Accordingly, in a competitive framework, traditional large-scale generating stations, long-term investments, become acutely risky. Electricity liberalization also happened to coincide with the emergence of gas turbines for continuous electricity generation, and cheap and abundant natural gas to fuel them. Gas-turbine generation, initially in the form of combined-cycle stations, could be ordered, commissioned and brought into service much more rapidly than traditional generation. A traditional power station might take at least six years to plan, build and commission - often much more. A gas-turbine station, however, can be producing both electricity and revenue in perhaps two years or less. Gas turbine generation, less risky, cheaper, cleaner and more convenient than traditional generation, became the technology of choice for new generation wherever electricity was liberalized and natural gas available.

Liberalization therefore triggered a shift in choice of generating technologies. One advantage of electricity is that it can be generated in many different ways, at an astonishing range of different scales. Traditional electricity always believed that a better power station was a bigger power station, farther away. Since liberalization, however, starting with gas-turbine generation, a better power station is more likely to be smaller and closer to users - possibly even directly on the site where the electricity is to be used. Other smaller-scale generating technologies are now emerging, including microturbines, fuel cells, microhydro, wind turbines, biomass gasification and photovoltaics. Innovation in generation, however, has outstripped innovation in networks. A traditional network is a radial one-way network, designed to carry large flows of electricity in one direction from large remotely-sited power stations, to subdivide the electricity and deliver it to loads mostly several orders of magnitude smaller. It was never intended to serve as the basis for a competitive market in wholesale electricity. Nor was it intended to accommodate large numbers of generators in sizes broadly similar to loads, probably connected to the network at voltages much lower than traditional transmission voltage. The consequent stresses and conflicts, over access to and use of electricity networks, are already evident. They will get worse.

Analysts and commentators now make much of the newly-instituted 'market' in electricity, as though it were equivalent, say, to the long-established worldwide market in oil. They say less, however, about the role of regulation in determining the unit price of electricity, even in this so-called 'market'. Regulators lay down the financial rules for managing and using electricity networks, which are still almost always treated as monopolies. Even in a liberalized context such as that of northern Europe, a substantial part of the cost of a unit of electricity is the charge for use of the network. This charge has only a tenuous connection with any 'market'. Rules for using the network are essentially arbitrary, imposed unilaterally by a regulator whose powers derive directly from the relevant government. Only within this arbitrary framework does any residual 'market' exist. The regulator has a profound influence also on the maintenance, expansion and evolution of the network, and accordingly on its evolving functional relationship with generation and loads. Until recently the regulators of liberalized electricity systems have shown little sign of interest in having networks evolve away from their traditional configuration and their traditional role. Such evolution is still at best preliminary and tentative. Until and unless networks evolve from a radial one-way toward a meshed two-way configuration, they will constrain severely the opportunities for fundamental change associated with small-scale decentralized and local generation. But the pressure for change is already intensifying.

One option attracting increasing attention is that of so-called 'private wires' linking local generation with local loads that may not be on the same site as the generation but are not too far away from it. Such private wires, perhaps owned and operated by the local generation or jointly with the local loads, are separate and distinct from the regulated network. They thus effectively undermine its monopoly at least in this local area. At the moment, however, private-wire participants are usually excluded from use of the regulated network. The 'either-or' nature of the private-wire option as presently available limits its attraction, and probably entails less than optimal use of the assets involved. Private wires nevertheless point the way to the much more radical reorganization of the structure and function of networks that will almost inevitably ensue.

The stubborn and lingering mismatch between innovative generation and traditional networks, both technically and institutionally, demonstrates the pervasive inertia of what in the US are called legacy assets and legacy institutions. More stultifying still is the legacy mind-set - traditional concepts and ways of thinking that continue to shape our expectations about the role and nature of electricity in society. Lifting the burden of this legacy mind-set will be a major challenge to policy analysts and policymakers.

In its traditional role, the network is regarded essentially as a delivery conduit, carrying measured units of electricity from generator to load. If the network is so regarded, it severely limits the role and function of generators, particularly small decentralized generators. Remember, however, that electricity is different. For electricity in any context, whether digital watch or aluminium smelter, the network is not just an ancillary delivery system. It is an integral and essential part of the electricity process. That expression should perhaps be emphasized; it is an example of the change of mind-set, the changing conceptual framework, that electricity now demands. Electricity as we use it is not a quantity, much less a substance or commodity. Electricity is a process. We direct the process to achieve a remarkable variety of objectives. The objectives, such as comfort, illumination, motive power and information handling, we can call 'electricity services'; but electricity by itself is useless. It can deliver the desired services only by activating appropriate technology.

For historical reasons, we have come to focus on the measured amount of electricity that flows through the process and the technology. Historically, participants on electricity systems have been divided into one group acting as suppliers and another group acting as users. In transactions between suppliers and users we have considered electricity as equivalent to a fuel; and we have been preoccupied with the running cost of the electricity service process - the number of units of electricity flowing, and the price per unit. We have presumed that some form of financial equivalence can be constructed, to link the investment cost of the physical assets involved to the unit cost of the electricity flowing through the system. Even in the context of traditional electricity this approach has been more than somewhat arbitrary, though generally accepted. However, electricity can now often be generated economically close to where it is used; and generator and loads may even belong to the same owner. For such innovative decentralized electricity, focusing so obsessively on the rate of flow of electricity and the price per unit may become irrelevant and even nonsensical, both financially and operationally.

Consider, for example, your Walkman. You do not, after all, measure the electricity flowing through the Walkman, or pay for it by the unit. You purchase the entire system, including the batteries; then you use it as you wish. You may keep track of how long the batteries last and what a replacement set may cost; but you don't have a meter on the Walkman measuring the flow, nor do you think of how much the electricity costs per unit; indeed if you did you might be alarmed. The transactions involved when you purchase the Walkman and even when you purchase replacement batteries are more like investments than commodity transactions. The same may eventually apply to larger local electricity systems, at least in certain significant circumstances.

As small-scale decentralized generation becomes feasible and attractive, a crucial distinction comes into important prominence. Some generating technologies convert fuel energy into electricity. The process entails use, and therefore actual consumption, of fuel. Such fuel-based electricity can be usefully and accurately characterized according to the rate of fuel consumption, and the cost of the fuel per unit. In this case the attention paid to the flow of electricity and the unit cost of the electricity is a direct and appropriate corollary of the fuel-based generation. However, not all electricity generation requires fuel. Indeed, one of the oldest generating technologies was and is hydroelectricity, produced by converting the mechanical energy of falling water into electricity. For large-scale hydroelectric generation, the quantity and level of water behind a dam represents an analogue of fuel energy, in that the potential energy of the water can be stored and released as desired. In this case, the traditional approach can be justified: you can measure the flow of electricity, equate it to the flow or 'consumption' of water from storage and attribute a unit cost accordingly, just as you do for fuel-based electricity. By contrast, however, for smaller hydro installations, such as run-of-river plants on non-seasonal waterways, the mechanical energy of flowing water is continuous. A mini- or microhydro generator with water flowing through it will produce electricity continuously. The unit cost of this electricity can if desired be inferred by some form of accounting treatment of the investment cost of the generator. However, the flow of water itself is not paid for; indeed, provided it is sufficient to turn the generator it may not even be measured. No 'consumption' can be usefully identified.

In this case a physical asset generates electricity by converting natural ambient energy that is already present and free of cost. Other innovative technologies such as wind power and photovoltaics do likewise. For all these technologies, what matters is the investment cost of the physical asset, and how that asset is treated in financial accounting terms. Generating this electricity involves no commodity transaction at all. Using this electricity, accordingly, need not be treated as a commodity transaction either. The implications, especially for small, self-contained electricity systems, especially those based on natural ambient or 'renewable' energy, may be striking. Precedents already exist. If you have the right equipment you can already operate your Walkman or laptop computer on rechargeable batteries, and recharge them with solar energy from your roof, with no fuel or commodity involved.

The procedure is much more akin to that of purchasing a building. You buy the building as an investment. It will contain a variety of active technologies, and entail maintenance and running costs; but focus here on the physical asset that is the structure of the building itself - in general, the better the structure, the lower the maintenance and running costs. The structure itself delivers, among other things, energy services such as comfort, as and when you use the building. The energy service is not a commodity; you do not measure it or pay for it by the unit. The physical asset, the building, delivers the service continuously, as a function of infrastructure. The physical infrastructure of a building converts and reorganizes energy, particularly in the form of heat, as an inherent part of the function of the building. In general the flows of heat into, out of and through the fabric of a building are neither measured nor paid for; they are simply part of the performance of the building as built infrastructure, designed, paid for and used accordingly.

Suppose, now, you design an office building, whose energy performance extends beyond utilizing ambient heat and light to take advantage also of innovative electricity. In the basement you install a gas-fired fuel cell; and in the skin of the building you incorporate photovoltaic (PV) tiles and cladding. You include three sets of cabling from the outset - one for telecoms, one for synchronized alternating current (AC) from the external network, and one for low-voltage direct current (DC) from your on-site fuel cell and photovoltaics. All the lighting, computers and other electronics, the most sensitive loads in the building, operate on your own low-voltage DC; power electronics keeps the supply more stable and reliable than the electricity from the external network. So long as the lights stay on, the computers and other equipment work, and the building remains convenient and comfortable for its occupants and users, you may not even bother to measure the electricity flowing through your local DC system. You will measure and pay for the gas flowing into your fuel cell; but you may not measure the electricity coming out, nor that from your PV panels. You certainly will not pay for it by the unit. Instead, this unmeasured but functional electricity becomes analogous to the heat flowing through the fabric of the building. The electricity becomes part of the function of the infrastructure, part of the way the infrastructure delivers the energy services you desire.

Such a possibility brings in its train a startling corollary. Official prognoses of the future of world energy, from organizations such as the International Energy Agency, the World Energy Council, and the International Institute for Applied Systems Analysis, all indicate that whatever happens to world use of coal, oil and natural gas, world use of electricity will continue to increase essentially without limit, at least throughout this twenty-first century. They base their prognoses on so-called 'energy statistics', gathered assiduously by governments all over the world. Indeed, the word 'statistics' means 'information of interest to the state'. But consider the high-performance building just described. You don't need to measure the amount of electricity flowing through your local system in the building; and the government is certainly not going to measure it. Over time, if such local applications of infrastructure electricity, unmeasured and taken for granted, become commonplace, the statistical data available to record 'world electricity use' will become progressively meaningless. The implication underlines dramatically the distinctive difference of electricity, especially innovative electricity, as an aspect of energy policy.

The distinction between fuel-based and infrastructure electricity is now leading to some thought-provoking analysis intended to reassess the basis for estimating the cost of electricity. Conventional comparisons are now routinely adduced to assert, for instance, that electricity from a gas-fired combined-cycle station costs perhaps '2.8 cents per kWh', whereas electricity from a wind farm costs perhaps '4.9 cents per kWh', and that from a photovoltaic array '11.5 cents per kWh', or some similar comparative numbers. The policy inference suggested by such cost comparisons is that the gas-fired combined-cycle station is to be preferred to the wind farm, and that the photovoltaic array cannot compete with the other options.

However, closer examination of the financial techniques used to derive these cost figures reveals serious shortcomings - shortcomings that cast doubt on the costs traditionally used to compare different generating technologies, and the policy conclusions based on these comparisons. In particular, for fuel-based generation, the inferred cost of a unit of electricity depends to a significant extent on the cost of the fuel. Over the operating life of a gas-fired combined-cycle station, for example - twenty years or more - the cost of gas could rise substantially, but unpredictably. To an analyst considering the station as an investment, this fuel-price risk, raising the estimated lifetime cost of electricity from the station and thereby reducing its profits, must incur a premium. The result may be to double the estimated cost of electricity from the station. By contrast, the cost of infrastructure electricity, perhaps from a wind farm or a photovoltaic array, is known from the outset, an initial capital investment with no fuel-price risk to be considered.

The details of this analysis are still emerging, but some preliminary conclusions are startling. Recent commentary has taken for granted that official government support for renewable generating technologies, notably in Europe, increases the cost of electricity to users. However, if the aggregate generation on a system is considered as a portfolio of investments, adding low-risk infrastructure generation such as windfarms and even photovoltaics to the portfolio actually decreases the overall cost of the electricity generated on the system for a given level of risk, or reduces the risk for a given cost. Who receives the benefit of this reduction in cost is another matter; some participants are clearly accruing economic rents not yet adequately identified. Again, historical evidence indicates that an increase in fossil-fuel prices is correlated to a decrease in economic activity. Electricity prices that go up with fossil-fuel prices will aggravate the economic problem. However, for infrastructure generation, whose cost is made up almost entirely of capital servicing charges, a reduction in economic activity will also reduce interest rates, making the infrastructure electricity less expensive. In this way infrastructure generation adds stabilizing negative feedback and robustness to an economy, an attribute not hitherto sufficiently acknowledged or analyzed. The policy implications of these innovative financial insights demand much closer investigation.

An obvious corollary of the emerging analyses of risk is that so-called 'security of supply' issues for infrastructure electricity look very different from those for fuel-based electricity. The debate about 'energy security' still focuses mainly on the risk of fossil-fuel supply disruption and price volatility. Infrastructure generation eliminates both problems. Moreover, since such generation may be sited closer to users, infrastructure electricity also reduces other risks of traditional electricity with its remotely-sited large-scale generation, especially vulnerability to accidental or intentional disruption of networks.

The financial treatment of fuel-based versus infrastructure generation is only one of many financial issues arising in the transition from traditional to innovative electricity. In traditional electricity finance, revenues come ultimately from charges decreed centrally and paid by captive customers and taxpayers. For networks, at the moment, this approach still broadly prevails, if indirectly. For generation, however, such traditional arrangements were substantially swept away in the first phase of electricity liberalization. Instead generators earn revenues based ultimately on commodity transactions in units of electricity, at unit prices established by a 'market'. Wholesale transactions, mediated by a vast existing infrastructure, particularly of networks, appear to offer a plausible form of business, at least in the short term. However, for all but the most intensive industrial users, competitive retail transactions are yet to prove satisfactory. Vying to sell anonymous units of electricity at the customer's meter, a company can compete only on price. Margins become perilously thin. When customers can change supplier at short notice, a month or less, the customer base becomes hair-raisingly volatile. Even at the wholesale level problems are now surfacing. Wholesale prices in the UK, for instance, have fallen so low that some generators cannot even cover their cost of capital. In response, the owners have been shutting down power stations, potentially permanently. In such a situation the 'electricity market' could swing from glut to blackout with dismaying speed.

Partly to address this issue, some commentators have suggested the introduction of 'capacity payments', based not on commodity transactions in units of electricity but on a recognition that the continuous availability of a physical asset must be paid for accordingly, whether or not it is delivering a service at a given instant. Capacity payments are an early indication of what could gradually become a much more prominent feature of electricity finance, based on investment and contracts for assets, rather than on short-term commodity transactions. This will become especially the case for infrastructure generation such as microhydro, wind farms and photovoltaics, as well as for the networks that will become appropriate system complements of such generation.

It may also point the way for other business transactions and relationships on future electricity systems. Suppliers alarmed by the volatility of customers buying anonymous units of electricity as a commodity will want to win more customer loyalty, and create more long-term relationships. A possible way to do so will be by moving away from commodity transactions towards contracts for services. For instance, a supplier may offer to guarantee a customer the desired levels of comfort, illumination and other energy services, on the basis of a regular contractual payment not determined by a meter, and with a name and number to call at any time in case of problems. The supplier is effectively selling the customer 'peace of mind' - a very attractive proposition, provided the supplier can deliver. The idea is not novel. Some suppliers of unstaffed on-site cogeneration facilities, for example, have long done business on this basis. They sell not the physical plant but its on-site services, on a contract basis. The installations have remote diagnostics connected to a monitoring centre. Any potential malfunction or failure is usually detected and rectified by roving technicians even before the customer notices. A contract for services presents solid economic reasons to get the entire local system right. A supplier with the requisite competence can optimize generation and network together with building design, illumination, motors and drives, fans, pumps, electronics and other end-use equipment, to get the best available return on the combined investments in the entire system - electricity generation, delivery and use.

Such innovative financial and business arrangements could also help to address a fundamental and intractable flaw in energy investment. An investment, say, in a power plant whose output is to be sold, is treated for tax purposes as a business investment. On the other hand, an investment, say, in a high-efficiency deep freeze in a household is not a business investment, and is accordingly treated much less generously for tax purposes. This basic assumption, common in taxation regimes around the world, skews investment inevitably toward provision of more electricity generation instead of more efficient end-use equipment. If, however, the entire local system is integrated to sell not units of electricity but energy services, the entire investment can be legitimately treated as business investment. Over time, the consequences for the human energy-service infrastructure of this one single change of policy could be dramatic.

It also illustrates a central issue that must be addressed. What we call 'energy policy' is still really 'fuel and power policy', preoccupied with batch transactions in commercial energy carriers treated as commodities and priced by the unit. The expression 'energy policy' dates back to the so-called 'energy crisis' of the early 1970s, when the OPEC oil shock coincided with problems affecting natural gas, coal and electricity in many countries. 'Energy' became a headline shorthand for all these energy carriers; the term has been used this way in policy ever since. It is profoundly misleading. It implies that one form of so-called 'energy' can be readily substituted for another. In modern industrial society, on the contrary, a particular piece of end-use technology requires a particular specialized energy carrier. A particular car, say, must have high-octane unleaded petrol, not just petrol nor petroleum, much less coal. Changing energy carriers means changing end-use technology too; across society this is an expensive and long-term process. 'Energy policy' that concentrates entirely on the availability and cost per unit of commercial energy carriers misses the most important part of human energy systems - the energy service systems, especially buildings and their fittings.

Real energy policy should be far wider in scope than fuel and power policy. Real energy policy should encompass all aspects of energy investment - not just in facilities to produce and deliver commercial energy carriers, but more importantly in facilities to deliver the energy services people actually want. Real energy policy, therefore, should broaden its vision beyond batch transactions in commodities. The policy levers should include asset accountancy, asset taxation and all the related measures affecting investment in infrastructure of every kind, particularly energy-service infrastructure.

Electricity, with its distinctive attributes and its applicability to integrated local systems, could mediate the transition to real energy policy.

At the same time, local electricity systems might also help to counter one infrastructure trend that is now of increasing concern. Mergers and acquisitions are producing a rapid international agglomeration of ownership of electricity and gas networks into a handful of enormously powerful multinational companies. These new monoliths may pose major problems for national regulators, not to mention customers. A monolith may control, for instance, the supply of gas from a remote field. Electricity, however, can be generated anywhere, at a price, particularly infrastructure electricity. A customer discontented with the terms on offer from the neighbourhood monolith can opt instead for an integrated optimized local infrastructure electricity system, independent of the monolith. At the moment such an alternative is usually dismissed as too expensive. But more accurate comparative costing, combined with relentless technical advances, may soon make this alternative seriously attractive. Such complete local systems may indeed be more effective than simple on-site generation as a form of competition to keep monoliths from misbehaving.

A further consideration applies for those users with sensitive loads such as data processing facilities and server farms, an increasing proportion of electricity use. In the aftermath of liberalization, with reduced redundancy and reduced staffing of fieldwork, electricity networks themselves may now be the main source of disturbances such as transients and harmonics, voltage spikes, voltage sags and other potential trouble, not to mention actual power cuts. For a user with sensitive loads, such disturbances can be dismayingly expensive. An on-site system using highly reliable generation, especially infrastructure generation, may be an insurance premium worth paying.

Many if not most of the issues now facing electricity are complicated primarily by the existence of traditional legacy assets, institutions and mind-sets. Some commentators have argued for years that those parts of the world unburdened by the inertia of such a legacy - the two billion people without access to traditional electricity - may be able to 'leapfrog' over traditional arrangements, to take advantage more easily of the opportunities for innovation in technologies and institutions, and of innovative ways to think about energy in society. Innovative approaches to buildings, to local electricity systems and to infrastructure electricity, untrammeled by problems with fuel, may be both more necessary and easier where no stultifying electric legacy exists. Nevertheless, such leapfrogging can only take place with the active involvement of those who already have electricity, the technologies, the experience and the finances. The potential for mutually beneficial cooperation is vast; but the stumbling-blocks are many and obtrusive.

Much contemporary policy on sustainability, on energy and especially on electricity, focuses on reducing the environmental impact of energy provision and use, particularly the impact on climate. For at least three decades governments have been exhorting their citizens to use less energy. This is simply erroneous. We do not need to reduce the use of energy; we can use as much energy as we wish. We need to reduce the use of fuel, a very different and much narrower problem. We need to use less fuel, and more infrastructure energy - not only the familiar and unnoticed infrastructure energy in the form of heat, but also innovative infrastructure energy in the form of electricity. Indeed that approach may nevertheless reduce overall energy use anyway. Concentrating on infrastructure electricity in local systems will encourage optimized design, with high-performance loads to take full advantage of local electricity. Some commentators, including the present author, have speculated as to what 'sustainable electricity' might look like. As infrastructure electricity - unmetered, unmeasured, paid for as an investment rather than by the unit - gradually becomes a larger proportion of the mix, sustainable electricity may eventually be completely invisible.

We must, however, get there from here, around the world, while minimizing disruption and keeping the lights on. After this Overview, surveying the key issues, two more Working Papers, 'Generating Change' and 'Networking Change', will examine in more detail the problems and the policy options for this difficult transition. The prize could be a sustainable planet; but the task is awesome and daunting. It will demand technical flair, financial acumen and political courage. Can we meet the electric challenge?