Value-based decision making for hydro asset management

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Valuing investments goes far beyond computing simple financial indicators or ratios. Defining a value framework based on multi-criteria decision analysis techniques will generally optimize results. This is particularly true in the hydro industry, where assets can have extremely long lifecycles, thus increasing the relevance of valuation techniques that take the effect of time on value and risk into consideration.

Assets are acquired and managed because of the value they bring to the owners and operators, and considerable money and time are invested in maintaining and sustaining these assets to preserve their ability to deliver value. Yet many hydro companies struggle with how to define, measure and communicate value. The new ISO 55000 asset management standard underlines the importance of the concept of value, and encourages us to measure value in alignment with the strategic objectives of the operating company.

Each investment planned for hydropower assets, whether a greenfield, growth, sustainment or routine investment, should contribute value. It is important to quantify this value appropriately, as it is a crucial factor in determining whether or not an investment has merit, and how it ranks compared with other possible investments in a resource-constrained world.

1. Valuing investments

Every organization needs a mechanism by which it can determine the value of an investment if it intends to optimize the use of its often scarce resources. There are a number of elements that can contribute to assessing the value of an investment to an organization:

1.1 Risk mitigation

Risk mitigation represents operational risk which an investment is planned to avoid or mitigate. For example, a project to replace an aging transformer at risk of an explosive failure would mitigate the safety and financial risks associated with that failure.

1.2 Financial benefits

Financial benefits represent the direct financial return from a project. For example, if the replacement of a component reduces the maintenance regime required, there will be a financial savings. Or, if a newer and more efficient runner is installed, there will be a financial gain associated with the increased power production. Conversely, the cost of an investment is considered a negative benefit.

1.3 Non-financial benefits

Projects can also deliver benefits that are more difficult to express in financial terms, such as improvements in public perception or employee engagement. This category might also include key performance indicators (KPIs), which matter to the organization, and service measures that are relevant to the industry.

2. Financial metrics and comparisons

Some of these elements are relatively easy to value. Financial costs and benefits are the most straightforward to compute and compare, and as such are often used as the primary criteria for decision making. Typical tools used to compare financial value metrics are: payback period, net present value, internal rate of return, benefit-cost ratio and equivalent annual cost.

2.1 Payback period

This is generally the simplest metric: it determines the time required for the stream of incoming cash flows to equal the original investment (that is, the outgoing cash flows). Some organizations will set simple rules such as: all investments with a payback period of less than one year are approved. The catch is that this metric ignores both the order of the cash flows, and the flows after the cut-off date. This can lead to sub-optimal decisions.

2.2 Net present value (NPV)

NPV is the sum of the discounted present values of incoming and outgoing cash flows over a period of time. If this sum is positive, an investment has value for the company. In a constrained world, organizations typically rank projects by NPV and pick the highest NPV projects first. NPV is useful as it factors in the importance of time and the cost of money, but it does not indicate how profitable an investment might be. NPV ranking therefore tends to favour the largest investments, and not necessarily the ones with highest relative returns. Nevertheless, if one metric were to be used, NPV would be the best choice, as it avoids many of the pitfalls associated with other metrics.

2.3 Internal rate of return (IRR)

IRR is the rate of return at which an investment breaks even, or in other words, the rate of return at which an investment has an NPV of zero. In a constrained world, the investment with the highest IRR will be selected first. IRR is useful to estimate the profitability or yield of an investment, but does not take into consideration external factors such as interest or inflation rates. It cannot be used to select investments of different durations or mutually exclusive investments, the latter being a very important limitation, since it prevents the use of IRR to select between various options for the same project. Also, IRR is difficult to calculate in all but the simplest cases.

2.4 Benefit-cost ratio (BCR)

BCR is a good complement to NPV, as it shows the real value for money of investing, thereby avoiding the tendency to select the largest investments first. But if limited resources force the deferral of an investment, a simple look at the BCR might give the wrong answer:

Aligning risk consequences: a utility example						
	Catastrophic	Major	Moderate	Minor	Very minor	None
Compliance	Federal/Provincial: Regulated (including OEB, CSA).	n/a	Municipal: Regulated (local level through municipal by-laws).	Corporate/other: Corporate or other requirements (including contractual issues).	Legislation pending: May become regulated in future.	No corporate or legal requirements.
Distribution system capacity	Unable to service a new load.	Can supply all load but exceeding thermal limits.	Can supply all load but exceeding planning limits.	n/a	n/a	Able to supply load without exceeding planning limits.
Safety	Any loss of life and/or multiple serious long term health implications as a result of our actions.	Multiple life threatening injuries and some long-term health implications as a result of our actions.	Some life-threatening injuries.	Reportable incident but non life-threatening injuries.	Reportable incidents.	No risk of incidents.
Environmental	Impacts cause long-term (>20 years) damage to a water body, an environmentally/culturally sensitive receptor resulting in actual loss of flora fauna or fish habitat. Impact significant enough to gain attention in national news media.	Impacts are long term (>5 years) and are not contained on the worksite, resulting in potential loss of flora, fauna and/or fish haitat. Impact significant enough to gain attention in provicinial news media.	n/a	Impacts with medium term (1 to 5 years) cleanup implications that are contained to the worksite.	Known impacts contained to the worksite such as fugitive emissions, minor spills with short-term (<1 year) cleanup implications.	No noticeable impacts with minor cleanup implications.
US$	>10 million	>3 million	>1.5 million	>500 000	>100 000	<100 000
Reputational	Stakeholder loses confidence in the organization in the long term, such as public inquiry or federal inquiry.	Long-term negative and/or sustained concerns raised by more than one stakeholder resulting in indications of stakeholders' loss of confidence.	Long-term adverse local media publicity OR public confidence in the organization undermined OR sustained concerns raised by one or more stakeholders.	n/a	Short-term local adver media coverage OR some public embarrassment OR minor effect on overall staff morale/public attitudes.	Immaterial consequence.
IT capacity	n/a	Lack of capacity (or currency) of an enterprise wide system that impacts the entire PowerStream workforce significantly (>10 per cent average decrease in productivity).	Lack of capacity (or currency) of a system that impacts >150 PowerStream workers significantly.	Lack of capacity (or currency) of a system that impacts >50 PowerStream workers significantly.	Lack of capacity (or currency) of a system that impacts >10 PowerStream workers significantly.	Lack of capacity (or currency) of a system has no expected impact on PowerStream workforce.

one then has to consider the curve of the BCR over time. It is also important to note that BCRs for different projects cannot be summed up to compute a 'total' BCR for a portfolio of investments, whereas project NPVs can be added to compute the total value of a portfolio.

2.5 Equivalent annual cost (EAC)

EAC is useful to compute the average cost per year of owning and operating an asset over its entire lifespan. Technically, it is the NPV of the project divided by an annuity factor. It is important to note that the EAC calculation assumes that when assets reach end of life, they will be replaced with similar assets at similar costs; however this might not be true as a result of technical obsolescence or other factors.

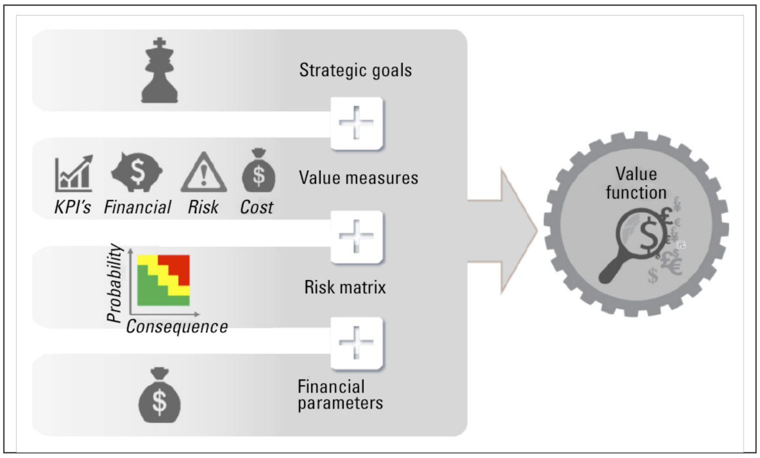
3. Risk valuation

Investments are often undertaken to avoid or mitigate specific risks. The benefit, or value, of investing to mitigate or defer a risk, is often a blend of various tangible and intangible factors which are more complex to value than the straight financial benefits discussed above. When determining the risk matrix of a company, various types of risks will typically be considered (safety, regulatory, environmental, lost hydro production, and so on) and an attempt will be made to normalize the specific consequence levels for each type of risk. For instance, a 'high' safety risk might be defined as resulting in permanent disability of one or more employees. If a 'high' financial risk is defined as resulting in a cost of between US$ 100 000 and US$ 1 million, it follows that the company values a permanent disability somewhere between these two values. If this is not correct, the consequences of these two risk types should be re-aligned.

3.1 Pairwise comparison

One of the more popular methods to align risk consequences is known as 'pairwise comparison'. Such techniques can be misleading, because the subjective opinions of those involved in undertaking the compar-

Fig. 1. Elements of a value framework.



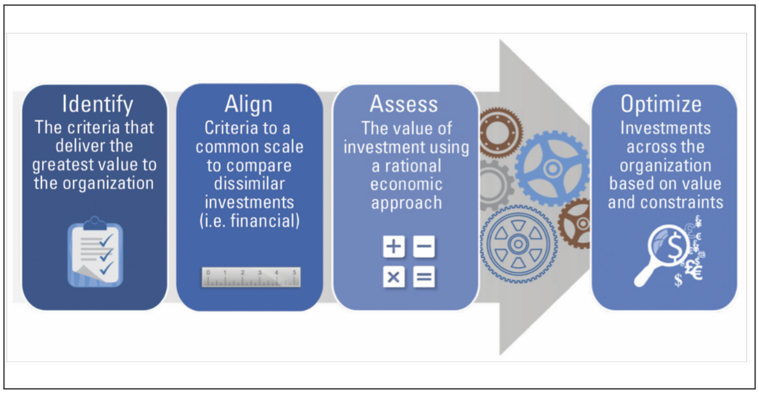


Fig. 2. Multi-criteria decision analysis.

ison process will come into play. Lack of familiarity, biases and beliefs can also influence the outcome. It is therefore recommended to use actual risk quantification whenever possible (as in the risk consequence table on the previous page), and restrict the use of pairwise comparison to truly intangible factors.

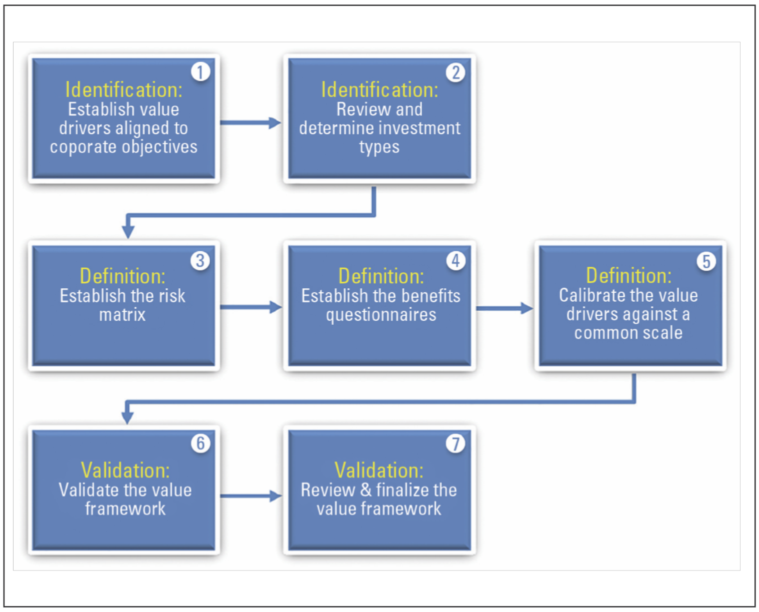
4. Value frameworks

Developing and normalizing a risk matrix provides an idea of the complexity of comparing the dissimilar, and possibly intangible, benefits of an investment. Over the course of a year, a company might consider investments delivering very different benefits, yet eventually an overall value must be assigned to each candidate investment so that the optimal mix and timing of investments can be selected. This is especially true if the company operates under financial and resource constraints and cannot undertake all the proposed investments. Many methods are used to assign a value, and then to rank each investment. One of the more common and simple scoring methods is discussed below, as well as the state of the art multi-criteria decision analysis method.

4.1 Quantized scoring method

A commonly used method is 'quantized scoring', which assigns each corporate strategic objective a maximum fraction of the total score that an investment can generate. This effectively 'caps' the amount any strategic objective can contribute to the investment's overall score. This can significantly skew an investment's valuation, and lead to unsatisfactory results that do not align with maximizing the value for the corporation.

Fig. 3. Developing a value framework.



4.2 Multi-criteria decision analysis

MCDA techniques can be used as a base to create a value framework. Specifically, these techniques encourage the development of a well-documented framework where:

- The corporation's value measures are identified and mapped to its corporate objectives. Ideally, more than one measure is used to quantify each investment's contribution to a specific corporate objective. Preliminary weights are assigned to each value measure, without a maximum value being assigned to any value measure.
- The types of typical investments and the risk matrix are determined.
- The various benefits expected from each type of investment are defined and used to develop questionnaires that will 'force' investment sponsors to quantify each benefit of their investments (including risk mitigation) using standardized criteria.
- The value measures are calibrated against a common scale (ideally monetary, but it can also be an internal 'neutral' value unit).
- A sampling of investments of different types is evaluated, and the results compared with what various stakeholders would have expected. This might lead to adjustments in the weightings applied to the corporation's value measures; to their calibration to a common scale; and/or to reviews of the benefits and risks tied to different investment types.

This is typically an iterative process, where various types of tests might be used to ensure thorough validation:

- Binary tests can be used to confirm that positive value investments do indeed contribute value
- Pairwise comparison can be used to check if two investments rank as expected
- A prioritization test can be used to check if the value ranking of all investments in a portfolio matches stakeholders' expectations
- Finally, an optimization test can be run if a suitable optimization engine is available.

Unexpected or unsatisfactory results of these tests will drive adjustments as explained above. After a few iterations, this process should result in a stable and reliable value framework that can then be applied to the valuation of all investments. Fig. 4 shows an example of how different projects which contribute value in very different ways can be directly compared with one another.

Another very important aspect of value is understanding how it changes, based on when a project is completed. Often a project can be very important, but have some flexibility in timing. When working in a portfolio context and looking at how to build a plan that fits within monetary and resource constraints, it is critical to be able to understand the incremental cost and/or risk exposure that will be incurred if a particular investment is deferred. This will deliver much better overall portfolio performance, rather than applying a cutline approach where the highest value projects are completed first, regardless of their level of urgency. Looking at project timing rather than just total value also makes it much easier to understand the potential trade-offs between a single large project and multiple small projects that might require the same resources.

5. Applying the Copperleaf value framework to hydro modernization initiatives

Hydro modernization initiatives have traditionally been one of the classes of project for which it can be difficult to build a complete business case using traditional approaches to project valuation. There are often many contributors to project value, ranging from unit availability, capacity, and green power incentives, to flood control, and environmental and recreational impacts.

5.1 Unit availability

Power generation is obviously one of the key benefits of a hydro system, and the economics associated with avoiding lost generation will typically be one of the key drivers for a maintenance or modernization scheme, especially for larger units. Replacement of aging components increases the reliability of the hydropower system. This has a potential economic impact in terms of the availability of the unit to produce power as well as the role played by the unit within the grid in terms of voltage support, load following ability, and impact on the transmission network.

The lost generation value can be calculated by multiplying the system's marginal unit capacity by the expected duration of the unit outage by the cost per MWh of replacement power. This value is then multiplied by the percentage probability of failure of a piece of equipment to be replaced, to obtain the value of the lost generation risk that can potentially be mitigated through investment. This risk may be fully or partly mitigated through investment, depending on the work being planned.

Marginal unit capacity is essentially the capacity that would be lost if one unit were unavailable. This is the capacity of the unit multiplied by its capacity factor minus any capacity that would be possible to transfer to other units. For example, if a plant has two 12 MW units that typically run at 60 per cent each (7.2 MW) but in the event of a failure of one unit, it would be possible to run the other unit at 90 per cent (10.8 MW), the marginal unit capacity would be the unit capacity times its capacity factor, minus the portion of the capacity that can be transferred: 12 MW(60 per cent) – [12 MW (90 per cent) – 12 MW (60 per cent)] = 3.6 MW.

Capacity factors typically vary significantly throughout the year, based on the volume of water available. Because investments are planned to avoid an asset failure at some unknown point in the future, a long-term average should typically be used.

The expected outage duration is the time that it would take to replace or repair a piece of equipment that fails in service. This takes into account the availability of spares and the lead time to order replacement parts in the case of a catastrophic failure. It can also be used to model the total annual impact of a number of shorter outages over a year caused by reliability problems which result in numerous repairable failures.

Depending on the organization's circumstances, the cost of replacement power may include the incremental cost of replacement generation (for example, the marginal cost of natural gas generation), the market price to replace the power not generated, or the lost revenue for power not exported. For island grids, or in areas where transmission limitations exist, or where non-dispatchable renewables form a significant component of the generation mix, and the hydro unit is relied upon for its ramp rate and voltage support, these factors will also drive other value measures around firm capacity, grid stability and transmission impacts.

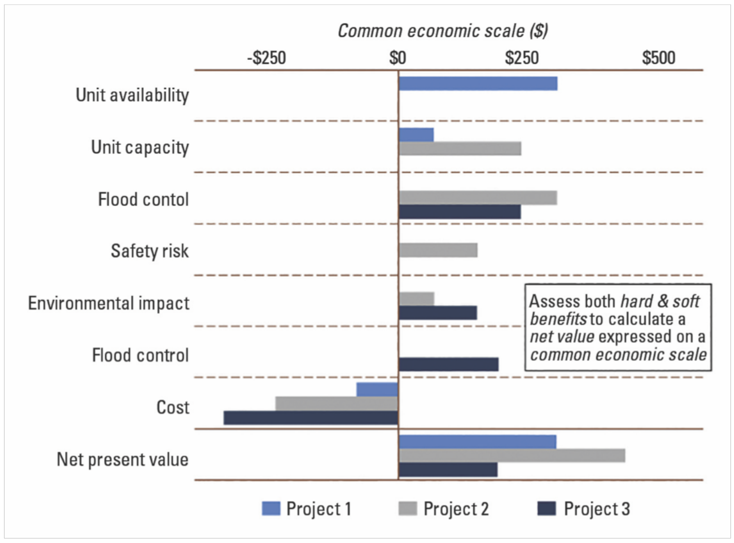


Fig. 4. Evaluating investments on a common economic scale.

5.2 Capacity

Many improvement and modernization projects increase system capacity. The value of increased capacity can be calculated based on the incremental generation in a manner similar to that described above for lost generation risk.

As with the cost of lost generation, the value of additional capacity is impacted by stream flows and the availability of water to utilize the additional capacity. Incremental hydro capacity can also have significant benefits in terms of firm capacity, load following response and grid stability.

5.3 Green power incentives

Many jurisdictions have tax credits or portfolio targets for retail suppliers of electricity, to encourage or mandate the development of renewable energy sources. For example, in the USA, the IRS offers Section 45 Production Tax Credits as a financial incentive to renewable energy production, while the European Union Renewable Energy Directive and the California Renewable Portfolio Standard mandate portfolio targets for a percentage of energy generated from renewable sources. Incremental hydro capacity is eligible for participation in almost all of these schemes. Generally, it is straightforward to model a financial benefit using this mechanism, because the credits are typically traded independently of the power produced, and they have an explicit financial value.

5.4 Flood control

Many power-producing dams also play a key role in flood control. The failure of key components can compromise the ability to manage reservoir levels and to maintain flood control capabilities effectively. Many dam operators are also challenged with the fact that older dams and impounding systems were not designed to meet current regulations regarding dam safety, flow control and reservoir level management. For example, many older impoundment structures were constructed with wooden flashboard assemblies which fail to meet current flood control standards.

Projects that improve or maintain the flood control ability of an installation can be valued in several ways, depending on the situation. In almost all cases, there is tremendous value to downstream communities in maintaining or improving flood control capabilities. It is typically possible to look at historical flooding events to understand the extent of property damage and safety concerns that may ensue from inoperational or insufficient flood control equipment, as well as the frequency with which such events would be expected to occur. In addition, ensuring the effective management of flood waters and avoiding damage to impounding structures, spillways and power canals provides a direct financial benefit to the utility.

There can also be a regulatory or compliance component to flood control requirements. For example, for privately operated hydro installations in the USA, upgrades to reservoir management capabilities and flood control facilities is frequently a component of the requirements for Federal Energy Regulatory Commission (FERC) relicensing of a project. In cases like this, the completion of upgrades as part of a modernization initiative in advance of a relicensing cycle can help the utility build its relationship with FERC, as well as with the local community and local government agencies. It can also help avoid the potential for additional project commitments and associated costs during a relicensing cycle, a period where significant demands on available capital and resources are expected.

5.5 Environmental impact

Since the original installation of many hydropower projects, much has been learned about the impact of such projects on river ecosystems, and many innovative technologies have been introduced to help mitigate these impacts. Newer system designs, for example, may also have an incremental positive impact on the survivability of fish and other aquatic life.

The ability to maintain flow control and minimum flow levels impacts fish health and populations. Depending on the project configuration, water oxygenation, water temperature and minimum flow levels can all be affected if components of the hydro system fall into disrepair. In addition, if the current project configuration does not allow for the desired minimum flow to be maintained at all times, system upgrades that allow for greater flexibility in flow rates can have a beneficial impact on habitats.

These impacts can be measured by looking at the expected impact of the proposed investment on water quality parameters and on the various aquatic species the lifecycle of which is affected by the hydro project. For example, in many areas, extensive studies have been completed on the relationship between reservoir discharge levels and the downstream trout population, making it possible to estimate the impact of an investment that increases minimum flows on population levels.

As with flood control, there is often a regulatory or compliance benefit to initiatives which enhance wildlife habitat and survivability, in addition to the direct environmental benefits.

5.6 Recreational impact

Reservoirs and tailwaters can be important recreational assets for a community. These recreational opportunities provide a significant contribution to the local economy and have a positive impact on the lives of local residents. Ensuring the continued reliable operation of a system, and enhancing the interaction between the system and aquatic life, can be beneficial to both personal and commercial recreational users. These benefits can be assessed based on the economic impact to communities, the number of local recreational users of the facilities created by the project, the degree of expected impact, and the annual probability of a failure.

6. Using value frameworks to optimize investment portfolios

Discussed so far have been: how to value individual projects and build a comprehensive value score for each project; and, the importance of understanding how that value score changes depending on project timing. This provides all the information needed to determine the optimal timing for each project, and to provide the maximum possible value while staying within the financial and resource constraints.

Unfortunately, if one considers an investment portfolio of any size, the number of possible permutations is staggering: there may be millions or tens of millions of options for a moderately sized portfolio of projects. This is where an optimization engine can provide a huge benefit. Modern MCDA techniques can be used to solve problems of this complexity very rapidly, using mixed integer linear programming engines.

Being able to determine quickly the optimal portfolio that can be delivered for a given set of constraints has several benefits. First, it provides a clear understanding of the value that is being delivered at any given level of portfolio expenditure, and the incremental value that is delivered by increasing that expenditure. This allows management teams to evaluate multiple expenditure levels and understand the levels of risk mitigation and overall value associated with each option.

In addition, there are often circumstances where portfolio values depend on external factors, such as the market price of electricity, fuel prices, labour costs, the value of renewable energy credits, and so on. Using an optimization engine to identify quickly the optimal portfolio contents and the value delivered makes it possible to adjust these parameters and carry out a sensitivity analysis on each variable. This can allow either for the selection of a portfolio strategy that accounts for these sensitivities, or the implementation of an appropriate hedging strategy.

Finally, for many utilities, one of the main constraints in portfolio execution is the availability of key resources. For example, specialized design engineers or project managers may be required for many different types of projects, yet might be in short supply. If an organization has identified certain types of resources as a bottleneck, optimization can be used to construct a plan that fits within this constraint in the short term.

This capability can greatly enhance the organization's ability to deliver an 'executable' plan that can be accomplished with the available resources. Even more powerful, though, is the ability to plan further into the future to analyse the risk and value implications of such bottlenecks in the medium term. In a 3-5 year horizon, these issues can be more actionable, and analysing the portfolio value implications of either increasing or reducing staff in certain areas can guide hiring or contracting strategies, as well as the development of training programmes.

7. Conclusions

Valuing investments goes far beyond computing simple financial indicators or ratios. Defining a value framework based on multi-criteria decision analysis techniques will generally lead to superior results compared with artificially capped methods, such as quantized scoring. Multi-criteria decision analysis uses an uncapped value scale and calibrates all benefits to a common weighted scale, delivering a tangible score that is an accurate reflection of the value each investment returns to the corporation.

While such techniques are applicable to any business, they are particularly important in the hydro industry, where assets can have extremely long lifecycles, thus increasing the relevance of valuation techniques that take the effect of time on value and risk into consideration. Moreover, hydro projects often have large environmental and societal benefits and challenges, and these again call for valuation methods which quantify such effects properly.

Buy-in to the investment valuation approach and criteria are best achieved by the active participation of the affected teams and stakeholders in the process though structured workshops and brainstorming sessions. The results should be documented and reviewed. This will ensure the engagement of the teams in the process, the understanding and acceptance of the final recommendations across the organization, and commitment to the ultimate execution of the work. ◊

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