Annex 1

Consultancy:
Technical expertise on issues related to the increase of electricity generation in hydropower stations due to Decision Support System (DSS) optimization

I. Introduction and Objectives

The objective of this report is to analyze the technical soundness and applicability of the proposed text for defining "baseline and monitoring methodology", entitled as "Increased electricity generation from existing hydropower stations through Decision Support System (DSS) optimization". To undertake this evaluation, particular attention is paid to two reports by the CDM Executive Board. These reports are the "Combined tool to identify the baseline scenario and demonstrate additionality" and the "Tool for the demonstration and assessment of additionality".

In text under evaluation, a DSS is proposed as a CDM project activity. On the other hand, the text is also proposing a monitoring methodology (based on the flow-output relationship curve) for evaluating the baseline scenario, which is considered to be the present status quo of the system. This monitoring methodology is definitely necessary for comparison of alternatives under natural randomness and variability.

According to the CDM reports, the additionality shall be defined after carrying out a number of different Steps, in which the proposed alternative is compared to other possible alternatives. Nevertheless, in the proposed methodology, the authors have somehow suggested that the proposed DSS would be the best alternative, without properly addressing the other potential alternatives, for increasing energy production of reservoir-based hydropower systems. This is one reason why it is difficult to properly evaluate whether or not the DSS, as a CDM project activity, could be considered as Additional or not and, consequently, whether it should be considered as a CDM project activity.

For assessing the additionality of the proposed project, the comparison of different activities should be done with more rigors, and other alternatives should also de compared to each other or further discussed. More attention should be given to the points and steps indicated by CDM document "Tool for the demonstration and assessment of additionality". Another issue given on the proposed methodology refers to the monitoring methodology for calculation of the baseline scenario. The latter should also be further extended covering some of the points indicated later in this report.

In the next sections some of the topics presented here are further discussed. First, an overview of DSS is given, followed by a discussion on some factors influencing the energy production of system. Then, an evaluation of the technical soundness of the proposed monitoring methodology is given, followed by some final remarks and conclusions.

II. Decision Support System

Some of the most important management decisions made in the field of water resources have long-term impact. Years after the decision time, false or even no optimal decisions may imply the reduction of the system reliability, the inability to serve new regions and meet increased water demand and great economic losses. One of the methods in constantly progress and which has been taken the attention of researchers and water engineers is the Decision Support Systems (DSS).

2.1 Objectives and Benefits of implementing a DSS

The DSS can bring many other benefits besides the only one proposed here, the maximization of energy production. These other benefits may be a more sound water management with an increase of human safety and better environmental conditions. Some of the objectives of a DSS in the field of water resources, besides energy production, include:

- flood control
- water quality management
- environmental management
- irrigation for agriculture use
- domestic and industrial water supply
- water and wastewater treatment plants

In this respect, it is important to keep in mind that the application of a DSS with the single objective of maximize hydropower production could be contradicting some recommendations of international organizations and experts, in regard to the need of a multi-objective approach towards our natural water resources.

Moreover, there are other important issues regarding the DSS such as how to define what a DSS is, how to evaluate single and multi-objective DSS, what the minimum set of DSS components and the difficulties in actually implementing it are.

III. Definition of DSS

The development of a DSS requires an interdisciplinary research approach and involves disciplines such as computer science, decision theory, statistics, psychology, information and knowledge engineering, and organizational science (Eom, 1999). The concept of DSS emerged in the 1970s, but due to the rapid advances in computer science and related research fields, the boundaries of DSS have expanded such that the understanding of what a DSS is (or might be) has become less apparent. According to Power (1997), any system supporting decision-making, including executive information systems, executive support systems, geographic information systems, online analytical processing and software agents, may be called a DSS. The ambiguity of DSS definition has been discussed by several authors, some of whom go even further by viewing DSS as having matured to the point where they have lost their identity and became part of the mainstream field of management information systems (Carlsson and Turban, 2002).

The above discussion points out the need for a proper definition of what is understood as a DSS, before trying to propose such project activity. In the proposed text, the definition given by the authors is rather vague and weak to support a definitive definition, as many hydropower facility systems already apply some sort of computer-based approaches. The definition given by the author is as follows "a DSS is an integrated set of computer programs (modules) that use forecasting methods and both optimization and simulation techniques to optimize the long-term and short-term benefits of power system operation".

Therefore, it may be difficult to define to which extent the already-in-use computer programs can be defined or not as a DSS. For example, lets suppose that a hydropower system operator is already using some computer models (it is difficult to not image that nowadays) to execute some tasks based on tradition methods, such as multi-regression prediction and linear optimization models. Even though, these models may not be "completely" integrated, and may not present a good user interface, the operators may still be able to associate somehow the results of different models, and in this way obtain a better decision. In this case, is it a DSS? These issues could also result in another problem related to the evaluation of a DSS, such as what is a good DSS? Moreover, the implementation, of whatever can be called a DSS, is taken usually by progressive stages and may be infinitely under modification and improvements, such as by upgrading models' methodologies, training operators, acquisition of powerful computational machines, installation of more efficient observation network and so on. This discussion is particularly important as it is related to the first assumption made by the authors, which refers to the applicability or not of the proposed project as a CDM project activity.

3.1 Components of a DSS

Regardless of finding a definitive definition to what a DSS is, some of the common components found in many of the existing DSS, which could be considered to be essential for the successful of a DSS are (Koutsoyiannis et al., 2003):

- User interface (e.g. computer graphics)
- Decision models (e.g. optimization and simulation)
- Hydrological models (e.g. inflow and precipitation prediction)
- Data management (e.g. network of observation station, telemetric information and databases)
- Reporting system (e.g. communication networks).

3.2 Difficulties in implementing a DSS

Moreover, the implementation of a DSS may face several problems, which may be related to technical, financial, cognitive and regulatory issues. Some of these technical problems may be concerned to data availability, lack of trained users, lack of powerful computers and no existence of enough theoretical knowledge to derive possible solutions, and to discover and analyze the underlying complex and non-linear cause-effect relationships. A user friendly interface is another of the most important characteristics of a successful DSS, and increasing efforts in computer science have been devoted to developing intuitive, 'easy to understand' interfaces (Giupponib, and Rosato, 2005).

Moreover, cognitive obstacles, such as an aversion among senior executives to DSS technology, may also play a significant role. In fact, DSS still tend to be used by front-line employees and middle management (Carlsson and Turban, 2002). There are other problems related to the acceptance and use of a DSS that may arise even after its implementation. For example, the DSS may become obsolete because the end user, after some time, may become familiar with its logic and is able to apply it on his own. Similarly, decision-makers using a DSS for awhile may be able to obtain detailed insights into the decision problem and then understand their own preferences better, even though the solution eventually to be adopted is different from that determined with help of the DSS (Giupponib and Rosato, 2005).

3.3 DSS and the developing world

The application of a DSS, to improve water resources management, has been intensively investigated and documented by the academic community, particularly during the last decade. However, the majority of actual implemented DSS are specially found in the developed world. The problem of implementing such high technological demanding systems is properly due to the already mentioned barriers and conditions needed for their implementation, particularly, the lack of investments in the field of Research & Development by government and companies, and also by lack of appropriate equipments, facilities and infrastructures. Another very important reason is that the development and implementation of such information systems requires well-trained personal, which is usually not easily found in developing countries.

Finally, concerning the implementation and operation of such systems, lack of data and information, lack of technological infrastructure, and even the constant political instability may also be seen as great barriers of its success application. Regardless the barriers and difficulties that may be faced on developing, implementing and operating a DSS for increasing hydroelectricity production, this alternative is very promising as its effectives has been already shown in many other real world example and its costs may be relatively low when compared to some structural alternatives, such as increasing reservoir size and upgrading machinery.

IV. Energy generation by reservoir-based hydropower systems

Water resources management may be divided into four basic stages: planning, design, operation plan and operation. During the planning stage, attention is given to the identification of how the structural planned facilities can affect, quantitatively and qualitatively, the natural distribution of water within the basin. During the design stage, a detailed investigation should be undertaken to assess the risks involved in the implementation of such facilities. In general, during the planning and design stages, hydrological studies focus on deriving prognostics and estimations of average and extreme values, such as the minimum and maximum flows and the returned periods associated to them. During the operation plan stage, focus is given to the identification of efficient operational rules and strategies, which is frequently carried out by the application of optimization and simulation techniques. These rules should be defined in a way to achieve the objectives already defined during the planning stage, taking into consideration safety, total production and associated costs. Finally, the operation stage itself refers to the actual operation of the controllable facilities (reservoirs), through the application of the previously defined operational rules and strategies.

4.1 Hydropower System Optimization

Optimization techniques, when implemented, tend to be rather simplified due to the innumerous aspects related to the water resource management of a single or multiple reservoirs system. Water resources management is a very complex problem and, therefore, it would be almost impossible to try to address all of the related points at once by a single optimization model. The reasons for that are first of all, due to the lack of a unique and absolute point of view on what is the best way to deal with these different issues and their dimensions. Another reason could be originated by the lack of efficient technological tools and techniques able to deal with it. Moreover, the unpredictable and random hydrometeorological characteristics of the natural system may result in even more complexity and uncertainties to be dealt with.

Accordingly, in the last two decades or so, the focus and efforts of the research community on the development of complex optimization/operational tools (such as DSS) have been shifted to deal with multiple objectives and multi-purpose problems. However, on practical existing applications, few or none of them can really deal with the whole complexity of water resources management. Fortunately, research and practical applications continue to be carried out through out the world in an attempt to achieve this goal. Of course, in the last decades, we have seen more and more applications, which, even though are not able to deal with all the associated issues, are getting constantly more sophisticated and effective. These new methods and tools, in which the DSS may be considered one of them, are in fact a promising way to maximize benefits from the use of our natural resources.

4.2 Factors affecting the energy generation by reservoir-based hydropower systems

Some of the aspects that could be taken into account in optimizing power generation system based on storage reservoir can be listed as follows:

- the inflow volumes into the reservoirs
- the total storage capacity and restriction of reservoirs' volumes
- the restrictions to volumes of downstream released water from the reservoirs of the system
- the sedimentation and erosion problems affecting the reservoirs, riverbed and generation facilities
- the restriction to volumes of hydropower and spillway water releases
- the total installed energy of all the hydropower units of the system
- the existing transmission grid
- the energy demand in the grid system
- the multiple water uses (including flood control, irrigation, domestic and industrial consumption, navigation, aquatic life conservation, water quality and recreational use)
- the hydro-meteorological and climatological patterns
- the regulations and rules governing the water use
- the economic and financial aspects involved in the water sector
- the local and regional socio-economical development

As mentioned above, there are a variety of factors that may influence the operation of a system of reservoirs for maximizing hydropower generation. Moreover, at an integrated hydropower system of reservoirs located under different hydrological conditions, total energy production may be increased through the application of more efficient controls of its sub-systems. In this way two factors play an important role and should be considered, the existing energy transmission grid and the location of generation units within the same river system.

Therefore, for the proposal of introducing a DSS to maximize energy production, it is important to keep in mind that the proposed methodology will not reflect truly the characteristics of the system unless the whole system is under consideration. For example, in integrated systems, it is common to see situations in which one sub-system is sometimes "sacrificed" in favor of another sub-system, in a way that the latter can reserve water for production at future stages.

4.3 Relationship between spillway release and system optimization

Another point raised by the Executive Board is concerned to the water released through the spillway. In this respect, the volumes of water discharged through the spillway (spillway releases) are not at all only a consequence of a non-optimal operation (e.g. lack of a DSS). Spillway water releases are often unavoidable even under perfect operational conditions. For example, in integrated energy systems, operators may decide to release water through the spillway, after maximum intake of turbines is achieved, to increase production of other hydropower plants located downstream from that reservoir (either reservoir based or run-of-river units). Also, it may be decided to release water through the spillway at low-productivity sub-systems, flowing the water to high-productivity ones for later use and, in this way, achieving higher energy productivity in the long run. Additionally, safety is another point that could be taken into consideration when deciding on spillway releases.

4.4 Effects on the operation of run-of-river units due to the DSS

The optimization of volumes of controllable reservoirs should be carefully undertaken when run-of-river units exist within the same river system, as already pointed out by the Executive Board. As hydropower projects are usually regulated by the government and require a large amount of investments, even from the planning stage, a kind of optimization is carried out to define the best layout of units. In this sense, the productivity of existing run-of-river units is closed related to the operation of the units with controllable storage volumes.

Hence, any changes in the operation strategy used for the latter will definitely affect the productivity of the former. In this way, implementing a DSS is much like to affect the productivity of all units located within the systems. Therefore, a successful DSS, which intends to increase energy production, must take this fact into account.

However, it is not possible to make a definitive statement to whether a DSS is like to increase or reduce the productivity of run-of-river units. This will depend on the physical characteristics of the system as well as demands in the grid and other regulations governing the specific system in consideration. Nonetheless, for the implemented DSS to be considered successful, the overall productivity of the system in the long run must be considered. Moreover, if other objectives, besides the maximization of energy production, have been defined, this should also be properly analyzed.

4.5 Increase in generation due to reasons other than the DSS

Many DSS, applied to a variety of problems, have been successful in achieving their goals. Therefore, a DSS has as well great potential to increase the energy production of hydropower systems. Nevertheless, there are a variety of other methods that may be as well used in an attempt to increase energy production of a hydropower system. Some of these alternatives may be listed as follows:

- Increase of dam height
- Modernization and upgrading of turbines and generators
- Increase reservoir capacity, thorough dragging and sediment remove
- Deviation/transferring of water from other water bodies and water basins
- Changing restrictive regulations and rules

On the proposed text, the authors have mentioned one potential alternative to the DSS system, the "spillway dimension". However, more explanation to what the authors meant should be given as it is not clear what they meant with it.

A difficult matter though concerns how to evaluate such benefits originated not only by the implementation of a DSS, but also other alternative methods available to do it. This evaluation becomes even more complex when knowing that these systems are usually very influenced by random and unpredictable natural factors (e.g. prediction patterns). The attempts of proposing a methodology able to properly address these improvements are indeed needed. Nonetheless, the most affecting factor in this analysis is the intrinsic characteristics of the environment in which the generation systems is located in.

In this respect, the authors of the proposed CDM project activity have proposed as well a monitoring methodology which is able to evaluate and measure the benefits of the status quo of the system, prior to the implementation of the DSS. The proposed monitoring methodology for evaluating the baseline scenario can be considered to be technically sound in most of its aspects. Later in the next section, more discussion is given about the monitoring methodology presented by the authors.

V. Methodology for estimating energy produced flow observer during the project activity year

In the operational and optimization research, whenever a new optimization/operation technique/methodology is proposed, there are different ways to evaluate the performance of the proposed method. One way for evaluating the performance of different optimization methods, for example, is through the application of the new proposed method to the operation/optimization of a case study system. Then, the results found by the new method are compared to the ones found after the application of more traditional methods or the application of the current method in use at the present case study. As these applications do not necessarily need data of generated energy, but use the same historical hydro-meteorological data, an unbiased evaluation can then be achieved. One disadvantage of this methodology is the difficult, in many times, to rigorously reproduce the already-in-use operation strategy. Accordingly, the monitoring methodology proposed here could also be seen as another way for comparing the performance of different techniques, when applied to the optimization of systems influenced by random natural characteristics.

5.1 The proposed monitoring methodology

The Executive Board argued whether the proposed baseline is able to "differentiate between the increase in generation due to the decision support system and that which occurs due to change due to hydrological conditions". In this respect, it is possible to state that the proposed methodology can indeed differentiate these two situations by using a kind of normalization of the observed values during the baseline year through a relational polynomial curve. Nevertheless, in defining this curve some important points have to be adequately addressed.

The proposed methodology is based on a flow-output relationship curve, which correlates the energy output to a certain hydrological condition. Therefore, for future conditions this curve may serve as a reference (baseline), from which we can estimate how much energy would be produced if the new operational strategy (e.g. DSS) had not been implemented.

After defining the flow-output relationship curve and following the implementation of a DSS, the energy output for a given week in the project year can be compared to the energy output that would had occurred in the baseline year in respect to the same hydrological condition. After some time from the implementation of the DSS, lets say one year, if an increase in energy output is achieved, (which can be calculated from the summation of the recorded weekly energy output minus associated baseline weekly energy output), this would indicate an increase in energy output due to the use of the DSS for that week. Since the energy output is being compared to two exactly periods with same weekly hydrological condition, for project and baseline years, there would be no effects on whether the baseline year, used for the calculation of the baseline curve, is a particularly wet or dry one, as the corresponding weeks would still share the same hydrological characteristics.

5.2 Advantages of the proposed monitoring methodology

The flow-output relationship proposed as the monitoring method for measuring the baseline scenario is technically sound in its essence. Some of the positive characteristics of the proposed monitoring methodology may be listed as follows:

- The proposed methodology is able to normalize results against hydrological input for the week of the project year which is under review, so that the electricity generated from a specific weekly flow in the project year is compared directly with the electricity from the exact same condition of the baseline year.
- It also states that situations in which physical changes are made to the system should be excluded (e.g. incorporation of new units and change in volume of already-existing ones).
- Also, the methodology proposes a 95% significance level of the baseline year outcomes to ensure a more conservative result, which consequently ensures more confidence to the obtained results.

The authors suggest that many years should be used (e.g. three), but if data is not available, at least one-year period could be considered. However, as questioned by the EB, "is one-year data adequate to estimate the flow-output relationship used to evaluate the baseline condition?"

Well, the minimum number of years that should be considered as the ideal number is not a straightforward answer. Theoretically, as many years of data are used (as proposed by the authors), better estimation of the flow-output relationship should be expected. Nevertheless, the availability of such data may not be ready for most of the systems in the world for such long periods, particularly due to the constant structural and non-structural changes occurring in the systems and its operational strategies. To avoid any miscalculation of the relationship curve, the authors recommended that the data used should be observed only under similar conditions. The next sub-section discusses this matter, pointing out the important issues to be considered if only few data points are available.

5.3 Shortcomings of the proposed monitoring methodology

- If only one annual cycle of data is available, it may be acceptable to be used but only under certain conditions and after a critical evaluation of its applicability.
- First, the valid interval of the relationship polynomial curve should be defined to be only between the minimum and maximum observed limits of total water volumes flowing through the dam (see Figure 1).
- Second, outliners of the calculated data points should be properly excluded to avoid any distortion on the calculated relationship curve (see Figure 1).
- Moreover, it is important to keep in mind that if there are few available data points, other factors which might not have been properly identified as project boundaries, such as changes on regulations, malfunctioning of facilities, odd changes in demand, may as well interfere on the final calculated data points.
- Another interesting issue that should be further investigated is the influence of initial and final storage volumes on the final produced energy within the year of considered data. This would also depend, of course, on the size of the reservoir and its regularization capability. For instance, data calculated on relatively small reservoirs (relative to reservoir's regularization in comparison to its system) might not suffer much distortion as other reservoirs built for regularization of one or more hydrological years.

Some of these problems may be exemplified with the following example. Lets assume that the one-year period is adopted for calculation of the relationship curve of the baseline year. If the data present good variability of observed data points, covering proportionally the range of valid flow values, it could be possible that one-year period is enough for the calculation of the flow-output relationship. This would be still valid independently whether the period in question is considered to be (in average) a wet or a dry year. The problem may arise when this variability of data points does not cover the whole range of operational flow values. As a consequence, during the project year, for a hydrological condition (flow) to which there have not been any observed similar flows during the baseline year, the expected output energy for this hydrological condition may not be properly estimated.

Additionally, for a certain range of flow values, which has few observed data points during the baseline year, the estimation of the monitoring curve may be more susceptible to miscalculation of single observed data points; as such points may greatly influence the final shape of the monitoring curve. Figure 1 shows an example of this case, for which the middle range of values presents only one observed data point that is assumed to be wrongly estimated. Miscalculation of such data points may be originated from factors occurred only for short periods of time. Some examples of the problems that may occur during short periods of time are, for example, malfunctioning of observation stations and facilities that support better operational practices or changes of some operators for less experienced ones. Therefore, these factors may have not been properly identified when setting the boundaries of the project activity. As a consequence, the calculated monitoring curve may be underestimated.

Hence, more than defining a precise minimal number of observations to be considered for the calculation of the baseline flow-output relationship, a visual analysis of the plotted observed data points should be also undertaken. This would reassure the effectiveness of using a curve, which has been calculated, based on data points that are well distributed through out the relevant range of flow values.

Another problem that may arises, when taking only few data points of the flow-output relationship curve, regards to the regulatory capability of the reservoirs within the system. For example, for systems with a regulatory capability of several years the proposed methodology may not be valid, as the year assumed as the baseline year may be affected by the long-term operational objectives. For example, the current year energy production may be compromised for saving of water to the coming years. In this way, it is here recommended that more explanations about this topic should be given.

As an illustration of some of the problems described above, in Figure 1, we can see that due to scarcity of points within a certain middle range of values, if some of the few points presented within this interval are miscalculated, this may drastically affects the shape of the polynomial curve. And therefore, this could mislead the calculation of the emission reduction. Again, in cases where the calculated value in the project year falls outside the data set found on the baseline year, this data point should not be accounted for the calculation of emission reduction for that week (as mentioned by the authors). Another obvious point, also mentioned by the authors, concerns the importance of proper handling of outliners, when calculating the baseline monitoring relationship curve.

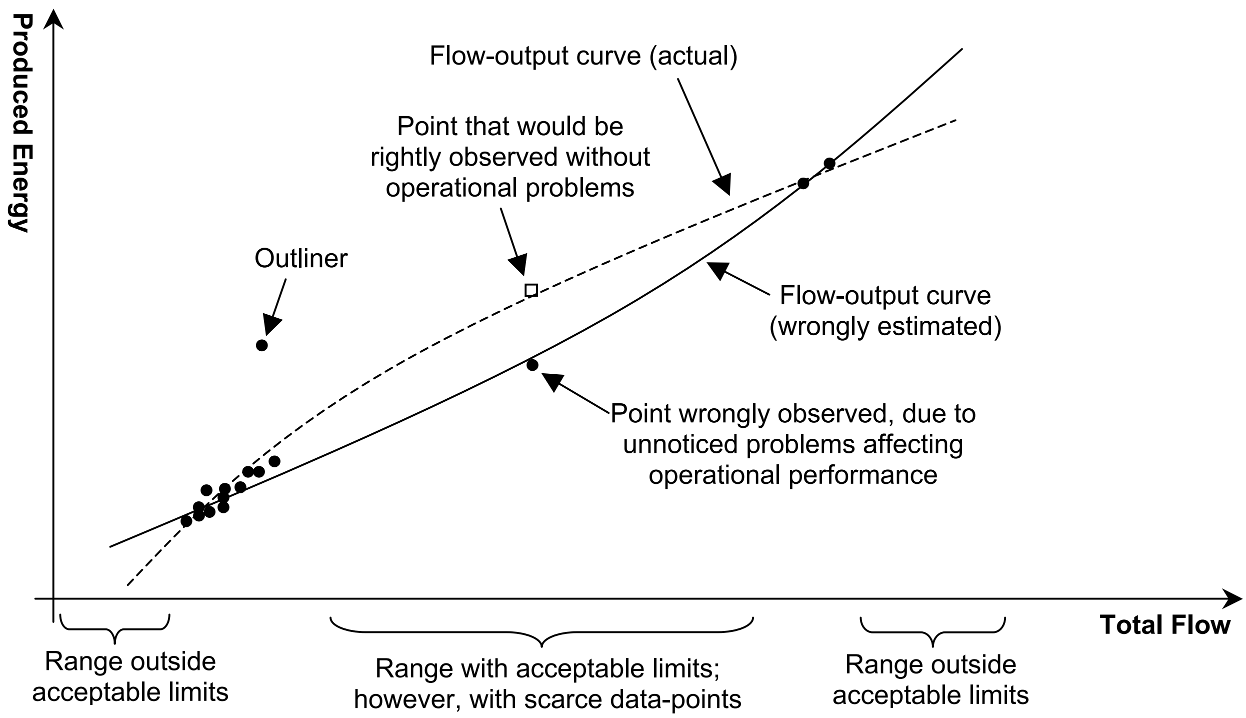

Figure 1. Some of the problems that may arise with the proposed monitoring methodology

VI. Conclusions and Recommendations

Regardless the barriers and difficulties that may be faced on developing, implementing and operating a DSS for increasing hydroelectricity production, this alternative is very promising as its costs may be relatively low when compared to some structural alternatives. Some of the conclusions related to this report are:

- When introducing a DSS to maximize energy production, two factors should be carefully considered, the integrated energy transmission grid and the existing units within the same hydrological system.
- The volumes of water discharged through the spillway are not at all only a consequence of no optimal operation system (e.g. lack of a DSS). They are often unavoidable even under perfect operational conditions.
- The implementation of a DSS is much like to affect the productivity of all units located within the systems. However, it is not possible to make a definitive statement to whether a DSS is like to increase or reduce the productivity of run-of-river units.

For the sake of clarification, final remarks and recommendations are made regarding the proposed project activity and methodology, as follows.

- More discussion on the definition of what a DSS is, and how to evaluate its goodness, should be given. This could be followed by discussion on the single- vs. multi-objective approach when dealing with the water resources management by DSS.
- The other alternatives to the implementation of the DSS could be also analyzed based on the proposed “Steps” (barriers, financial and common practices analysis) to establish baseline and additionalities”.
- The proposed monitoring methodology is technically sound. Nevertheless, when only few data points are available (e.g. one-year period), extra attention and restrictions to its use should be considered, as follows:
    - data should be uniformly distributed within the range between the minimum and maximum observed values,
    - values of the project year outside the minimum and maximum observed values of the baseline data points should not count for calculation of emission reduction.
    - the influence to the proposed monitoring methodology by long-term (one or more year) regularization reservoirs should be further discussed.
    - whenever data is scarce, extra analysis should be carried out (by DOE or other experts) to guarantee the appropriateness of the available data in determining the baseline monitoring curve.

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