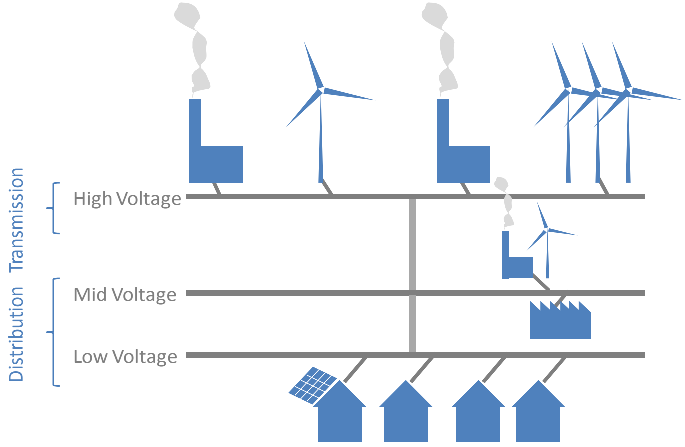
Methodology used to calculate T&D investment

1 Introduction

Electricity networks perform the vital task of connecting electricity end-users to electricity generators. Networks can be broadly classified into two categories. Transmission networks transport large volumes of electricity over large distances at high voltage. Most large generators and some large-scale industrial users of electricity are connected directly to transmission networks. Distribution networks transform high-voltage electricity from the transmission network into lower voltages, for use by light-industrial, commercial, and domestic end-users. Because distribution networks have to reach every home and building that uses electricity, their length is considerably greater than that of transmission networks: by length distribution networks account for around 90% of the total network capacity installed globally.

Figure 1: Schematic diagram of transmission and distribution networks



The *World Energy Outlook 2011* projects that a substantial proportion of the investment in the power sector over the *Outlook* period will be in transmission and distribution networks (see Chapter 5). This document outlines the methodology used to derive these numbers.

2 Components of investment in electricity networks

In our analysis we assume that the total annual investment in transmission and distribution (T&D) networks comes principally from three sources:

- **New growth:** investment required to expand and strengthen networks in order to accommodate growing demand;
- **Ageing infrastructure:** investment required to refurbish or replace network assets that reach the end of their operational lifetimes; and
- **Renewables integration:** additional investment required to connect renewable-energy generators to the network, which can entail higher costs than for other forms of generation.

We estimate each of these components separately, and then sum them to give the total investment required in electricity networks. This specification captures the main drivers of current and future network investment, but is not exhaustive. For example, investments to improve the reliability of supply to existing consumers would not be captured by any of the three components described here.

3 Investment due to new growth

Our projection of new investment due to growth in electricity demand is calculated separately for distribution and transmission networks, and is performed region-by-region, as the increase in line length per region depends on a number of region-specific factors (e.g. population density).

For each region, we calculate the investment required in transmission and distribution networks using the following relationship

$$I_{t,k}^{new} = \beta_k \cdot \left(G_{t,k} - G_{t-1,k}\right) \cdot \left\{(1-\lambda_k) \cdot c_k + \lambda_k \cdot c_k \cdot L_{t,k}\right\}$$

Where, for region k and in year t,

- $I_{t,k}^{new}$ is the investment in networks as a result of additional demand ($);
- $G_{t,k}$ is the volume of electricity generated (GWh);
- β_k is the additional length of transmission network required for each additional unit of generation (km/GWh);
- c_k is the current average unit cost of additional network assets ($/km);
- λ_k is the share of c_k that is due to labour costs; and
- $L_{t,k}$ is an index of projected labour costs over the *Outlook* period.

The term β_k, which reflects the additional amount of network length needed for each additional unit of generation, is estimated for each region using data on network length and generation for the period 1970-2014. The data on historic network size comes from a database collated by ABS Energy Research, a private firm that provides energy market research. The data until 2005 is in five-yearly intervals, but this is not an inappropriate level of granularity given the given the relatively gradual and monotonic nature of the change in generation and transmission lines over this period. The data on generation is the IEA's own, and for former Soviet Republic countries, the generation time series begins in 1990.

The term c_k, the unit cost of additional networks, is derived from observed capital expenditure data collated by ABS. For future years we assume that the real unit cost of networks increases as labour costs increase. We therefore divide c_k into a labour-related component $\lambda_k \cdot c_k$ and a residual component $(1-\lambda_k) \cdot c_k$, and multiply the labour-related component by a labour cost index $L_{t,k}$ for each country over the *Outlook* period.

4 Investment due to ageing infrastructure

As with the calculation for new infrastructure, our calculation for the cost of replacing ageing network infrastructure is performed separately for distribution and transmission networks and region-by-region. The relationship used to model these costs is:

$$I_{t,k}^{age} = R_{t,k} \cdot \left\{(1-\lambda_k) \cdot r_k + \lambda_k \cdot r_k \cdot L_{t,k}\right\}$$

- $R_{t,k}$ is the amount of network assets reaching forty years of age in year t (km);
- r_k is the current unit cost of replacing or refurbishing network assets ($/km);
- λ_k is the share of r_k that is due to labour costs; and
- $L_{t,k}$ is an index of projected labour costs over the *Outlook* period.

$R_{t,k}$ is used as a proxy for assets reaching the end of their lifetime. This is the best data currently available to us on the age profile of networks assets. r_k is assumed to be lower than c_k because building new assets entails additional costs to those entailed in refurbishing them.

5 Additional investment due to renewables

A considerable amount of the capacity additions projected over the *World Energy Outlook* period is from renewables. The geographical location of these technologies is often strongly influenced by the location of the underlying resource (e.g. areas where the wind is strong or insolation is high). In some regions these locations may not be close to existing centres of demand. In addition, some of these technologies operate at relatively low load factors because of the variability of the resource. As a result they require a relatively high-capacity network connection relative to the amount of energy they produce annually, compared to baseload forms of generation. This relatively low average power output means a relatively high cost for transmission and distribution network per unit of energy used.

Because the introduction of large quantities of remote or variable renewables was not a marked feature of the historic development of electricity networks (with the exception of regions where remote hydroelectricity represents a large proportion of the generation mix), the addition of more renewables is likely to increase the average length of network additions and the cost of transmission and distribution per unit of energy. This additional cost, which by definition is not included in our calculation of I^{new} as its determining parameters (in particular β) are estimated from historic data.

To account for the additional cost of T&D for renewables, we introduce an additional term I^{ren} to our calculation of transmission and distribution costs. This term is calculated based on the additional costs of renewables for the transmission and distribution networks, but with different calculations for the two types of network:

$$I_{t,k}^{ren} = I_{t,k}^{renT} + I_{t,k}^{renD}$$

5.1 *Transmission network costs*

For additional transmission network costs we derive the cost using the following relationship:

$$I_{t,k}^{renT} = \sum_i K_{k,t,i}^{ren} \cdot c_{k,i}^{renT}$$

where

- $K_{k,t,i}^{ren}$ is the capacity added of technology i (GW);
- $c_{k,i}^{renT}$ is the unit cost of connecting technology i to the transmission network ($/GW).

The values used for c^{ren} are derived from a number of studies that have examined the additional network costs of renewable energy (**Table 1**). Typically the methodology used in these studies is to compare comparing a base-case scenario to a scenario with increased wind and/or solar energy deployment. The grid integration can be measured in total addition grid investment per renewable capacity ($/kW) or as additional element on top of the cost of electricity generated from renewables ($/MWh)[1].

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[1] For the conversion from investment ($/kW) to additional cost of electricity ($/MWh) an economic lifetime of 25 years at a WACC of 8% is assumed and average full load hours of 2000.

Table 1: Renewable grid integration costs

Country/Region	Estimated cost ($/kW)	Estimated cost ($/MWh)	Studies[2]
United States	30-260	1-12	WWITS, EWITS
Europe	52-121	2-5	RoadMap 2050, EWIS
Germany	140-200	6-9	dena1 and dena2
Netherlands	84-154	3-7	EWIS
United Kingdom	63-226	2-10	EWIS
Ireland	215	10	EWIS
Denmark	378	18	EWIS

5.2 *Distribution network costs*

For additional distribution network costs associated with solar PV in buildings and biomass in industry, we assume that additional network investment is required only if the electricity generated from these technologies exceeds local demand and is fed back to the system. This is estimated using a simplified relationship between end-users' peak demand, the peak production of distribution-connected-renewables, and the correlation between the two. For each distribution-connected renewable technology the relationship between the two

$$I_{k,t}^{renD} = \sum_{i} \max\{0\,, \left(2 \cdot \left(1 - \rho_{k,t,i}\right) \cdot \delta_{k,t,i} \cdot D_{k,t}^{peak} - K_{k,t,i}^{ren}\right)\} \cdot c_{k,i}$$

where

- $\rho_{k,t,i}$ is the correlation between the output of the distribution-connected renewable energy source i and demand;
- $\delta_{k,t,i}$ is a scaling term that accounts for the non-uniform distribution of generators within a country;
- $D_{k,t}^{peak}$ is the peak instantaneous demand
- $K_{k,t,i}^{ren}$ is the installed capacity of distribution-connected renewables
- $c_{k,i}^{renD}$ is the unit cost of connecting technology i to the distribution network ($/GW).

6 Total investment cost for electricity networks

Combining the network investment arising from new demand, ageing infrastructure, and additional costs associated with renewables gives the total annual investment in electricity networks for each region:

$$I_{t,k}^{total} = I_{t,k}^{new} + I_{t,k}^{age} + I_{t,k}^{ren}$$

I^{total} is the figure presented in the WEO as the total network investment cost.

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[2] WWITS – NREL, 2010, *Western Wind and Solar Integration Study*; EWITS – NREL, 2010, *Eastern Wind and Solar Integration Study*; RoadMap 2050 – McKinsey & Co et al, 2010, *Roadmap 2050 – A practical guide to a prosperous, low-carbon Europe*; EWIS – EWIS Consortium, 2010, *European Wind Integration Study*; dena(1) – DENA, 2005, *Integration into the national grid of onshore and offshore wind energy generated in Germany by the year 2020*; dena(2) – DENA, 2011, *Integration of renewable energy sources into the German power supply system until 2020*.