7 HYDROPOWER

	2010	2013	2014	2010-2014 (% change)
New capacity additions (GW)	32	48	36	13%
Cumulative installed capacity (GW)	886	1 025	1 061	20%
Total installed costs (2014 USD/kW)	450 – 3 500	450 – 3 500	450 – 3 500	n.a.
Global LCOE range (2014 USD/kWh)	0.02 – 0.15	0.02 – 0.15	0.02 – 0.15	n.a.

Notes: 2014 deployment data are estimates. n.a. = data not available or not enough data to provide a robust estimate.

Highlights

- Hydropower produces some of the lowest-cost electricity of any power generation technology. The LCOE of large-scale hydro projects at excellent sites can be as low as USD 0.02/kWh, while average costs are around USD 0.05/kWh.
- Small hydropower projects have an average LCOE of 0.05/kWh and can be a very attractive electrification option, providing low-cost electricity to remote communities or for the grid.
- Hydropower is a mature technology, with limited cost reduction potential in most settings. However, significant low-cost potential remains to be exploited in many countries outside the countries of the OECD.
- Hydropower, excluding pumped storage, is currently the largest renewable power generation source, with a global installed capacity of around 1 025 GW at the end of 2013. At good sites it provides the cheapest electricity of any generation technology.

INTRODUCTION

Hydropower is a mature technology and the LCOE of currently installed projects and those coming online are generally low. Although cost reduction opportunities are low and typically tied to advances in civil engineering practices, hydropower can provide some of the lowest-cost electricity of any source, as well as grid services, in places where economic resources remain untapped. Hydropower is unique among other renewable power generation technologies in that it also provides other services, such as water storage, irrigation opportunities and flood control. However, it is important that hydropower developments respect the three pillars of sustainability; economic, environmental and social. Sustainable development of hydropower and early consultation with local stakeholders are crucial to reducing project lead times, reducing project development risks and accelerating the deployment of hydropower.

When hydropower schemes have storage that is manageable – for example, in the reservoir behind the dam – hydropower can contribute to the stability of the electricity system by providing flexibility and grid services. It can help with grid stability, as spinning turbines can be ramped up more rapidly than any other generation source to provide additional generation or voltage regulation to maintain voltage within the system quality limits. Pumped storage hydropower is specifically designed to provide these services, as well as to provide an arbitrage between periods of low and high electricity prices. However, the LCOE analysis does not include an estimate of the value of these services, as they are very system-specific.

With large reservoirs, hydropower can also store energy over weeks, months, seasons or even years. Hydropower can therefore provide the full range of ancillary services required to allow high penetration of more variable renewable energy sources, such as wind and solar photovoltaic. The importance of hydropower is likely to grow over time as the shift to a truly sustainable electricity sector accelerates, not just for the low-cost electricity it can provide, but for the flexibility it brings in order to integrate high levels of variable renewables at minimal cost.

HYDROPOWER CAPITAL COSTS

Hydropower is a renewable energy source based on the natural water cycle. It is the most mature, reliable and cost-effective renewable power generation technology available today, with a history of exploitation that goes back to the beginning of the use of electricity. Hydropower schemes often have significant flexibility in their design; they can be designed to meet baseload demands with relatively high capacity factors, or to have higher installed capacities and a lower capacity factor but meet a much larger share of peak electricity demand.

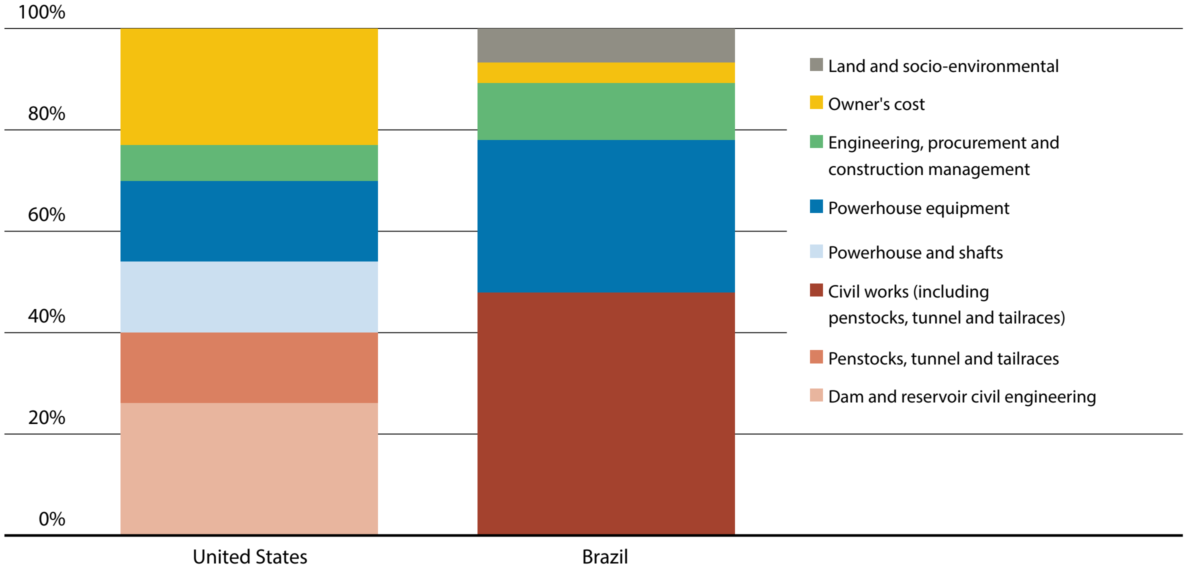
An advantage of hydropower is its ability to meet load fluctuations minute by minute – indeed hydropower can have the most rapid ramp-up rates of any power generation technology[28] – making hydropower an ideal complement to variable renewables such as wind- or sun-based technologies. Hydropower can thus meet the demands that arise when large ramping up or down of supply is needed due to increases or decreases in solar or wind generation.

Hydropower is the only large-scale and cost-efficient electricity storage technology available today, despite cost reductions for a range of electricity storage options in recent years. The promising developments in other energy storage technologies may one day challenge hydropower's monopoly on low-cost electricity storage, but for the moment hydropower is still the only technology offering economically viable large-scale storage. It is also a relatively efficient energy storage option.

Hydropower plants can be constructed in a variety of sizes and with different characteristics. There are a range of technical characteristics that affect the choices for turbine type and size, as well as the generation profile (e.g. height of the water drop to the turbine – "head" – seasonal inflows, potential reservoir size, minimum downstream flow rates, etc.). Hydropower schemes can be broadly classified into the following categories:

[28] Some electricity storage devices, such as flywheels, can match or even exceed these rates, but are more expensive and, in general, the more responsive they are, the less time they can be used before needing to be recharged.

Figure 7.1: Cost breakdown of an indicative 500 MW greenfield project in the United States and a 3 150 MW hydropower project in Brazil



Note: Penstocks are tunnels or pipelines that conduct the water to the turbine, while the tailraces are the tunnels or pipelines that evacuate the water after the turbine.

- Run-of-river hydropower projects have no, or very little, storage capacity behind their dams and generation is dependent on the timing and size of river flows.
- Reservoir (storage) hydropower schemes have the ability to store water behind the dams in order to de-couple generation from hydro inflows. Reservoir capacities can be small or very large, depending on the characteristics of the site and the economics of dam construction.
- Pumped storage hydropower schemes use off-peak electricity to pump water from one reservoir to a higher reservoir, so that the pumped storage water can be used for generation at peak times and provide grid stability and flexibility services.

Hydropower is a capital-intensive technology with long lead times for development and construction due to the significant feasibility assessments, planning, design and civil engineering work required. There are two major cost components for hydropower projects:

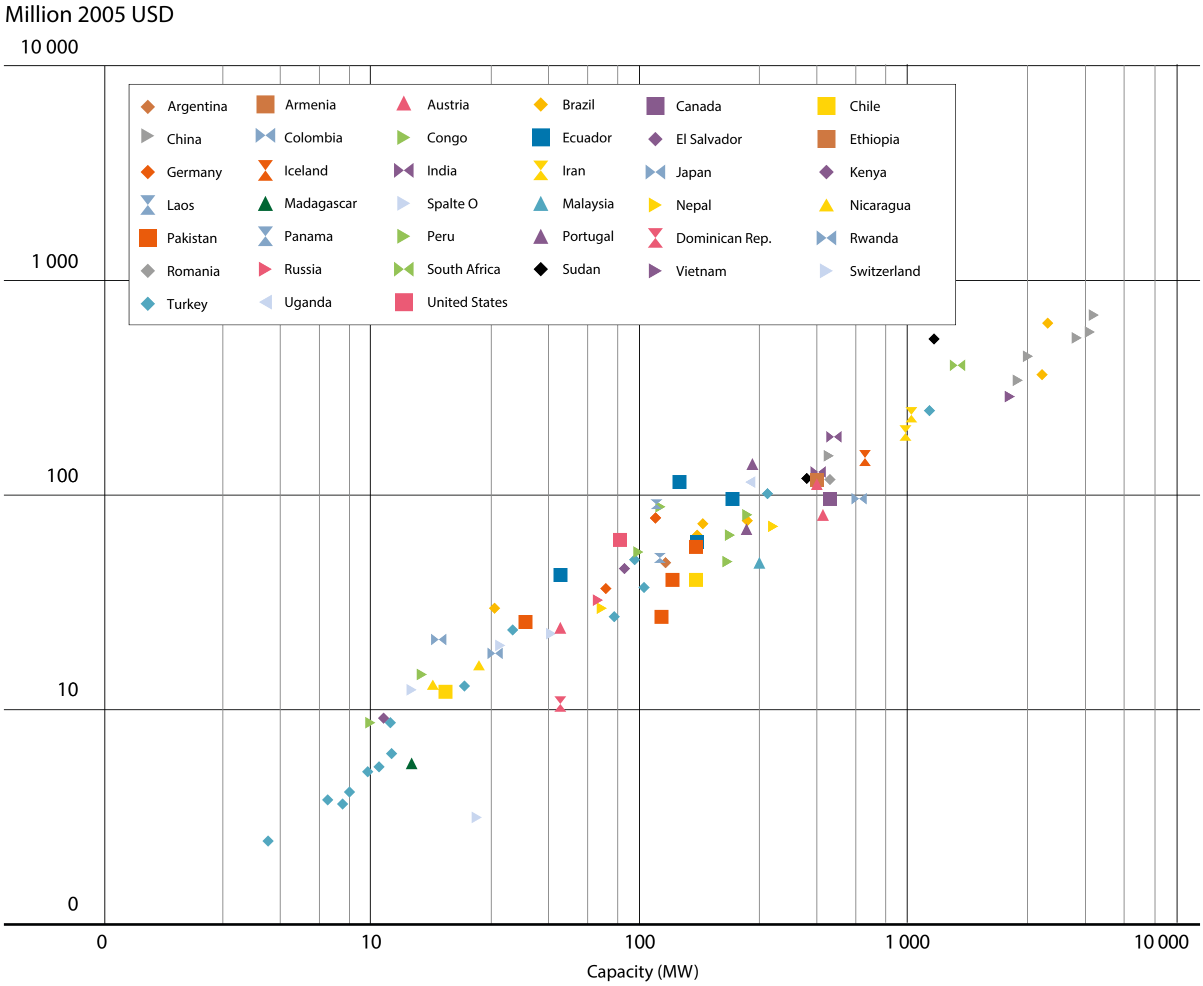
- The civil works for the hydropower plant construction, including any infrastructure development required to access the site and the project development costs; and
- The costs related to electro-mechanical equipment.

Project development costs include planning and feasibility assessments, environmental impact analyses, licensing, fish and wildlife/biodiversity mitigation measures, development of recreational amenities, historical and archaeological mitigation, and water quality monitoring and mitigation.

The cost breakdowns of an indicative 500 MW new greenfield hydropower project in the United States and a 3 150 MW hydropower project in Brazil are presented in Figure 7.1. In both projects, civil engineering represents the majority of costs. In the United States-based project, the civil works associated with the dam/reservoir account for just over one-quarter of the total costs, while penstocks, tailraces and tunnelling add another 14%. The Brazil-based project shows a similar breakdown, with civil works – including penstocks, tunnelling and tailraces – representing just under half of the total cost.

The largest share of installed costs for large hydropower plants is typically for civil construction works (such as the dam, tunnels, canal and construction of power house). Following this, costs for the power house (including shafts and electro-mechanical equipment in the case of the United States project) are the next largest capital outlay and account for around 30% of the total costs.

FIGURE 7.2: ELECTRO-MECHANICAL EQUIPMENT COSTS FOR HYDROPOWER AS A FUNCTION OF CAPACITY (LOG-SCALE)



The long lead times for these types of hydropower projects (7-9 years or more) mean that owner costs (including the project development costs) can be a significant portion of the overall costs due to the need for working capital and interest during construction. Additional items that can add significantly to overall costs include the pre-feasibility and feasibility studies, consultations with local stakeholders and policy-makers, environmental and socio-economic mitigation measures and land acquisition.

The electro-mechanical equipment costs for hydropower plants are strongly correlated with the capacity of the plant and exhibit economies of scale (Figure 7.2). Although electro-mechanical equipment costs usually contribute less to the total cost in large-scale projects, the opposite is true of small-scale projects (with installed capacity of less than 5 MW). For small-scale projects the electro-mechanical equipment costs can represent 50% or more of the total costs, due to the higher specific costs per kW of small-scale equipment. The proposed capacity of a hydropower plant can be achieved by using a combination of a few large turbines or many small turbines and generating units. There is an economic trade-off between the economies of scale of larger units and the revenue lost when a turbine goes offline due to unexpected problems or for regular maintenance. Regular maintenance of the turbine blades, as well as for the penstocks, will mean the turbine is offline.

The cost breakdown for small hydro projects in developing countries reflects the diversity of hydropower projects and their site-specific constraints and opportunities (IRENA, 2013). It would require a large dataset to identify the specific reasons for the wide variation in project cost breakdowns and to identify “efficient” levels. Electro-mechanical equipment costs tend to be higher for small-scale projects than for large-scale projects, but the range is very wide – from an estimated 18% to as much as 50% of total costs (IRENA, 2013). Infrastructure costs can account for up to half of total costs for projects in remote or difficult to access locations. It is also possible to have projects in remote locations where good infrastructure exists but there are no transmission lines nearby, resulting in significant grid connection costs.

Total installed costs of hydropower

The capital costs of large hydropower projects are dominated by the civil works and equipment costs, which can represent between 75% and as much as 90% of the total investment costs. Civil works costs are influenced by numerous factors pertaining to the site, the scale of development and the technological solution that is most economic. Hydropower is a highly site-specific technology and each project is designed for a particular location within a given river basin to meet specific needs for energy and water management based on local conditions and inflows into the catchment basin. Proper site selection and hydro scheme design are therefore key challenges, and detailed work at the design stage can avoid expensive mistakes (Ecofys et al., 2011).

The total installed costs for large-scale hydropower projects typically range from a low of USD 1 000/kW to around USD 3 500/kW (Figure 7.3). However, it is not unusual to find projects with costs outside this range. For instance, installing hydropower capacity at an existing dam that was built for other purposes (e.g. for flood control, water provision, etc.) may have costs as low as USD 450/kW. On the other hand, projects at remote sites, without adequate local infrastructure and located far from existing transmission networks, can cost significantly more than USD 3 500/kW due to higher logistical and grid connection costs.

Total installed costs are lowest in China and India and the highest in Central America and the Caribbean. In regions that have exploited most of their economic resources, most of the low-cost hydropower potential has already been exploited and installed costs are higher. In areas with poor infrastructure, higher costs will be due to the fact that many projects are in remote areas with poor access and thus have higher transport and logistical, as well as grid connection costs.

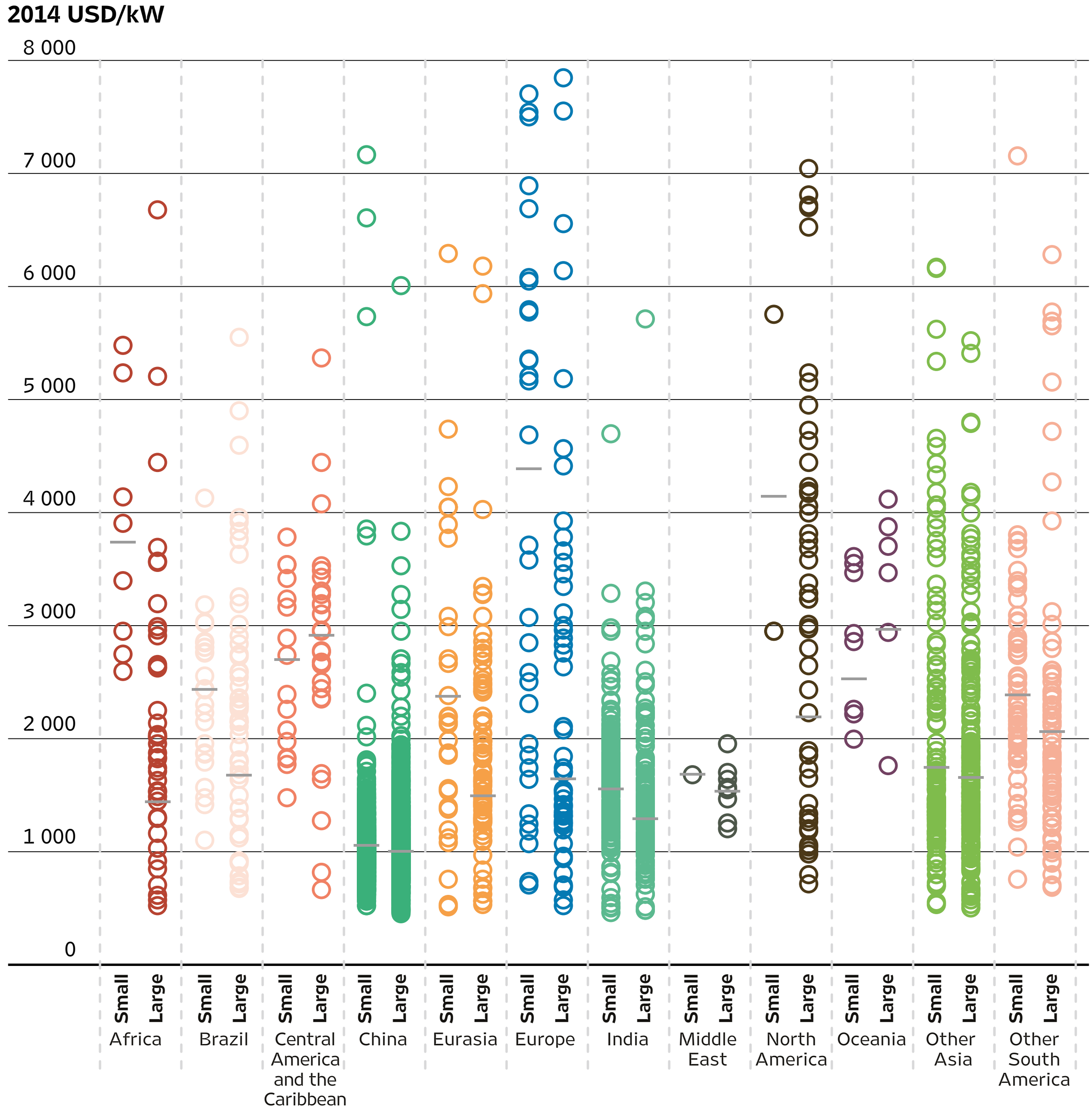
Weighted average installed costs for commissioned or proposed small hydropower projects are very similar to those for large-scale hydropower projects in China, India and other Asian countries. In Oceania and Central America and the Caribbean, weighted average installed costs are actually lower for small-scale hydro projects, but this is not statistically significant.

An important conclusion from this analysis is that, although the installed cost range for hydropower is wide, weighted average installed costs are typically low in regions with significant remaining potential and can provide electricity at very competitive prices. This is true despite the fact that costs for the other services they provide, such as potable water, flood control, irrigation and navigation are included in the hydropower project costs and are typically not remunerated. In addition, plants with higher installed costs are often associated with higher capacity factors, reducing their LCOE. This also does not take into account the additional value of grid services provided by hydropower in terms of short-term flexibility and long-term energy storage, which may have significant value over and above a simple LCOE analysis.

Capacity factors for hydropower

Weighted average capacity factors are around 50% for both small and large hydropower projects, with most projects in the range of 25% to 80% (Figure 7.4). Given the design flexibility of hydropower, depending on inflows and site characteristics, this wide range is to be expected. It is also unique to hydropower, where low capacity factors are a design choice to meet peak demands, not a handicap for project economics. In South America and Brazil, where there are significant excellent – but as yet unexploited – hydropower resources, average capacity factors for new small and large hydropower projects are 63% and 66% and 52% and 61%, respectively. In most regions, capacity factors for large hydro projects are higher than for small hydro projects, but not by a significant margin in China or India.

Figure 7.3: Total installed cost ranges and capacity weighted averages for commissioned or proposed small and large hydropower projects by country/region

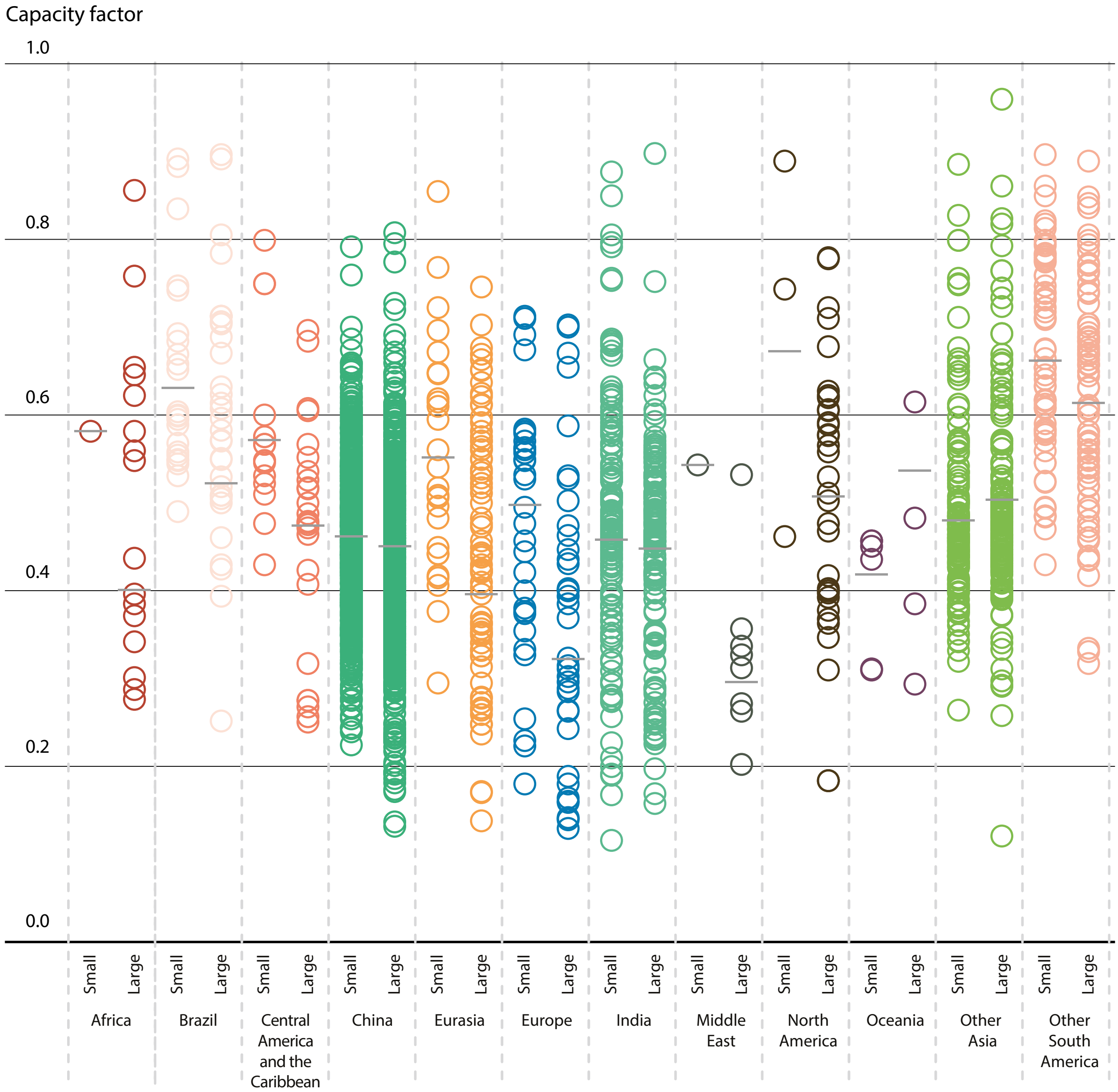


Operations and maintenance costs for hydropower

Hydropower plants typically have low operations and maintenance (O&M) costs over their lifetimes and large-scale hydropower plants have O&M costs similar to those for wind, but not as low as for solar PV. When a series of plants are installed along a river, centralised control, remote management and a dedicated operations team to manage the chain of stations can reduce O&M costs to very low levels.

Annual O&M costs are often quoted as a percentage of the investment cost per kW per year, or as USD/kW/year. Typical values range from 1% to 4%. The International Energy Agency (IEA) assumes 2.2% for large and 2.2% to 3% for smaller hydropower projects, with a global average of around 2.5% (IEA, 2010). Other studies (EREC/Greenpeace, 2010) indicate that fixed O&M costs represent 4% of the total capital cost. This figure may be appropriate for small-scale hydropower plants but large hydropower plants will have significantly lower values. An average value for O&M costs of 2% to 2.5% is considered the norm for large-scale projects (IPCC, 2011), which is equivalent to average costs of between USD 20 and USD 60/kW/year for the average project by region in the IRENA Renewable Cost Database. This will usually include an allowance for the periodic refurbishment

Figure 7.4: Capacity factor ranges and weighted averages for commissioned or proposed small and large hydropower projects by country/region



of mechanical and electrical equipment, such as turbine overhaul, generator rewinding and reinvestments in communication and control systems.

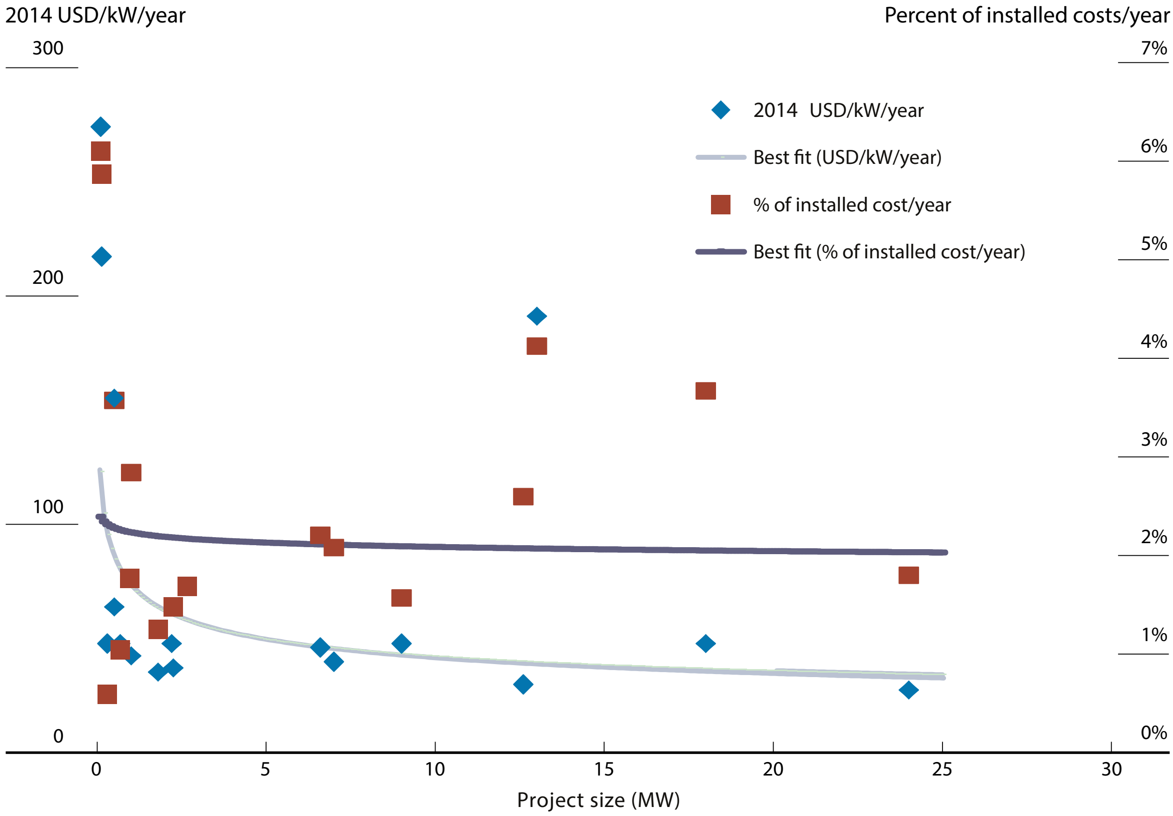
These values are consistent with data collected by IRENA and GIZ for small hydropower projects in developing countries (Figure 7.5).[29] Average O&M costs for mini- and pico-hydro projects can be significantly above the average, as the fixed O&M costs can be significant for these very small projects, which don't benefit from the economies of scale for O&M costs that are presented by large hydropower projects.

The O&M costs reported do not typically cover the replacement of major electro-mechanical equipment or refurbishment of penstocks, tailraces, etc.[30] These replacements are infrequent and these components have design lives of 30 years or more for electro-mechanical equipment, and 50 years or more for penstocks and tailraces, meaning that the original investment has been completely amortised by the time these investments need to be made and therefore they are not included in the LCOE

[29] The high values in the 13 to 18 MW size range, in terms of percentage of installed capital costs per year for O&M costs, appear to be partly explained by the remote location of these projects.

[30] Penstocks are tunnels or pipelines that conduct the water to the turbine, while the tailraces are the tunnels or pipelines that evacuate the water after the turbine.

Figure 7.5: Operations and maintenance costs for small hydropower projects in developing countries



analysis here. They may, however, represent an economic opportunity before the full amortisation of the hydropower project, in order to boost generation output.

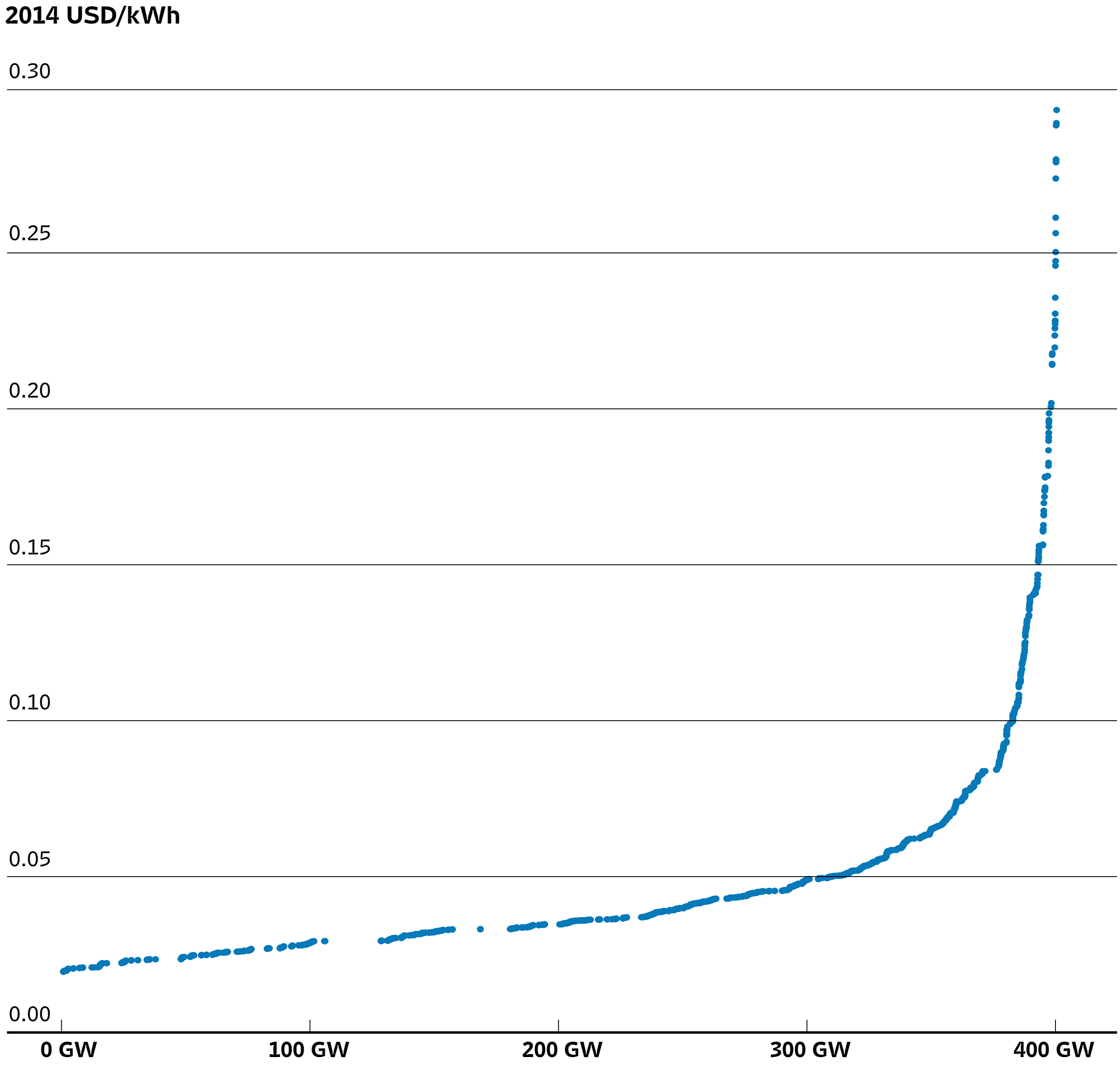
The levelised cost of hydropower electricity

Hydropower is a proven, mature, predictable technology and can be a very low-cost source of electricity. Although the weighted average total installed costs of hydropower are typically quite low for large-scale projects in regions with unexploited economic resources, installed cost ranges are quite wide and are highly dependent on location and site conditions. However, on average, the low investment costs, good capacity factors and very long economic lives (with parts replacement), as well as low O&M costs, mean that hydropower is typically very competitive. As a result, the average LCOE from hydropower is typically low and excellent hydropower sites offer the lowest cost electricity of any generating option.

Hydropower projects can be designed to perform very differently, which complicates a simple LCOE assessment of hydropower. Installed capacity can be low relative to inflows where storage is possible, in order to ensure that the plant is nearly always generating and achieves high average capacity factors. Alternatively, a scheme could have relatively high installed electrical capacity that is not designed to run continuously and would have a lower annual capacity factor, but would meet peak demands by providing large amounts of capacity at short notice, as well as providing a spinning reserve and/or other ancillary grid services. The latter strategy would involve higher costs and lower capacity factors, but where system flexibility is required it is likely to be the cheapest and most effective solution to minimising total electricity system generation costs and hydropower could capture a large part of this extra value.

Deciding which strategy to pursue for any given hydropower scheme design is highly dependent on the local market, structure of the power generation pool, grid capacity and constraints, the value of providing grid services, etc. Perhaps more than in the case of any other renewable energy, the true

Figure 7.6: Levelised cost of electricity of unexploited hydropower resources in the IRENA Renewable Cost Datbase



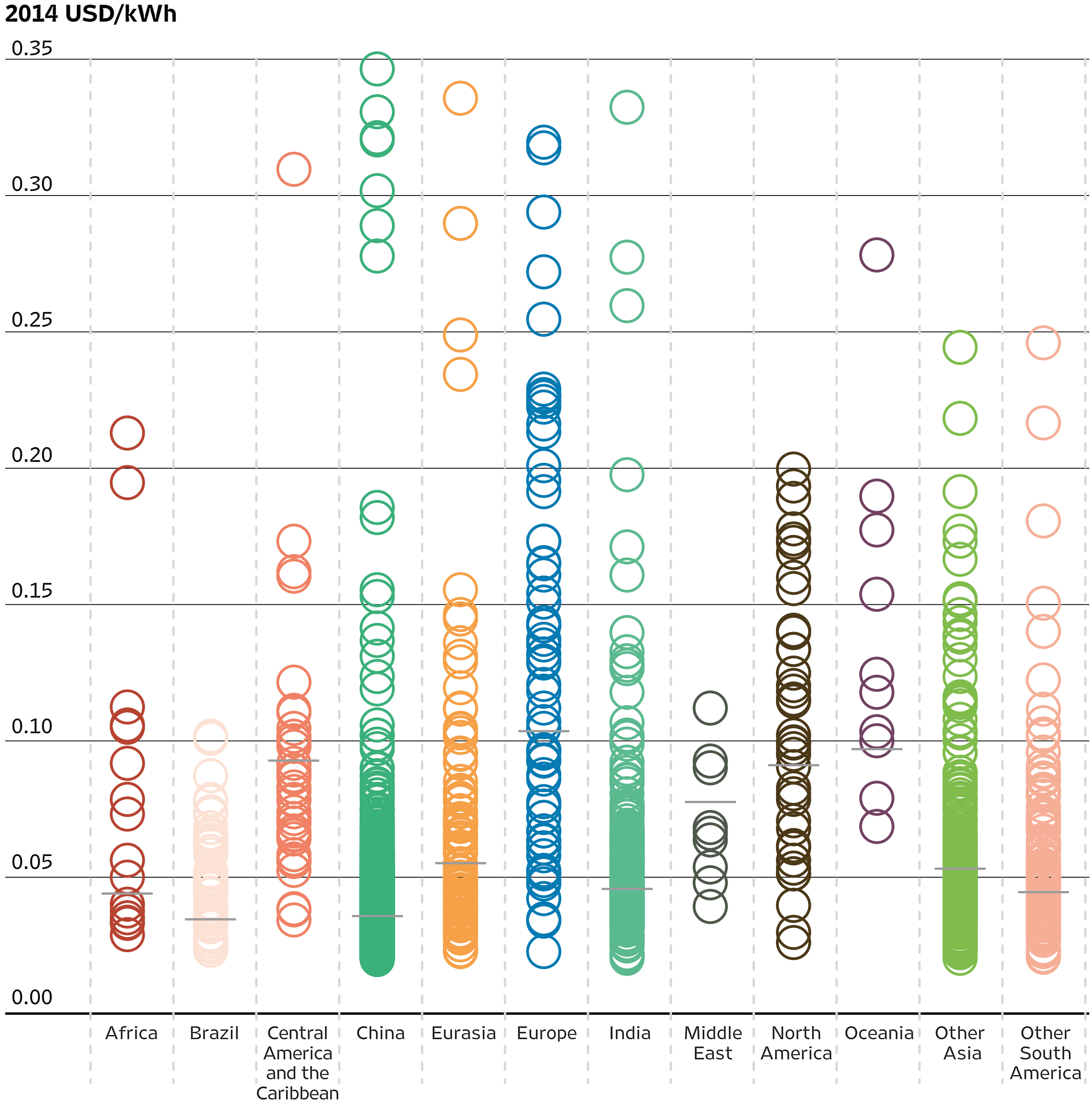
economics of a given hydropower scheme will be driven by these factors, not just by the number of kilowatt hours (kWhs) generated relative to the investment, as the value of peak generation and the provision of ancillary grid services can have a large impact on the economics of a hydropower project.[31]

Figure 7.6 presents the supply curve for the LCOE of 2 444 hydropower projects contained in the IRENA Renewable Cost Database – for all projects commissioned and proposed. It shows that many new hydropower projects are expected to be highly competitive. The LCOE of the evaluated projects ranged from a low of around USD 0.02/kWh to a high of USD 0.35/kWh for a 680 MW large hydro project with a capacity factor of 37%. The weighted average cost of all the sites evaluated was USD 0.042/kWh. The LCOE for 90% of the projects was below USD 0.09/kWh and for roughly 70% it was below USD 0.05/kWh. If the data were available, it would be interesting to compare these ex-ante project cost estimates with ex-post data to identify whether there are systematic errors in project cost estimations as is suggested in an analysis of 245 dams installed between 1934 and 2007 (Ansar, 2014). However, even if there were systematic under estimation in ex-ante cost estimates, hydropower would still remain the cheapest of electricity generation sources.

Data for the LCOE range of hydropower in countries with the largest installed capacity are

[31] This is also without taking into account the other services being provided by the dam (e.g. flood control) that are not typically remunerated but are often an integral part of the project's purpose.

Figure 7.7: Levelised cost of electricity ranges and weighted averages of small and large hydropower projects by region



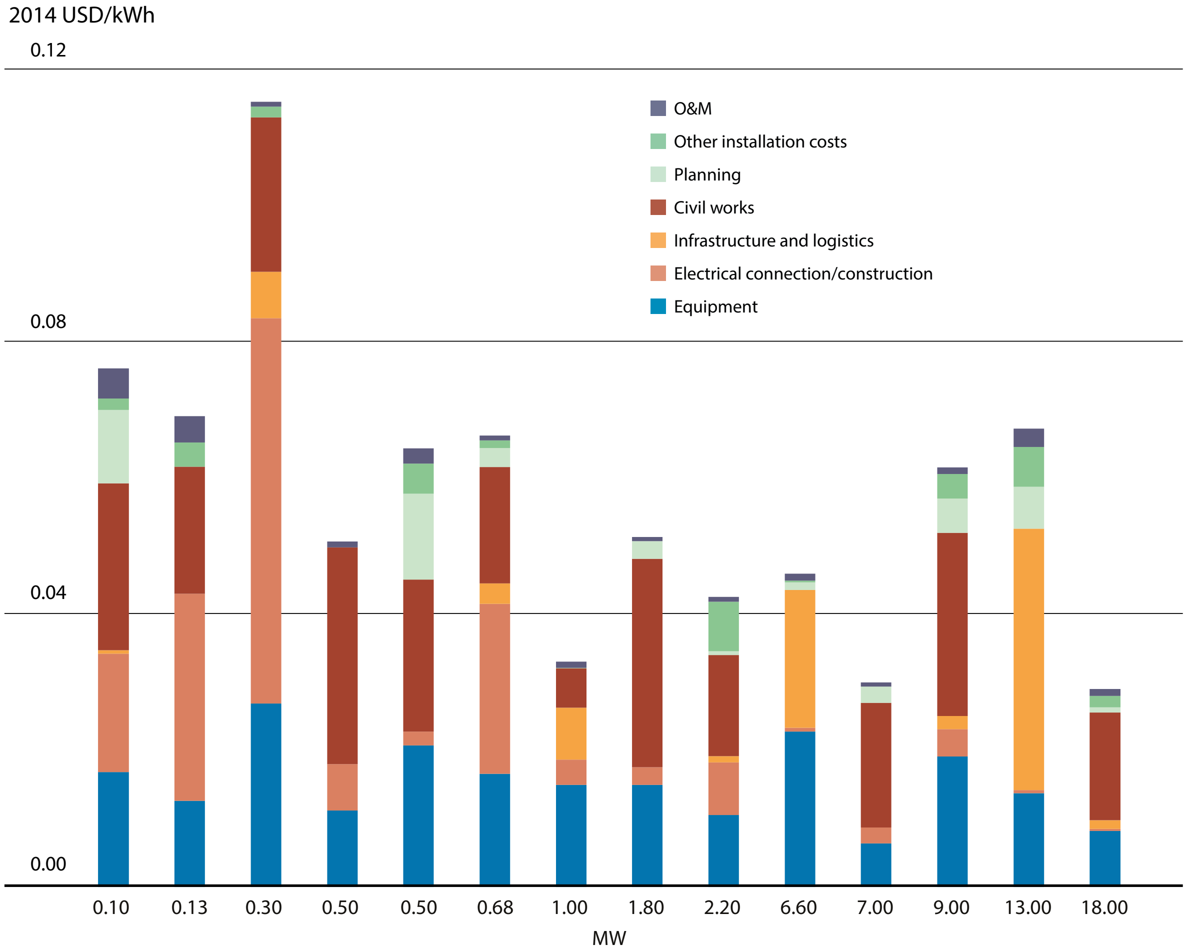
revealing. At the best sites, the LCOE of hydro is very competitive and can provide the cheapest electricity available in the world today (Figure 7.7). Although the range of estimated costs is wide, the weighted average LCOE of projects is very low, suggesting that the smaller-scale projects with higher LCOE are typically being built because they are the least costly supply solution in remote areas or are providing valuable grid services.

Figure 7.7 highlights that the weighted average costs for new capacity are low, typically ranging between USD 0.04 and USD 0.06/kWh in regions with remaining untapped economic resources.

In Europe and North America, where a large proportion of the economical hydropower potential has already been exploited, the situation is quite different. In these two regions, new projects are relatively few in number, face long lead times to develop and have higher weighted average LCOE – USD 0.09/kWh for large hydro and USD 0.11/kWh for small hydro in North America and USD 0.10/kWh and USD 0.14/kWh for large and small hydro, respectively, in Europe.

Figure 7.8 presents the LCOE of small hydropower projects in developing countries, broken down by size, and highlights just how competitive

Figure 7.8: The levelised cost of electricity breakdown by cost component for 14 small hydropower projects in developing countries



small hydropower can be for grid supply, rural electrification and economic development. The LCOE ranged from a low of around USD 0.03/kWh to USD 0.115/kWh, while the share of O&M costs in the LCOE of the hydropower projects examined ranged from 1% to 6%. The largest share of the LCOE is taken up by costs for the electro-mechanical equipment and civil works. The share of the electro-mechanical equipment in the total LCOE ranged from a low of 17% to a high of 50%, with typical values falling in the range of 21% to 31%.

However, the cost of civil works made the highest contribution to the total LCOE in nine of the projects examined, with a share across all projects that ranged from zero (for an existing dam project) to a high of 63%. In some remote projects, grid connection and electrical infrastructure dominated costs, and they were significant, without being dominant, in a number of other projects. Similarly, infrastructure and logistical costs can be a significant contributor to overall costs where site access is difficult and/or far from existing infrastructure.