Issue Brief

TRANSMISSION AND DISTRIBUTION

WHAT IS T&D?

T&D grids consist of two major elements:

1. *Transmission* networks carry electricity over long distances, generally using pylons and overhead power lines. They operate at high voltages (110 kilovolts and more), linking large generation plants to substations.
2. *Distribution* networks take the electricity from these substations and transport it to consumers (e.g., industry, commerce, households). They have many more lines than those for transmission and are generally underground. They operate at progressively lower voltages, with those supplying households at the lowest voltages (medium-voltage distribution ranges from 1 to 110 kV, low-voltage distribution below 1 kV).

Both transmission and distribution networks are "natural" monopolies – it would be too costly to have competition based on parallel networks. They are regulated whether they are in public or private ownership.

This *Issue Brief* concentrates on the mature T&D networks served largely by centralized generation that provides the vast majority of the world's electricity. Please see the special section in *Powering a Sustainable Future* for a discussion of the potential, and the advantages and disadvantages of decentralized generation.

WHY IS T&D IMPORTANT?

Sustainability goals for the grid of the future are:

1. Security/reliability of supply (no blackouts, and better access in developing countries);
2. Market integration and interconnection to allow power trading and increased reliability;
3. Integration of renewables;
4. Minimization of losses (increasing efficiency);
5. Reduction of environmental impacts from T&D lines.

To achieve these goals, the public focus on power generation must be complemented by a similar focus on transmission and distribution. A sustainable electricity supply can only be granted with a broad understanding of how to secure a reliable grid.

INVESTMENT

Before addressing the key dilemmas in achieving each of the sustainability goals, it is important to highlight the role of investment, which is one of the key constraints on electricity grids: the International Energy Agency (IEA) has estimated that US$ 1,500 billion will be needed globally between 2001 and 2010, approximately two-thirds of which will be for distribution grids.[1] Also according to the IEA, T&D investments are expected to be larger than those needed for new generation plants, with 54% of the IEA's total power sector investment estimates earmarked for T&D (see Figure 1). Investment conditions have to be suitable to actually mobilize this amount of capital.

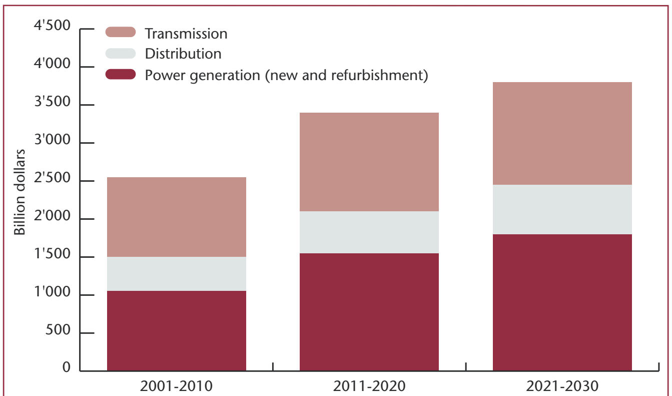

Figure 1: Electricity Sector Investment, 2001-2030

Source: International Energy Agency (IEA). *World Energy Investment Outlook*. 2003.

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However, incentives to invest are rarely adequate. Investments in grid reliability often do not take place because the investor is not the one who gets the payback or because of competing interests between generation and transmission owners. Figure 2 shows that transmission investments in the US have lagged behind demand growth for decades and have only just started to catch up.

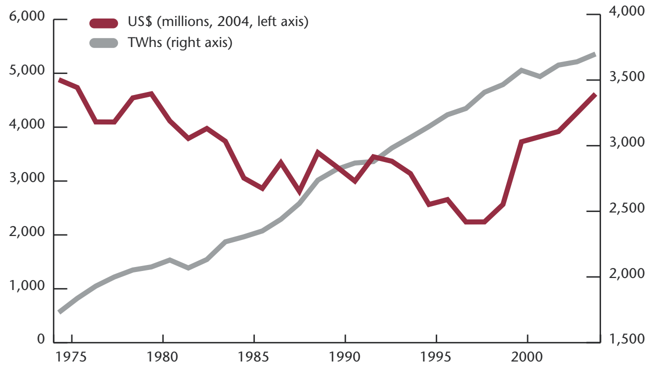


Figure 2: US transmission investments and power demand

Sources: Edison Electric Institute[2] and US Energy Information Administration.[3]

ENSURE SECURITY/RELIABILITY OF SUPPLY

Many utilities see reliability of supply as one of the most pressing concerns to be addressed in their business (see Figure 3). Uninterrupted electricity supply is becoming more and more important to customers as well as for society as a whole. For instance, it is estimated that the major blackout in the US on 14 August 2003 cost US$ 7 to US$ 10 billion.[4] Blackouts are often the result of under-investment in T&D capacity and the use of outdated technology.

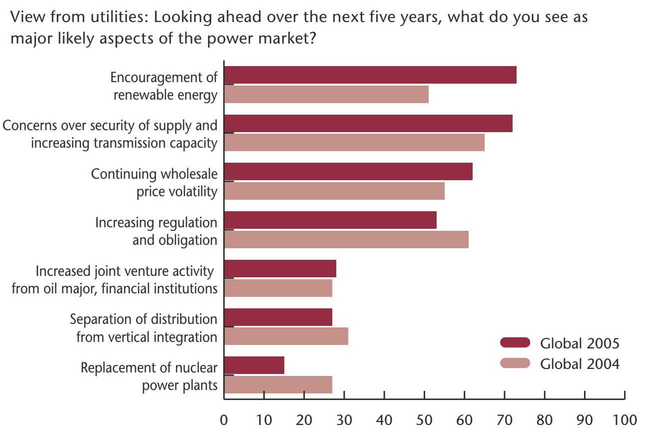


Figure 3: The importance of transmission capacity from the perspective of utilities

Source: PricewaterhouseCoopers. *Under Pressure*. 2005.

Article: "Transforming the Electric Infrastructure", Physics Today, December 2004

In the 1990s, capital expenditure of the US electricity sector was about 12% of total revenues. That life-support level of investment, about half the historic average, was only previously approached during the depths of the Great Depression and World War II, times when private investment was generally low. Such low levels of investment are dangerous and unacceptable. Moreover, a large share of the investment during the 1990s was in power generation rather than improvements in power-delivery infrastructure. That period of low investment saw the economic cost of power disturbances, from minor blips to major outages, grow to roughly US$ 100 billion per year in the US, according to an Electric Power Research Institute survey of key industries. In other words, for every dollar spent on electricity, consumers are spending at least 50 cents on other goods and services to cover the costs of power failures.

Downtime in most developed countries is low (see *Table 1* below), but major blackouts have become more frequent in some countries.

Country	
Japan	4 min.
Germany	15 min.
Netherlands	25 min.
France	57 min. (excluding impact of heavy storms)
Great Britain	63 min.
Sweden	152 min.
Norway	180 min.
Italy	191 min.

Table 1: Average time of interrupted supply per customer (1999)

Sources: Council of European Energy Regulators. 2000; VDEW (Verband der Elektrizitätswirtschaft (Association of the electricity industry in Germany).

Proven T&D technologies are available to meet today's need for grid reliability (without further research requirements, see the end of the issue brief), but the main obstacle remains investment.

A sustainable power supply is only guaranteed if reliable transmission is complemented by reliable power distribution. In many emerging markets there is a need to increase the level of equipment quality to provide more access and reduce technical losses, but commercial losses through theft and insufficient metering equipment prevent the necessary investments.

The high incidence of T&D losses in India is partly responsible for huge power shortages and distorted tariffs. T&D losses in India in the late 1990s are shown in Table 2 below. A reduction in T&D losses by 1% would result in savings in capacity of about 800 MW.

Source: India Infoline Ltd.

Years	%
1995-96	22.2
1996-97	23.0
1997-98	21.8
1998-99	20.8
1999-00	NA

Table 2: T&D losses in India

MARKET INTEGRATION AND INTERCONNECTION

The legal framework in many mature markets demands an open market for electricity, the prime objective of which is economic efficiency and price benefits to customers. But a lack of power grid interconnectors across regions (e.g., in Europe) or countries (e.g., in the US) is an obstacle to the implementation of market integration. Interconnectors can bring:

- Connections between isolated markets and core markets;
- Improvements in supply security;
- Transit of electricity;
- Full market integration;
- Exploitation of price differences.

The European Commission has stated: "reaching a minimum level of interconnection of around 20% of peak demand in any area with the rest of the European Union could help eliminate segmented markets and create a really competitive internal market".[5] The average rate of cross-border flows in 2004 was only 10.7% of national consumption.[6] Strengthening the internal market will require the further development of cross-border trade tariff-setting rules, and congestion management rules.

Within the EU, a greater proportion of customers has switched suppliers (a measurement of competition) in the countries where market opening started early.[7]

Increased reliance on cross-border trade could destabilize electricity grids unless sufficient grid capacity and more sophisticated technologies are employed. At the same time, liberalized markets also put more cost pressures on utilities, often resulting in a lack of investment in grid capacity. In many countries Independent System Operators (ISO) are being installed to ensure the right priorities.

Nevertheless, once there is sufficient capacity and technology, market integration with increased power trading can enhance reliability, as the system becomes more flexible, and the failure of a single component has a relatively smaller impact.

The electricity system of the future has to be built on existing infrastructure. Breakthrough technical components are not foreseen, but future grids will be more interconnected than today's "island" power systems that we have inherited. Real-time control of transmission networks will reduce the risk and scale of blackouts. The power grid could develop towards an Internet-style structure, but with important differences: electricity is a physical commodity whose transport (unlike information signals) requires more expensive and sophisticated technological solutions.

The development of interconnections is a sure way to market integration, but at the other end of the network (on the consumer side), a technological breakthrough in intelligent metering would permit consumers to enter the market. In distribution, IT and "Smart Networks", coupled with intelligent metering and time of use (TOU) tariffs, will allow embedded generators to export to the grid and peak demand to be reduced. In this environment, broad cooperation between network managers and regulators will be essential to ensure smooth operation and quality of service.

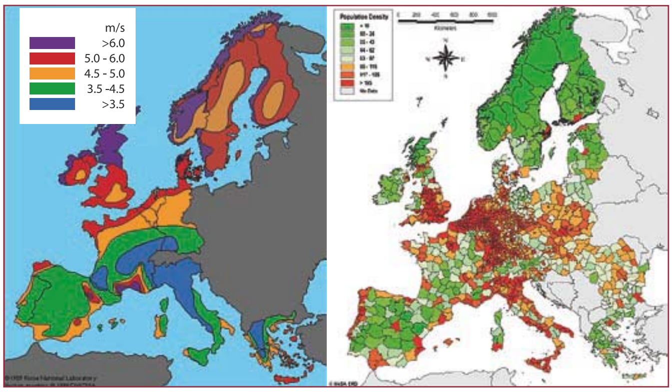
INTEGRATION OF RENEWABLES

One of the key benefits of T&D grids is that they allow the generating mix to change without altering the service supplied to customers. However, if all options are to be available (including wind and other renewables), this has major implications on grid design and costs.

The design and operation of the T&D system has a major effect on what type and quantity of electricity generation plant can be attached to the system, and thus on the quantities of CO_2 (and local pollutants) that are emitted during power generation.

The key issue is often the ability of the system to incorporate renewables (principally wind), potentially in large quantities. Locations for windmills with a capacity factor as high as 40% – compared to the average 20% in today's wind plants – can be found e.g., offshore or on remote costal areas.

This is not a straightforward problem: those sites with the most favorable wind conditions and minimal visual impact are generally far from existing transmission grids as well as from load centers (see Figure 4). The intermittent nature of renewables generation poses additional problems for grid design and operation. If remote locations with a high capacity factor are chosen, the cost of grid reinforcements are typically more than offset by the higher production of power. In addition, transmission losses are more than compensated by higher production.



Sources: Risø National Laboratory[8] and International Institute for Applied Systems Analysis (IIASA).[9]

Figure 4: Wind speeds and population density in Europe

Technical solutions exist to solve these problems – the main challenge is the cost of new connections, and who should pay for them. Many countries have support schemes for renewables, but to date these have principally focused on generation rather than T&D. As a consequence, bottlenecks and instabilities are created, which do not allow installed renewable capacity to be used optimally.

Germany and the UK have started to estimate the required T&D investments along with wind power investments. Germany has more installed wind capacity (currently 17 GW) than any other country in the world and has plans to increase this further. The German energy agency DENA verified the costs of bringing this wind power to the grid. For an expansion of capacity by 21 GW by 2015, DENA estimates an associated 400 km of grid upgrades and 850 km of new construction, at a cost of EUR 1.1 billion.[10]

MINIMIZATION OF LOSSES

Reducing system losses will clearly reduce generation requirements and the environmental impacts associated with generation.

Modern T&D systems tend to lose about 6-7% of the electricity they transport. Approximately 70% of these losses occur in the distribution system, which is more extensive than the transmission system, but also operates at lower voltage. Losses in lines are inversely proportional to the square of voltage, i.e., doubling voltage reduces losses to a quarter of their original value. Losses of more than 30% are quoted for developing countries, but it is important to distinguish between physical losses and commercial losses (i.e., electricity which cannot be accounted for, generally due to illegal connections). Technical losses are rarely above 20%, and technologies such as high-quality transformers and reactive power compensation, plus operational measures to configure the network optimally as a function of load variation, can be used to reduce these to down to a minimum of 5-7%.[11]

High levels of commercial losses can be devastating to system operators; if they cannot collect sufficient bills, they cannot generate capital for investment. Utilities can only invest in installations if they are financially viable. The commercial loss problem should thus be treated as a priority issue.

Network tariffs and intelligent metering may also be used to give customers the opportunity to monitor their consumption and shave peaks. Such "load leveling" can lead to very high marginal savings both in terms of costs and emissions.

REDUCTION OF ENVIRONMENTAL IMPACTS FROM T&D LINES

Visual impact of overhead power lines

Sometimes the impacts of power lines can be a substantial barrier to new projects. The NIMBY syndrome ("not in my backyard") sometimes hampers necessary investments in power infrastructure. One problem is that reliable power is taken for granted – without recognizing the need for T&D investments. Additionally, as in any NIMBY situation, people wonder why they should have to suffer the local impacts when most of the other people who benefit from power lines do not.

One solution to the NIMBY problem may be technologies for underground power transmission (e.g., high-voltage direct current based on voltage source converters), which eliminate the need for overhead power lines and – at the same time – increase grid reliability. Underground lines have generally been used only for lower voltage lines in built-up areas and for high-voltage lines in environmentally sensitive locations.

Incorporating the visual impact of overhead power lines into economic costs is not a straightforward process and no generic estimates have been developed. Conventional estimates indicate that the ratio between the financial costs of underground and overhead lines is of the order of 8:1 for a 400 kV line in flat country, decreasing to approximately 4:1 for 100 kV lines.

Such financial costs do not take into account the full range of costs: more complete estimates of costs include differences in losses, reliability and availability, maintenance and changes in contractual costs and time to market (of these, differences in losses tend to have the biggest impact). Using such estimates as the basis for comparison tends to halve the ratio of costs of underground and overhead power lines. For the highest voltages, the economic costs of direct current (DC) lines are in line with those of overhead lines (see Figure 5 below). For long distances, DC is the lowest cost option. Underground cables have the further advantage of being much less vulnerable to damage from storms and earthquakes.

Source: ABB calculations. 2006.

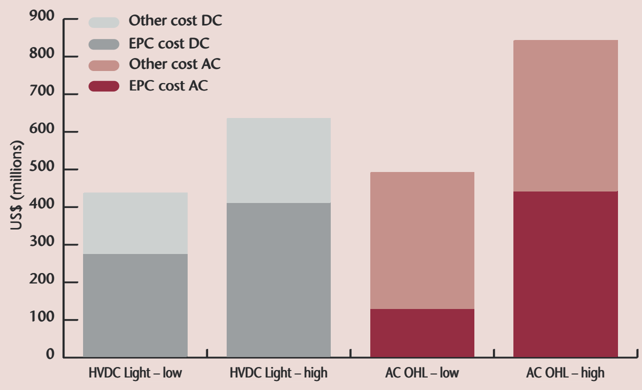


Figure 5: Costs of underground power links, 700 MW example

Notes:
Other costs include interest during construction, losses, pre-contractual costs, time to market, reliability & availability, transmission line maintenance, increased AC system capacity (negative cost, only for HVDC alternatives)

EPC – Energy performance contracting

HVDC Light – High voltage direct current light (underground transmission)

AC OHL – Alternating current overhead line

Electromagnetic fields (EMF)

There are concerns about the health impacts of magnetic fields generated around power lines. The strength of the field, and hence any possible impact, increases according to the voltage of the line. Studies have not established any significant impact but research is still being carried out in this field. Nevertheless, some countries (e.g., Holland, Sweden, Switzerland) have recently imposed much tighter requirements on EMF and it is being discussed in other countries. Despite the lack of any demonstrable impact, people often try to avoid living close to power lines. This is based on the "Precautionary Principle", that states that if there are doubts, economically reasonable measures should be taken to avoid raising the "natural" levels of radiation.

Emissions of SF_6

SF_6 is a particularly potent greenhouse gas. A final major source of direct environmental impact is from the insulation material used in switching gear. Switching gear is used to interrupt electricity supply (i.e., to switch it on or off). The high voltages of these lines mean that materials with very high insulation performance are needed, such as the greenhouse gas SF_6.

A recent study has shown that such SF_6 emissions from electrical equipment now make a very small contribution to total emissions (0.05% in the EU-15 in 2002), and that they have been reduced by 40% since 1995 in the EU-25 plus Norway, Switzerland and Iceland through voluntary industry measures.[12] This is due to voluntary action by the industry in improving the emission rates from the manufacture, use and disposal of switchgear equipment (see Figure 6).

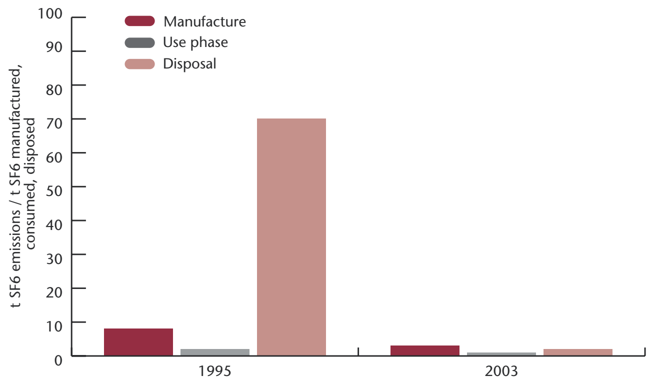


Figure 6: Development of SF6 Emission rates 1995-2003 in the EU 25 +3

Source: Ecofys. *Reductions of SF_6 emissions from high and medium voltage electrical equipment in Europe.* 2005.

RESEARCH AND DEVELOPMENT AND STATE-OF-THE-ART TECHNOLOGY

Many of the issues raised above need to be solved using policy and regulation. From a technology perspective, research & development (R&D) has been conducted and the following technology is state-of-the-art:

- Information technology such as supervisory control and data acquisition (SCADA) gives distribution systems the ability to continuously monitor and control power use.
- Transmission grid reliability is also achieved using real-time control systems such as wide area monitoring systems (WAMS), which can be integrated into SCADA systems. WAMS help prevent the collapse of entire power networks, limiting outages to smaller geographical areas than the current "cascades" which can see major parts of networks failing consecutively.
- Both congestion management systems (e.g., FACTS – flexible alternating current systems) and the high performance overhead conductors issuing from present research can increase system capacity by 30% on average without additional lines. FACTS benefits security, flexibility and voltage stability.
- High voltage direct current (HVDC) transmission allows transmission over longer distances, with lower losses. Voltages of up to 800 kV are currently available, which allows lines of up to 2,000 kilometers. This would effectively allow many more regional and cross-border interconnections, for large countries such as China and India. Options with lower costs than DC are currently available for all but the longest distances.
- HVDC light is a new power transmission technology, which uses voltage source converters. It is designed for underground or underwater power transmission for longer distances and has a capacity of up to 1 GW. Technology benefits include: no visible impact, a neutral electromagnetic field, oil-free cables and their small size.
- Gas insulated switchgear (GIS) – new developments in conventional technologies now allow large amounts of power to be transmitted unobtrusively. GIS permits compact indoor substations. This reduction in the plant's "footprint" can often release valuable land for development in a city's center.
- Superconductors in power applications will not be economically viable within the next decade, but they remain an area for further research.

REFERENCES AND NOTES

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6 European Commission. Communication from the Commission to the Council and The European Parliament. *Report on progress in creating the internal gas and electricity market.* November 2005. See http://ec.europa.eu/energy/electricity/report_2005/doc/2005_report_en.pdf; the percentage of cross-border flows in total consumption is not directly equivalent to the ratio of imported capacity to peak capacity (referred to in the 20% figure). These figures are only comparable as an approximation, and as an illustration of the "fact that the interconnection capacity available to the market between many Member States is still broadly insufficient to allow proper integration of national markets and competitive pressure from imports" (quote from report cited in this footnote).

7 Ibid.

8 http://www.risoe.dk/vea/projects/nimo/flashhelp/EuropeanWindResource.htm.

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Our **mission** is to provide business leadership as a catalyst for change toward sustainable development, and to support the business license to operate, innovate and grow in a world increasingly shaped by sustainable development issues.

Our **objectives** include:

- **Business Leadership** – to be a leading business advocate on sustainable development;
- **Policy Development** – to help develop policies that create framework conditions for the business contribution to sustainable development;
- **The Business Case** – to develop and promote the business case for sustainable development;
- **Best Practice** – to demonstrate the business contribution to sustainable development and share best practices among members;
- **Global Outreach** – contribute to a sustainable future for developing nations and nations in transition.

Acknowledgements

This issue brief is part of *Powering a Sustainable Future: An agenda for concerted action*, a product of the WBCSD's Electricity Utilities Sector Project.

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