Environmental Impacts of Long Distance Energy Transport: Additional Benefits of Efficiency

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Demand side management (DSM) has both economic and environmental benefits. The economic benefits are the incremental capital and operating costs incurred in the absence of DSM, and the principal environmental benefits are reduced emissions from avoided fuel use. For electric and gas DSM, avoided emissions occur at the extraction, fabrication, and transportation stages of the fuel cycle, as well as the widely studied final conversion/usage stage. The role of transmission and distribution has begun to be included in cost-effectiveness analyses of DSM, as T&D costs, T&D losses, pipeline leaks and pumping energy are considered.

Here we focus on environmental impacts of power transmission, which can contribute significantly to the benefits of electric DSM. Since our approach can also be used to explore the environmental impacts of gas pipelines, and the related benefits of gas DSM, we also provide examples for gas transport. The environmental impacts of T&D are particularly important as transport of energy (e.g., hydro, low sulphur coal, renewable) over long distances to effect economies or environmental benefits is pursued in an increasingly competitive and diverse energy sector.

We develop a framework for both generic and site-specific environmental impacts from both operation and construction, including land-use, emissions, noise, EMF, and habitat impingement. Our aim is to provide a basis for screening or strategy analysis useful in DSM, IRP or transmission line routing from a life-cycle perspective. The framework could be used with ecological constraints, monetized values, or a systematic matrix of impacts to which planners could apply judgments.

Introduction

Over the past two decades, international energy trade has grown at roughly 2% per year, about the same rate as global growth in primary energy supply (2.5%). However, as shown in Table 1, these aggregate figures, dominated by fairly flat global oil trade, mask the rapid growth in international trade in electricity (8% per year) and natural gas (9% per year) over the same period.

Historically, the primary objectives of long-distance energy trade have been to access new energy sources and to guarantee system reliability. Increasingly, potential economic gains of international trade are becoming the driving force for distant transportation. In electric systems the existing generation capacity can be used more efficiently by expanding the transmission links between different power pools.

Transmission of electric energy is also being used to shift environmental impact from densely populated areas with high environmental burden to rural areas, or to access remote sources of renewable energy, e.g., hydropower. In the U. S., for example, transmission is used to displace fossil fuel generated power in Southern California with hydropower from the Pacific Northwest or to interconnect load areas in New England and down-state New York with Canadian hydropower. Potential environmental benefits of transmission projects have been the object of several studies (e.g., (Parson 1988), (Neme 1987)).

Our approach to the analysis of energy systems in general, and to energy transportation options discussed in this paper is based on the concepts of integrated resource planning (IRP). According to IRP the objectives for

Table 1. International Trade in Energy (PJ), 1971-1990. Source: International Energy Agency (export data)

	1971	1975	1980	1985	1990	Annual Growth 1971-90
Coal	4916	5728	7663	9662	10997	4%
Natural Gas	2011	4097	6716	7922	10163	9%
Oil	67350	71256	77769	62542	79727	1%
Electricity	252	357	585	790	1099	8%
Total	74528	81438	92733	80916	101987	2%

transmission/transportation projects are not only of a strict economic nature and should include (DeCicco et al. 1992):

- minimizing the cost of services for customers
- maintaining reliability
- minimizing local environmental and health impacts
- minimizing regional and global environmental externalities.

In recent years, IRP, which was originally based on the concept of least cost planning, has been extended in a number of ways. Integration is not only between supply and demand, with the cost of more efficient demand measured against the avoided supply costs. It suggests application across fuels, and across sectors to achieve additional economies. Building on the Public Utility Regulatory Policy Act of 1979 which attempted to promote conditions for cost-effective cogeneration and small power production to play a role in the regulated electric industries, IRP is now paying specific attention to these options and the renewable resources and technologies often associated with them.

Beyond concerns with long-run costs and system reliability, IRP has been increasingly concerned with non-traditional “costs” and benefits such as diversity/ flexibility, environmental externalities, economic impacts, and social equity. Some have suggested that truly integrated planning requires that the full fuel cycle be taken into account in IRP analyses, since significant environmental impacts occur in the extraction, processing and transport segments of the cycle.

In this paper we do not investigate the overall economic and environmental effect of energy transport, but we focus on the transport system itself, a stage often neglected in past full fuel cycle analyses. Long-distance energy transport, particularly for electricity and natural gas, requires major infrastructure investments for transmission, transportation, and distribution. These investments and their operation can have significant environmental impacts of a multiple nature, including land-use, emissions to air, water, soils, visual impacts etc. When comparing distant supply options, supply options closer to load centers and demand-side management (DSM) options it is important to consistently include these environmental impacts, because they represent an additional burden of distant supply options, or, expressed in other terms, an additional benefit of supply options closer to load centers and of DSM options.

In the following sections, we develop a framework for including these effects into IRP analysis. The aim is to provide a basis for a screening approach within IRP in order to include environmental and health concerns in an early stage of the planning process. A consistent screening procedure is at the same time an efficient tool in reducing conflict and improving communication in the subsequent stage of siting new lines.

Siting transmission lines and pipelines is becoming increasingly difficult. Local resistance to the lines usually involves concern about the perceived impact of both the line itself and the right of way (ROW) through which it runs. Residents worry that a power transmission line will change the area’s visual aesthetics. They also fear the impacts of the ROW, in terms of possible soil erosion and potential impacts on wetlands and wildlife. Finally, the public’s perception of electric and magnetic fields (EMF) raises further concerns that should be considered in the IRP framework. According to (CECA/RF 1990), environmental and land use concerns are, together with the technical and economic assessment of system need, the most important criteria applied in transmission line siting and certification throughout the U.S. (Table 2).

Table 2. Review Criteria Applied in Transmission Line Siting and Certification Throughout the U.S. Source: (CECA/RF 1990)

Criteria in Review Processes	Percent of Jurisdictions with Review Process
Need	71
Public environmental concerns	66
State environmental regulations	61
Public interest	61
Local land use and zoning	59
State land use requirements	50
Economics	16
Reliability	11
Size	7
Other	18

The environmental impacts of electric power lines occur in ecosystems both at the local and at the regional/global level. Typical **local effects** are related to the impacts on soils, local hydrology, flora and fauna caused by construction processes and management of the *right-of-way* (ROW)[1]. Impacts on the aesthetic quality of the landscape are also of a local nature. **Regional/global** effects arise from air pollutants emitted at the stages of construction, production of materials, additional generation to compensate electric losses, maintenance and decommissioning.

Avoided Transmission Costs: Ongoing Research

At present, the strongest incentive for including transmission and distribution systems in integrated resource planning is of a purely economic nature. Public service commissions and utility planners have realized that DSM measures, when properly targeted to specific geographic areas, can significantly defer the need for capital spending on transmission and distribution (T&D) systems. By peak load shaving on overloaded T&D components, DSM can reduce the need for new transmission lines, feeders, substations, and secondary equipment. (EPRI 1990; Amy 1991; Heffner 1993).

Since for many utilities T&D expenditures are significantly greater than expenditures for generation capacity, targeted DSM programs can produce substantial savings. To achieve this, DSM programs must be tailored to the area- and time-specific needs of the utility's T&D system; this task can be considerably more difficult than the design of DSM programs purely for systemwide energy savings.

The value of T&D savings available through DSM varies widely from area to area.[2] Moderate savings can be expected in areas with excess T&D capacity and slow load growth. Significant savings can be achieved in areas with capacity in short supply due to continuous but moderate growth. On the other hand, it can be more difficult to achieve significant savings in areas with rapid growth (EPRI 1992).

The development of analysis tools and the collection of data needed for the analysis of avoided T&D costs is ongoing at all levels of the electric power industry. In the near future it should be possible to allocate T&D costs with greater accuracy to different DSM options. In conjunction with the allocation of costs, it will also be possible to allocate environmental impacts of T&D systems with greater precision.

Avoided Environmental Impacts of Transmission: Developing a Framework for Analysis

Introduction

The importance of including the avoided environmental impacts in addition to the avoided economic costs of transmission into IRP is the starting point for developing a quantitative classification framework to be used as a screening tool.

Environmental and health impacts occur both locally and far away from the transportation system. Some impacts are continuous during the operation of the system, others are discontinuous (Table 3). We use a life-cycle analysis approach covering all impacts that are functionally related to the energy transportation system. This includes impacts from construction, material production, operation (including compensation of losses) and decommissioning.

Table 3. Environmental and Health Impacts of Energy Transportation Systems

Time Space	Continuous During Operation of System	Discontinuous (at Beginning/ End of Operation)
on-site (close to transmission system)	• land-use • emissions from operation and maintenance • audible noise during operation • electrical effects of power lines (corona, electric/magnetic fields) • visual/aesthetic impact on landscapes	• natural habitat impingement • emissions from clearing the "right-of-way" and construction • audible noise during construction
off-site (far from transmission system)	• energy losses of the line, that must be compensated by increased generation	• emissions from the production of materials for infrastructure

We use the classification system developed by (Knoepfel 1994) including six major environmental impact categories: natural habitat impingement, land depreciation, audible noise, potential electric and magnetic field impacts (these are treated separately) and air emission impacts (Table 4). Other impacts are not included because of their distinct local nature: e.g., visual/aesthetic impacts, impacts on ground-water and aquatic systems, impacts on soil stability and erosion, waste heat. Other instruments, e.g., environmental impact assessments (EIS), should be used to fully capture the local dimension of these impacts.

Table 4. Classification Framework According to Knoepfel 1994

Environmental and Health Impact Category	Unit of Measurement
Natural habitat impingement	m2, square meters
Land depreciation	m2*years
Audible noise impact	impacted persons*hours
Potential electric field impacts	impacted persons*hours
Potential magnetic field impacts	impacted persons*hours
Air emission impacts	external costs (U.S. dollars)

We are fully aware that the choice of impact categories, the definition of the units of measurement, the decision itself to quantify certain impacts is already a matter of valuation. This is common to all classification systems, even to those that assert to be totally “scientific.” A classification system operates at the boundary between the objective, scientific part of the analysis, and the subjective part.[3]

Habitat Impingement and Land Depreciation

To keep the quantification of land use impacts manageable in an IRP framework, land use should be classified in a limited number of major categories. Different types of land use must be previously aggregated according to these major categories. This is in contrast with the very detailed inventarization of land use at the level of local EIS studies.

Here, we focus on the **ecological dimension** of land use, thus defining three categories of “biologically productive” land and one category of degraded land, as suggested by the World Conservation Union and World Wildlife Fund in their 1991 report (IUCN/WWF 1991) (Table 5).

Table 5. Land Categories as Reported in Knoepfel 1994

Type	Name	Criteria
I	Natural Systems	Human influence very small, high value from the standpoint of biodiversity, particularly sensitive ecological habitats, once used cannot be restored to its initial quality
II	Modified Systems	Human influence greater than that of other species, but also incultivated component
III	Cultivated Systems	Human influence clearly dominant
IV	Degraded Land	Predominantly built/sealed environment, very small biological productivity

Based on the four land categories defined in Table 5, it is possible to define six classes of land use, or land depreciation: I - II (natural land depreciated to modified land), I - III, I - IV, II - III, II - IV, III - IV. After operation and decommissioning of a system, land can either be used again by a follow-up system, be restored to its initial state or restored to some intermediate stage. From the definition of land type I, it follows that this “natural land, ” once used, can never be restored again to its initial quality. For this type of land we refrain from using a time-related measure (in m2*yr) and use a measure of final consumption in (m2).

Air Emissions from Construction, Materials, Operation and Decommissioning

The framework presented here is limited to the analysis of EPA criteria air pollutants (NOx, SOx, TSP, CO, VOC, and C02) and CH4. The extension to a larger number of pollutants is envisaged and is the object of ongoing research.

According to the life-cycle methodology described previously, emissions from construction, material production, operation and decommissioning are included in the analysis. **Electric losses** occurring during the operation of a transmission line must be compensated for by an increase in power generation. The related environmental impact is included in the analysis as part of the operational impact of power transmission.

The procedure for aggregating different emissions to the single impact category “air emission impacts” used in this paper is based on the U.S. externality valuation experience[4] (also refer to the section, “Approaches to a Full Aggregation...”). The approach used in our framework is based on the approach of regulator revealed preferences, relying on environmental policy goals and requirements and then calculating the marginal costs of control to attain these goals. This approach takes the view that regulators’ decisions reflect society’s willingness to pay to avoid the environmental and health impacts from air emissions.

Potential Impacts of Electric and Magnetic Fields

Research concerning EMF health effects is ongoing, and it is not possible at this time to say with certainty whether EMF causes harm to humans, animals or plants. Several recent studies suggest the possibility that EMF may increase cancer risk to humans. The epidemiologic evidence is most consistent for childhood leukemia. There is substantial evidence that attributes other than only field strength could play a role in EMF-related health effects, however little is known up to now. Possible exposure metrics include (Adams et al. 1993):

- average field
- cumulative field
- threshold effects
- switching
- field strength windows
- frequency windows
- presence of other agents such as a DC field or toxic chemicals.

It has been suggested that the best way to include potential EMF impact considerations in an IRP context or in a route selection procedure is to indicate the number of humans affected by the line (Brody 1993). An inventory of particularly sensitive populations, including children and communities already burdened by increased health risks is also important. Information on how many persons reside, work, or attend school along the route should be included. Also, baseline health data indicating cancer rates and the presence of factors that may increase cancer risk of the affected population should be included.

Several states in the U.S. have established standards for the maximum level of the electric field within or at the edge of a transmission line ROW. Only two states, Florida and New York, have established standards for magnetic fields so far. So far, the regulators have used **average electric and magnetic field levels** as an indicator of potential electric or magnetic field impact. Our aim is to rely as much as possible on the official interpretation of potential EMF risk by regulatory bodies in defining impact categories. This is why: (1) electric and magnetic field impacts are treated separately in our framework, (2) we use a threshold criteria in describing potential EMF impacts.

As described in (Knoepfel 1994), the area close to the transmission line with electric field levels > E_{krit} and with magnetic field levels > B_{krit} can be calculated.[5] As a measure of (potential) electric and magnetic field impact, the number of individuals residing in the disturbance area multiplied by the number of hours of exposure is reported. Because of the different characteristics of electric and magnetic fields, potential impacts are treated separately, and two impact categories are defined.

Potential Benefits of DSM Related to Power Transmission

We can now use the framework defined previously to estimate possible benefits of DSM options in reducing environmental impacts of long-distance power transmission.

Avoiding New Lines

Potential benefits greatly depend on the length of the transmission line and on the type of the line. Table 6 shows potential benefits in the case of rural lines, urban lines and lines crossing both rural and urban regions.[b]

Rural transmission systems have a greater impact on natural habitats and land depreciation. On the other hand, because they completely avoid human population areas, they have no impacts related to audible noise, electric and magnetic fields. The impact from air emissions (proportional to line length) is constant for rural, urban and mixed lines. This impact derives mainly from emissions at the power plant (to compensate losses) and from the production of materials.

For the 345 kV lines described in Table 6, the potential electric field impacts are zero, even for lines crossing densely populated urban areas. The reason for this is that electric field levels beyond the ROW edge (25 m from centerline) are lower than the critical level of 1.6 kV/m used in this report. [5]

Table 6. Environmental and Health Impacts of 345 kV AC Transmission Lines (per kWh and 1000 km length). Coal generation with modern flue gas desulfurization and electrostatic precipitators is assumed.

		All-Rural Lines	**50% Rural 50% Urban**	**All-Urban Lines**
Natural habitat impingement	0.001*m2	0.0012	0.0006	0
Land depreciation	m2*year	0.037	0.019	0.001
Audible noise impact	pers*hrs	0	1.8	3.6
(potential) Electric field impact	pers*hrs	0	0	0
(potential) Magnetic field impact	pers*hrs	0	2.4	4.9
Impact from air emissions	$	0.007	0.007	0.007

Reducing the Loading of Existing Lines

If coal, oil, or gas power generation is assumed, electric losses typically account for 70% to 80% of the total air emission impacts of a transmission line with the remainder attributable to life-cycle emissions from construction, and material production. Because electric losses are proportional to the square of the current loading, reducing the load factor is usually an efficient way of reducing air emission impacts.

Figure 1 shows the effect of increasing the load factor of existing 345 kV and 765 kV lines, starting from a load factor of 0.5. The effect depends on how the increased losses are allocated to the increased transmission capacity. The **incremental** or **marginal** approach (allocating additional losses directly to the additional transmission capacity) yields values that are almost twice as high as if calculated on an **average** basis.

Reducing the loading of a line can have other positive side-effects. Magnetic field levels, for example, are reduced (they are proportional to the current loading). On the other hand, the reduction of specific air emission impacts and magnetic field levels must be weighted against the reduced transmission capacity of the line.

Downsizing a Planned Line

The possibility of implementing DSM measures is an incentive for transmission line planners to build smaller lines. Often oversized lines have been built in the past, because of the uncertainty of future electricity demand. An integrated DSM and transmission expansion plan helps to reduce this type of uncertainty. As a result, smaller lines can be used, with both economic and environmental gains. A reduction of visual and aesthetic impact can often be achieved by using lower voltage levels and smaller support structures.

Reducing transmission capacity needs through DSM also opens new possibilities to better use existing ROW corridors and existing lines. Because of the increasing costs of new ROW acquisition and because of time-consuming approval procedures, utilities are increasingly considering options like:

- adding new lines on the same right-of-way
- reconductoring old lines, thus replacing infrastructure in advance
- adding circuits or phases to existing lines
- replacing old lines with lines that yield higher voltages and capacities.

By managing and reducing demand growth, DSM can increase the relative attractiveness of these options, as alternatives to new lines.

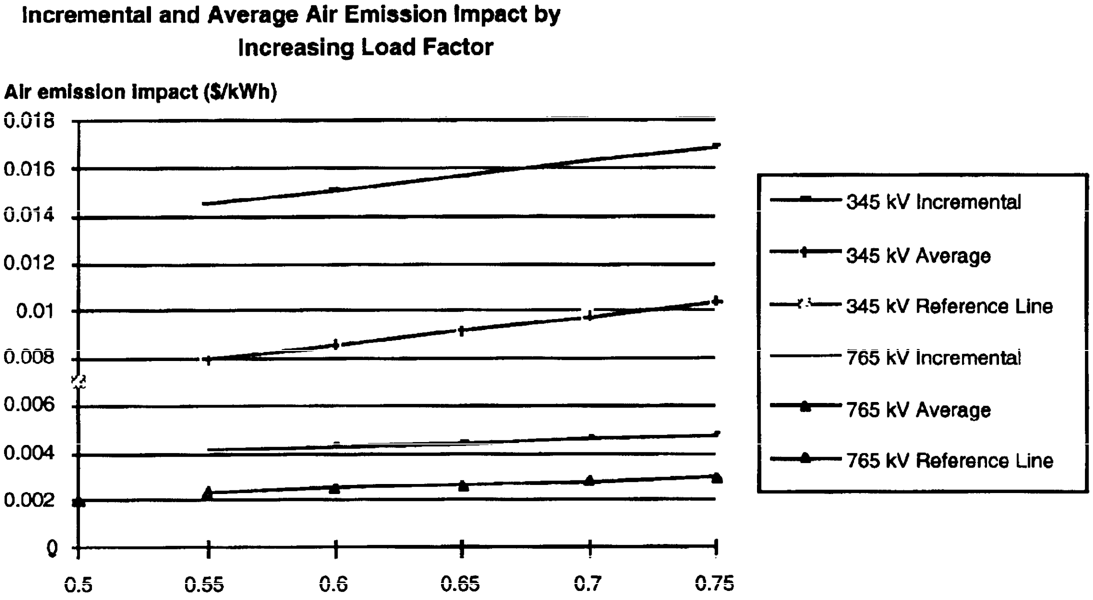

Figure 1. Incremental and Average Alr Emission impacts of increasing the Load Factor of 1000 km Lines (coal generation) (Knoepfel 1994)

Potential Benefits of DSM Related to Oil, Gas and Coal Transportation

Natural Gas and Oil Transportation Systems

In Figure 2 we compare the relative contribution of transportation costs involved in electricity production from either oil or natural gas using a variety of transportation options. [7,8] For natural gas, for instance, one could deliver natural gas via pipeline or LNG via tanker to a nearby generating facility or generate closer to the production site and deliver the electricity via long-distance transmission. As shown in Figure 2, the LNG system (including liquefaction and depressurization of the gas) is the most expensive option, and pipeline the least. This is consistent with usual practice: LNG is generally used only when other options do not exist for accessing natural gas. For oil, road transport and long-distance electricity transmission are shown to be expensive options. For the case of electricity transmission, though, this strongly depends on line size (i.e., losses) and other factors. Oil pipeline and tanker transport are by far the cheapest options.

When environmental externalities are also considered current economic transportation costs increase by 5 to 20% for a "low" externality valuation scenario, and by 30 to 150% for a "high" valuation scenario, depending on the transportation system. It is interesting to note that the inclusion of air emission externalities does not change the relative order of the systems with regards to costs.

The wide range of the environmental externalities for "oil-by-wire" options derives from the very diverging valuation of SO2 emitted by the power plant to compensate for the line losses (residual oil is assumed).

Coal Transportation Systems

A range of coal transportation systems is in use worldwide: transportation by rail, waterways, truck, and slurry pipelines. Based on the tonnages transported, rail is the most frequently used system. In the U.S. for example rail transportation accounts for more than 70% of the tonnage transported, with an average haul distance of about 500 km (Chadwick 1987).

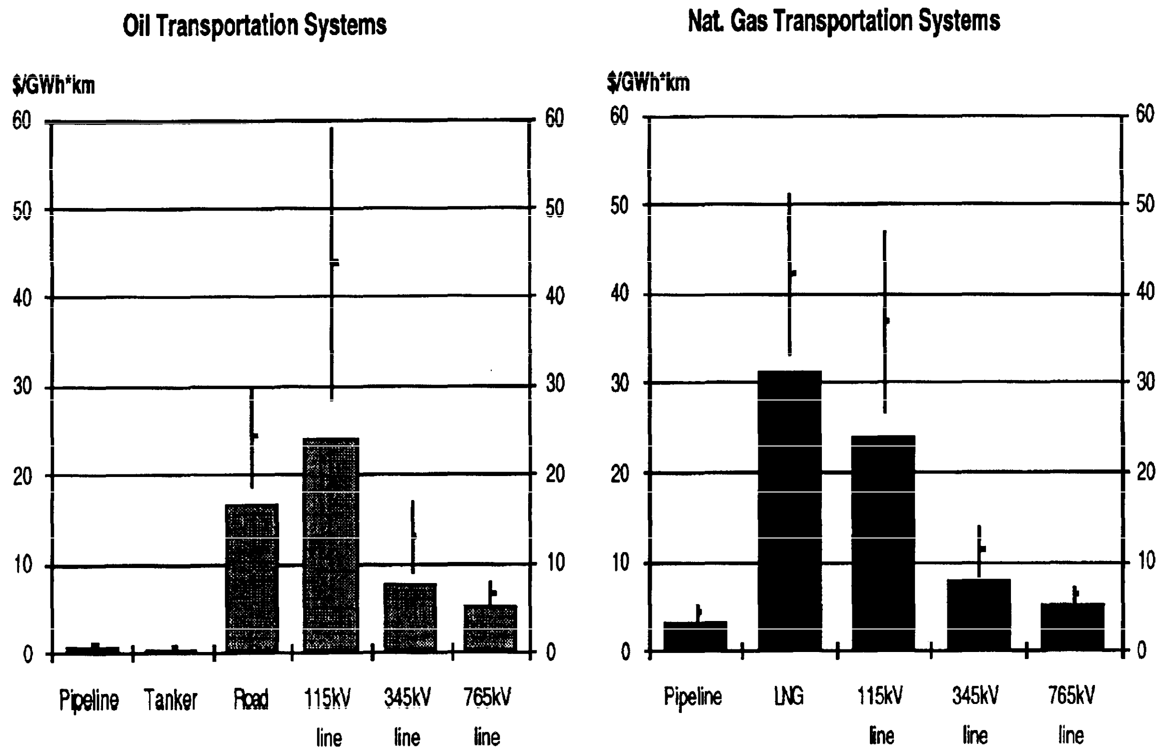

Figure 2. Typical Economic Costs (solid columns) and Air Emission Externalities (range for "high" and "low" valuation scenarios) for Electricity Generating Systems Based on Oil and Gas (Knoepfel 1994)

Economic and environmental considerations increasingly favor so-called **"coal-by-wire"** options. To avoid rail, water and road transportation, electricity generation is increasingly being shifted to sites closer to the coal mines. Electricity is then transmitted to the load centers with the use of high-voltage DC or AC power lines. The economic and environmental performance of "coal-by-wire" options is highly case-specific, depending on the distances involved, on the structure of the already existing transportation system, and on the relevance given to public and environmental risk issues.

Transportation of coal in all its forms involves fugitive dusts, which must be considered in the environmental analysis. It is generally estimated that O .02% of the coal loaded is lost as fugitive dust and a similar percentage is lost at unloading. During transportation fugitive losses also occur. It has been estimated that 16% and 23% of the mean particulate loading of the air in the U.S. Atlantic and Mountain regions, respectively, are due to coal handling (Chadwick 1987).

Results in Figure 3 indicate that "coal-by-wire" transmission with 115 kV lines is both the most expensive and the most polluting transportation option.[7] The uncertainty of the externality adder, though, is very high and is mainly due to a wide range of possible valuations of SOx and NOx emission at the power plant (compensation of electric line losses). Transmission lines with higher voltages, on the other hand, can in some cases compete with conventional rail transportation systems. The inclusion of external costs in present economic costs can, in certain cases, favor a shift from "coal-by-rail" to "coal-by-wire" systems.

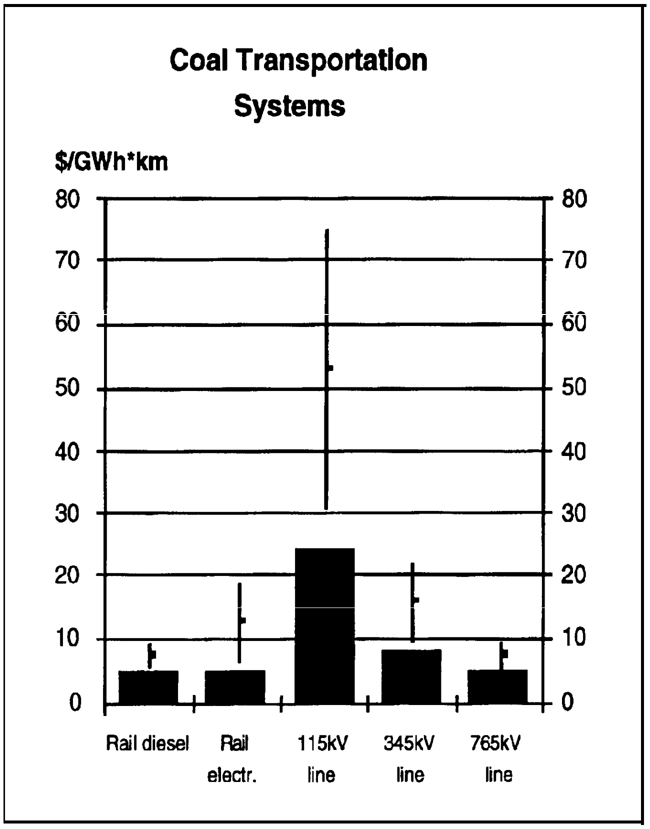

Figure 3. Typical Economic Costs (solid columns) and Air Emission Externalities (range for "high" and "low" valuation scenarios) for Electricity Generating Systems Based on Coal (Knoepfel 1994)

Approaches to a Full Aggregation (Valuation) of Environmental and Health Impacts

Many approaches have been suggested and adopted for dealing with the environmental externalities of energy production and consumption. These include damage valuation, marginal cost of control (regulators' revealed preference), multiple-attribute techniques (trade-off curves, optimization, etc.), and an environmental/ sustainability targets approach (Bernow and Biewald 1993; Hill and Lazarus 1994). However, these techniques have generally been limited to the comparative analysis of supply (and DSM) options at the state PUC and national levels, with an emphasis on air pollutants. In those cases, specific environmental regulations affecting the air pollution control technologies required and selected, provide a basis for estimating the marginal costs as a willingness to pay to avoid certain pollution impacts. Due the disparate nature of the impacts, as described above, the valuation of transmission and distribution externalities is particularly challenging. Moreover, there is a lack of scientific consensus on EMF impacts, and no straightforward regulatory basis for deriving the marginal cost of control for land use and aesthetic impacts.

Hedonic property value studies provide the only available economic estimates of damages associated with aesthetic impacts, land use, noise and EMF of transmission lines, although such studies aggregate all impacts into one estimate of damages. Several studies confirm an adverse impact of transmission lines on property values, even though these impacts do not appear to extend far from the lines (Furby et al. 1988). Typically, a decline of property value in the range of zero to 15% of the market price is reported in the literature. Other studies found no significant adverse impact on property values near transmission lines. Very little literature is available on potential externalities associated with converting open space to industrial uses or transmission line ROW, which may include recreational and ecological habitat values. Some information on the willingness to pay to preserve open space comes from data on purchases of easements by governments and land trusts to preserve selected open spaces (Warden 1989).

In our work we prefer to use a simple multiple-attribute framework for presenting and comparing the six classes of impact reviewed here, instead of using highly questionable estimates of damage. The framework does not provide a common numeraire or yield a preferred option. Nonetheless, in the use of open-ended frameworks to arrive at a final decision among T&D alternatives, explicit or implicit valuations of these attributes must be made. The framework presented here then, does not preclude the use of specific protocols for decision making, e.g., by ascribing monetary values to the impacts, by imposing sustainability targets and safe minimum standards, or both. Indeed, in our view "closing the loop" is necessary, and we have provided a framework which we hope will help the analyst and/or decisionmaker to work towards closure systematically and comprehensively.

Since many states have now adopted monetary valuation of supply option impacts, generally limited to the effects of direct fuel combustion, a similar monetized framework for T&D impacts is eventually needed. However, at present, most utility commissions in the U.S. have not recognized full fuel cycle impacts, which can complicate the analysis significantly, but which is required to accurately represent the true externalities that various supply options imply. Not only would T&D impacts need to be considered, but the externalities associated with fuel supply itself (coal mining, oil drilling, etc.), which often occur across state and national boundaries.

Conclusions and Recommendations

In the context of determining the benefits accruing to DSM options, the benefits of avoiding T&D-related environmental impacts should be considered along with the avoided impacts of T&D costs, power supply costs and fuel combustion, which are increasingly being considered in the planning analyses required by IRP in the U.S.

The framework that we present in this paper is a first attempt to characterize the environmental impacts of long-distance energy transport in a quantitative way. We hope that future research will help to improve the quality of the framework.

To be useful as a screening tool in DSM, IRP or transmission line routing the classification system should be restricted to a limited number of quantitative categories. The choice of the impact categories, the aggregation procedure within each category, the decision itself to quantify certain impacts is difficult, from a scientific perspective. With regards to each one of these steps, further improvements are needed. The aim should be to maintain a high degree of transparency at all stages of the analysis.

We have decided not to include impacts of a distinct local nature (e. g., visual/aesthetic impacts, impacts on groundwater and aquatic systems, impacts on soil stability and erosion, waste heat) in the framework. Ways of including these impacts, at least on the basis of a qualitative description, should be considered. We acknowledge that further research is also needed in the following areas: (1) Including additional air pollutants, emissions to water and soils. (2) Developing methods to include the environmental impacts of accidents. (3) Fully including the impacts of loading, unloading, and storage processes for traditional oil, gas and coal transportation systems. (4) Including regional characteristics (climate, state of the environment, etc.) at the stage of calculating air emission externalities.

Research on transmission and distribution avoided (economic) costs attainable by implementing DSM measures is ongoing. In this paper we have indicated that additional environmental "costs" can be saved. By contributing to avoid new lines, to reduce the loading of existing lines, or to better use existing ROW, an improvement can be achieved across different environmental impact categories. Considering only air emissions (the only impact category for which monetized values were defined in this paper) the additional avoided environmental costs are in the range of 5 to 200% of the economic costs, depending on the transportation system, on the type of fuel source and on the valuation criteria, Other impact categories that can not be easily assessed in economic terms (e.g., habitat impingement, land use) have the potential to considerably increase these figures.

Until today the energy system planners have not fully acknowledged the potential of an integrated DSM and T&D expansion strategy, preferring to rely on engineering and routing alternatives to reduce environmental impact of transmission and distribution systems.[9] Engineering and routing options can be an efficient means in reducing impacts locally. Nevertheless, because they are focussed on a limited number of impact categories, they usually do not achieve the overall reduction effect of DSM options.

Endnotes

1. The presence of the ROW with its low-growing plant community can have positive or negative effects on the local wildlife community, depending on the circumstances. Potential effects on surface water quality and aquatic ecology arise mainly from maintenance operations and from the use of service roads. Where

service roads cross wetlands and surface waters, soil erosion can cause elevated turbidity and sedimentation. Potential toxic effects of herbicide runoff should be considered when defining the ROW management plan. New techniques in ROW management have helped to considerably decrease the impact on ecosystems: e.g., the increased use of mechanical cutting instead of herbicide treatment, the selective clearing of the ROW (allowing for different vegetation types), and the use of vegetation buffers to stabilize erosion and drainage (DeCicco et al. 1992). From past experience, it has been shown that high priority should be given to the protection of wetlands and floodplains. Negative impacts occur if wetlands are filled or channeled, and if heavy equipment is used for construction and maintenance. The impact of transmission lines on the **aesthetic quality** of the landscape is a function of visibility, which in turn depends on the apparent size and the apparent contrast between the transmission towers, the ROW, and their surroundings. A complex array of cultural attributes of the viewer influences the perceived aesthetic impact. Nationality, gender, childhood residence (urban/rural), childhood environment (temperate/arid/tropical), and ethnic identity have all been shown to play a role in the perception of visual impact of energy facilities (Palmer 1993).

2. Several utilities have reported avoided transmission and distribution costs related to DSM. Results are strongly dependent on the local situation. Typical annualized capital costs at selected U.S. electric utilities are in the range of $17 to $60 per kW of new transmission capacity and in the range of $41 to $182 per kW of new distribution capacity (Chernick 1993).

   Yearly marginal costs can be estimated using the present worth method. This method essentially determines the value of an incremental change in load, based on the opportunity cost of deferring the T&D expansion plan of a service area. The application of this method has been shown in a detailed case study of the Pacific Gas and Electric "Delta" service district (Orans et al. 1992). For this specific case the marginal costs for distribution expansions decrease from about 500 $/kW (1991) to 250 $/km (2009), and for transmission expansions from about 50 $/kW (1991) to 5 $/km (2009).

   The study includes a detailed evaluation of different DSM programs for the "Delta" area, based on the total resource costs and benefits of different programs. Selected results are presented in Table 7. It is shown that avoided T&D costs play an important role in the overall performance of DSM programs.

3. In order to maintain a high level of objectivity in defining a classification system, the following rules should be followed:

   - the decision to include or exclude a certain type of impacts in a quantitative framework should be explicitly stated. An alternative to completely omitting impacts is to describe them in qualitative terms.

   - the definition of impact categories should be transparent, exhaustive and non-duplicative. All sub-attributes of a category should be explicitly stated.

   - the definition of categories should be based on a common level of aggregation (detail)

   - the definition of categories should refer to the same stage in the causal chain leading from emissions to impacts.

4. In this paper we use a HIGH externality valuation scenario with the following externality values in U.S. 1992 dollars: SOx:6, NOx:ll, TSP:13, CO:l.4, NMVOC:ll, CO2:0.1, CH4:2.1. Accordingly, a LOW externality valuation scenario with the following externality values in U.S. 1992 dollars is defined: SOX:0.6, NOx:3, TSP:l, CO:0.01, NMVOC:l.8, CO2:0.01, CH4:0.1

5. Critical field levels of 1.6 kV/m and 2 mG are used for E_{krit} and B_{krit}, respectively, in this paper. The 1.6 kV/m value is based on the State of New York public service commission interim transmission line electric field standard; the 2 mG value for magnetic fields was used by the New York State Attorney General's Office to identify "possibly at risk" schools.

6. Rural areas are defined as a mix of 0.1% land type I (sensitive habitats), 49.9% land type II (forests), and 50% land type III (agricultural). Urban areas are a mix of 50% land type III (agricultural, suburban) and 50% land type IV (urban).

7. Most emission data is derived from a Swiss study (Frischknecht et al. 1994). As a first approximation this data can be used also for the U.S. situation. Also refer to (Knoepfel 1994).

8. Typical natural gas consumption for pipeline compressor stations is 2% of transported gas per 1,000 km (Frischknecht et al. 1994). Electricity consumption for oil pipeline compressor stations is typically in the

Table 7. Evaluation of Selected DSM Programs in the Delta District of Pacific Gas and Electric (Orans et al. 1992)

	Annual Energy Savings (kWh)	20 yr Present Value Cost ($)	Total Benefits ($)	Local T&D Benefits ($)	% of Total (%)
Commercial retrofit air conditioner upgrade	1,042	510	812	187	23
Commercial new lighting	2,126	325	1,234	162	13
Residential retrofit lighting	100	39	91	48	53
Residential retrofit insulation and shading	531	879	1,083	536	49
Residential new lighting	233	91	213	111	52

range of 15 to 30 kWh per ton of oil for a distance of 1,000 km. An additional source of energy loss in pipelines are gas leakages. These are low, almost negligible, in the high pressure pipeline system (in contrast to the higher losses in low-pressure distribution systems). According to (Jennervik 1991) and (Okken 1990), the leakages in high-pressure pipelines amount to 0.001 to 0.15 % of the transported gas.

9. A discussion of routing and engineering alternatives other than implementing DSM to reduce the environmental impacts of power transmission can be found in (Knoepfel 1994). Natural habitat impingement can be reduced or avoided by detouring the line or by using already existing ROW. Visual/aesthetic impacts can be reduced by using smaller support structures and by minimizing the contrast between the line and the surrounding landscape. Electric losses leading to air emissions can be reduced by using lines with higher voltages or by increasing the conductor cross-section. Each of these alternatives has environmental "costs" that should be weighted against the expected benefits. In the context of **prudent avoidance policies** to minimize potential effects of electric and magnetic fields a number of possible options exists, beside implementing DSM (OTA 1989): detouring the line to avoid population centers or to avoid particularly sensitive populations such as school children, expanding the width of the right-of-way (exclusion zone), raising the height of transmission towers, using new conductor configurations or underground cable systems.

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