Life Cycle Costing: a tool to manage the urban water cycle

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ABSTRACT

The Water Framework Directive puts much emphasis on the role of economics for improving the management of water resources. In the context of the urban water cycle, previous studies have proven that Life Cycle Costing (LCC) is a useful methodology for assessing the costs of the whole cycle. However, there are many elements and factors that can influence the results of the LCC assessment and therefore affect the decision making process. The main aim of this study is to identify the main difficulties for carrying out LCC studies in the urban water cycle and to propose some solutions to overcome them. Hence, the conclusions obtained from the assessment of several case studies will be more robust. Moreover, the transferability of the results will be improved.

Key words | economic savings, LCC, Life Cycle Costing, urban water cycle

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INTRODUCTION

Water is an essential resource for life. In this context, urban water activities (wastewater treatment, drinking water treatment, distribution and sewer, etc.) are essential in any urban system to assure a reliable and safe supply of drinking water for human consumption and to reduce impacts when discharging water to the environment.

Besides the obvious benefits of water activities, all processes involved in the urban water cycle also have significant economic costs. In this context and from an economic policy approach, the Water Framework Directive (Directive 2000/60/EC) states that all the costs assumed in the urban water cycle have to be recovered by the different agents involved. A previous and essential requirement to cost recovery is the knowledge of cost structure from the current and future water management activities.

In this context, most of the previous works have analysed the costs of urban water activities separately, such as Iglesias *et al*. (2010), Molinos-Senante *et al.* (2011b) and Pollitt & Steer (2012) have done. However, very few studies have assessed the costs of the whole urban water cycle. For this purpose, the Life Cycle Costing (LCC) methodology is a very useful tool since it is capable of providing a common framework to calculate costs associated with the urban water cycle activities. Thus, it enables the comparison of different technologies and helps in the decision making process. LCC analysis is defined traditionally as the estimation of the total cost associated to an asset over time, including investment, operation, maintenance and major repairs and disposal. Nevertheless, LCC can be defined in different ways, depending on the expected use of the results obtained.

Although LCC has been proven to be a useful methodology, there are many elements that may influence the results and therefore the decision making process. Moreover, there are some components that should be taken into account when an LCC is carried out since they may

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significantly influence the outcomes of the assessment. Against this brief background, the main aim of this paper is to identify difficulties for carrying out LCC studies in the urban water cycle and to propose some solutions to overcome them. Moreover, the main components affecting LCC results have been identified.

ELEMENTS HAVING AN INFLUENCE IN LCC OF URBAN WATER CYCLE

Goal of the LCC

The first issue to be considered is the definition of the main goal of the paper. In the context of the urban water cycle, it is very important to identify product groups with the highest associated cost for each stage of the cycle. Hence, it would be possible to set up recommendations of best practices to improve the efficiency of the urban water cycle activities.

System description

The urban water cycle includes the following activities: water abstraction, drinking water treatment, water transport and distribution, sewer network and wastewater treatment. The water abstraction phase corresponds to the raw material abstraction or pre-production phase of the life cycle. The drinking water plant corresponds to the production phase (which includes the transportation to the users) while the wastewater treatment resembles the end of life phase (including sewage network from the users to the plant). Figure 1 shows the urban water cycle which is the system boundaries in LCC.

Costs categories

Several costs categories may be considered in the LCC. The selection of them will influence not only the results of the LCC but also the comparability of the study. As shown in Figure 2, a complete LCC must include the following cost categories: (i) first cost; (ii) operating costs; (iii) use and maintenance; (iv) major repairs, modernization and rehabilitation; (v) surrender value; and (vi) indirect and global costs.

Methodology

The usefulness of the LCC depends also on the methodology used. In this sense, there are two main approaches: (i) *engineering methodology* and (ii) *parametric methodology*. The first one divides the process in many different parts. The sum of a detailed cost analysis of each part gives the final costs (Fabricky & Blanchard 1991). The latter is based on the estimation of equations that describe relationships between cost and some variables.

In spite of that, the engineering methodology allows for an extensive analysis of costs since they may vary for different cases at the same moment in time. For instance, they may depend on plant size, quality of water to be treated, even on the price policy followed by the seller. For this reason it is difficult to generalize LCC based on calculations coming from specific case or from other plants and systems. Then, we need to complement engineering estimations with other information which will be processed with a parametric methodology in order to be able to extend results to other case studies.

Temporal component

Investment in assets is done in specific times but its operational costs and benefits last for many years, so LCC has a temporal component. Costs must be quantified for each year included in the time horizon. Prices may vary year to year, and not at the same rate for all the components included in LCC analysis, then there is a source of variability related to lifespan.

As shown in Figure 3, the first cost is considered at the very first stage of the life cycle; operating costs, use and maintenance, major repairs, modernization and rehabilitation, indirect and global costs are assumed along the lifespan; and finally surrender value is considered at the end of life of each facility.

The present value must be obtained before adding costs because they take place in different years. As it is known, this value is estimated through the application of a discount rate. In this sense, the discount rate reflects the fact that

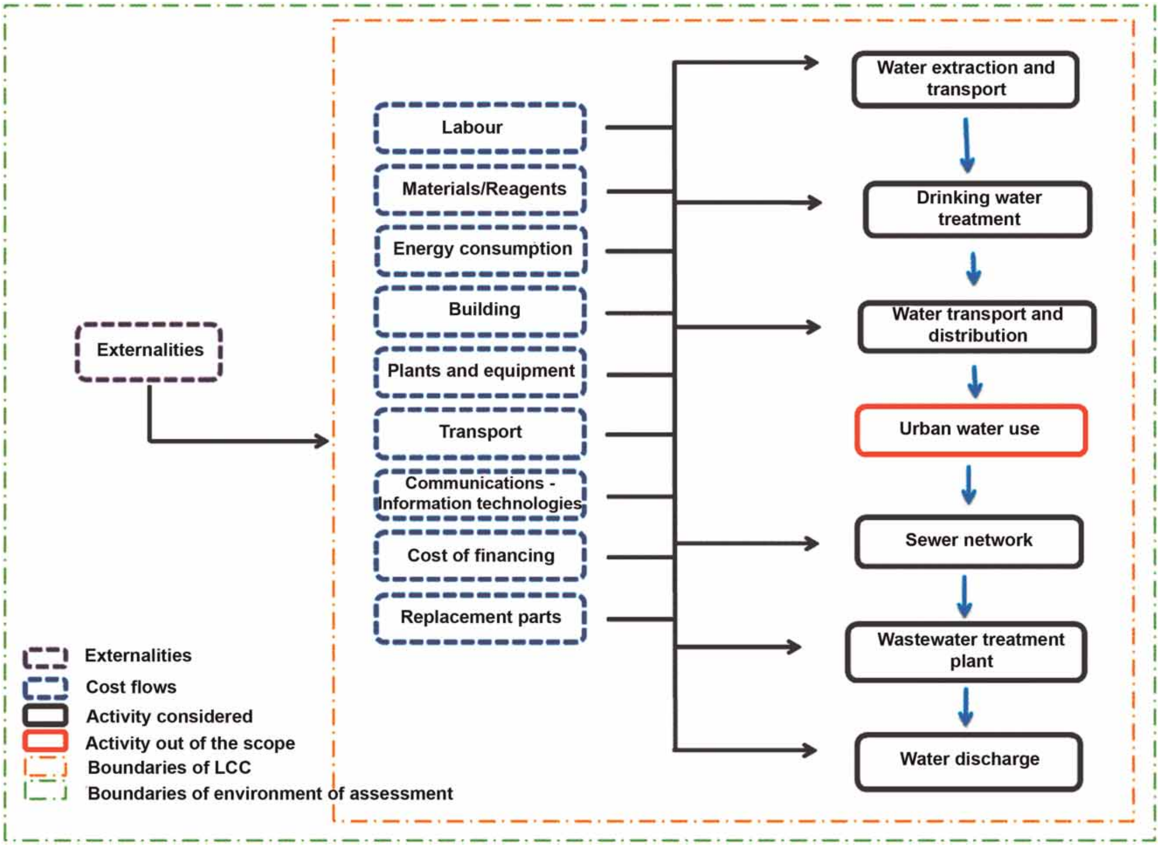

Figure 1 | System boundaries in LCC.

people generally prefer having money in the present rather than in the future so, costs that will take place in coming years may have a lower value than those in the present time. One difficulty in calculating the present value of an item is to obtain an appropriate value for the discount rate.

LCC calculated for private investments considers discount rate values closely related to real market interest rate because it reflects opportunity costs in financial markets (Howarth 1996), since the main aim of LCC is to help in deciding whether a project is profitable or not. For projects that last for a long time, it is recommended to use lower values of discount rate than in projects with a shorter lifespan. When dealing with a long-term project, a declining value for the discount rate at different time periods may be used. A good discussion about discounting can be found in Swarr *et al.* (2011) and Ciroth *et al.* (2011). When a decision is about environmental aspects, a very low value should be used, even near to zero, since environmental damage may have an impact that is likely to last for many years in the future.

Pearce *et al.* (2003) stressed the need for modification of the traditional assumption in discounting rates. In this context, an alternative approach is the use of a declining discount rate which replaces the exponential discount factor with a hyperbolic function. Hence, the viability of projects is improved in which the costs occur early in the time horizon. More details about this approach have been provided by Weitzman (2001) and Guo *et al.* (2006). Another approach suggested by Almansa & Martínez-Paz (2011) is the use of a dual-rate discount rate which involves the use of different discount factors for tangible and intangible goods. An appropriate discount rate can be also determined by the Delphi method, i.e. by consulting individually and anonymously to a panel of experts (Almansa & Martínez-Paz 2011).

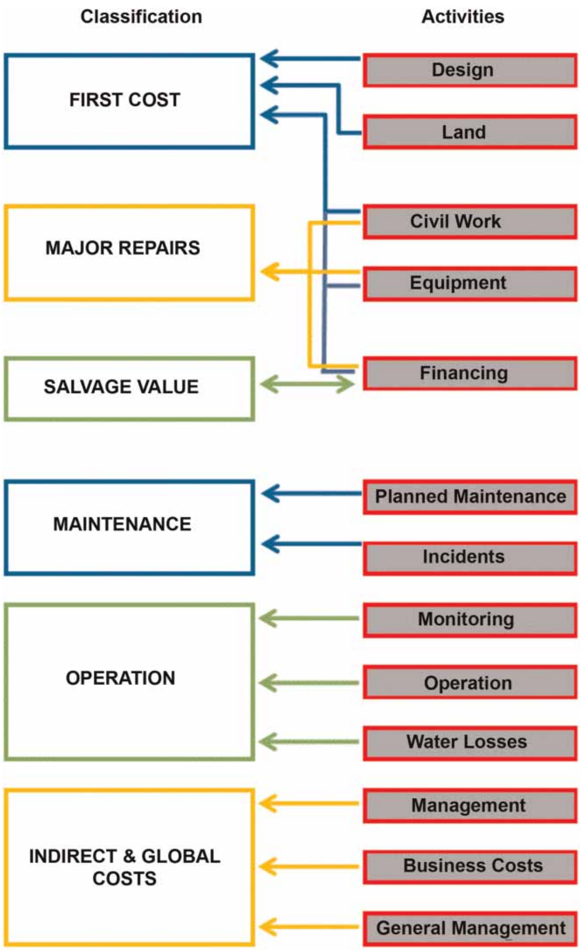

Figure 2 | Cost categories in LCC.

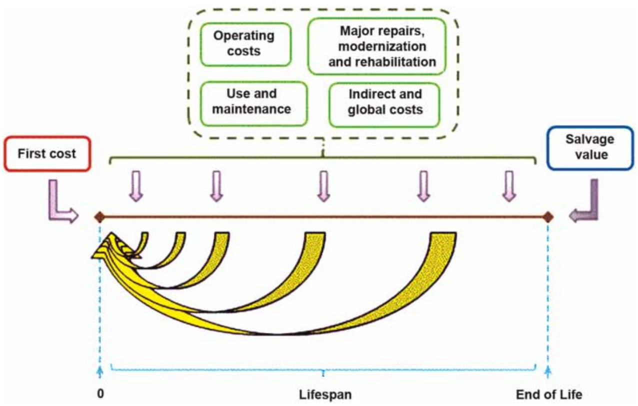

Figure 3 | Time location of costs.

ADDITIONAL FACTORS TO BE CONSIDERED IN THE DEVELOPMENT OF LCC IN AN URBAN WATER CYCLE

Source of data

The source of data will be different depending on whether engineering or parametric methodology is used for carry out the LCC.

The engineering method is based mainly in case studies. Hence, it is important that all stages in the urban water cycle are representative. Focusing on specific case studies will allow detailed information of activities to be obtained at a unit process level. However, as has been reported before, the information from case studies should be supplemented by other data in order to provide more general results (parametric approach). Some additional sources of data are as follows.

- Literature: most of the previous works have been focused on just one activity of the urban water cycle. Some examples are Barrios *et al.* (2008), Teuler *et al.* (2011), Molinos-Senante *et al.* (2011a), among others. However, it is necessary to obtain information of each activity of the urban water cycle and to integrate it.
- Databases: often they provide information at regional or state level. Nevertheless, they are very useful because it is difficult to estimate specific data about some processes directly from case studies. Some examples are: (i) EnerbuiLCAn which is a database on energy and construction related to SUDOE project; and (ii) Instituto de Tecnología de la Construcción de Cataluña (ITEC) database for building costs (year 2009, www.itec.cat/nouPdf.c/presentacio.aspx).
- Direct consultation with sellers: some prices and factors of variability in economical offers can be obtained directly by consulting with vendors.

Comparability of the results

If the objective of the study is to compare the costs of the urban water cycle of various cities, technical aspects must be taken into account. In this sense, it is well known that both investment costs and operation and maintenance costs are influenced by several aspects, as can be seen in Table 1.

As for the urban water cycle, it is not easy to achieve an exhaustive knowledge of the costs associated with each activity nor is it easy to obtain comparative figures for various technologies. LCC analysis for a few case studies cannot be standardized directly to be used in other facilities. Hence, it is very important to supplement engineering methods with parametric ones.

Within parametric methodologies, it is proved that costs functions are the most useful since they allow the simulation of results for new facilities. Cost functions enable us to improve the understanding of the relationship between the costs of the water cycle activities and their most representative variables. For that reason, this is a scientifically rigorous approach for planning new facilities or water services.

Many examples are found in literature, where cost functions for different parts of the process are estimated such as Tsagarakis *et al.* (2003), Dogot *et al.* (2010), Hernández-Sancho *et al.* (2011), among others.

As has been reported by Molinos-Senante *et al.* (2012), there are three main methodologies for developing cost functions in the field of 'water economics':

1. Considering the facility as a system of components or subsystems (Panagiotakopoulos 2004), each of which is simulated in detail.
2. In the so-called 'factor method', major cost drivers related to specific major cost parameters are known and they are directly estimated (Le Bozec 2004).
3. Statistical and mathematical methods are often used, when cost figures (actual or estimates) are available. These figures might relate to set-up cost and/or operating cost to the main variables of the facilities.

Previous studies (Sipala *et al.* 2005; Papadopoulos *et al.* 2007; Hernández-Sancho *et al.* 2011) show that the statistical method is the most common approach for developing cost

Table 1 | Factors influencing costs for each stage

Stage	Different conditions
Water abstraction and transport	(a) Origin of raw water (sea, surface water or groundwater) (b) Height of abstraction spot (c) Distance to the water treatment plant
Drinking water treatment	(a) Raw water quality (need for different treatment complexity or desalination) (b) Water treatment plant technology (c) Water treatment plant size (economies of scale) (d) Plant location (need for pumping) (e) Plant management
Water transport and distribution	(a) Distance and slope from water treatment plant up to urban core's network (b) Pipe's dimensions and material (c) Mains age (maintenance and repairing) (d) Soil characteristics (e) Water quality
Sewer network	(a) Sewer system (combined or separate) (b) Urban core's slope conditions (pipe's depth, need for lift pump) (c) Soil characteristics (water table level, rocky soil and low cohesion soil impact on construction cost) (d) Distance and slope from urban core's network to waste water treatment plant (e) Pipe's dimensions and material (f) Mains age (maintenance and repairing)
Wastewater treatment	(a) Wastewater treatment plant technology and design (b) Water treatment plant size (economies scale) (c) Solution to return the treated water to environment (d) Raw water quality (e) Wastewater reuse

functions. As a second step, it is very important to check the significance of the independent variables. In doing so, a statistical hypothesis test must be carried out. To conclude, it is necessary to evaluate the quality of the adjustment. Despite being several indicators, the most common is the coefficient of determination which measures the proportion of total variability of the dependent variable relative to its average, which is explained by the regression model.

The estimation of the costs functions allows calculating an LCC which can be applied to other cases. The comparison between LCC calculated by engineering and parametric methodologies should be done in order to analyse the consistency in results.

Variability of costs though lifespan

Costs must be estimated for every year through the lifespan considered in LCC. Ideally, the cost data should be referred to recent years. Nevertheless, recent data availability is not possible for all cases, so past data should be collected. It can be considered that elements in cost breakdown may have an evolution more or less similar to that of inflation. When they do not evolve like inflation, they introduce a variability factor in the relative prices of the system which has to be taken into account and calculated. Forecasting of explanatory variables values in cost functions is also needed.

In the urban water cycle activities, the variables influencing costs which seem to have more yearly variability, and thus need to be modeled, are energy consumption costs and interest rate. In fact, energy consumption cost has received special attention in many LCC studies. For instance, the US Department of Commerce published the document 'Energy Price Indices and Discount Factors for Life-Cycle Cost Analysis'. This is the supplement to NIST Handbook 135, Life-Cycle Costing Manual for the Federal Energy Management Program (FEMP). It provides energy price indices and discount factors for use with the FEMP procedures for life cycle cost analysis. These indices and factors are provided as an aid to implementing life cycle cost evaluations of potential energy and water conservation and renewable energy investments in existing and new federally owned and leased buildings.

To deal with variability through time span with cost modeling, two main methodologies could be used: (i) probabilistic cost estimation and (ii) regression analysis. Regarding the first one, a probability distribution function is selected for the cost data by fitting the data against major theoretical distribution functions. Once the distribution function is selected, cost estimates for different probabilities can be computed and range estimation performed. Finally, cost estimation could be performed using a Monte Carlo simulation technique. This methodology is suitable when variables influencing cost data are not available. One of the main drawbacks of probabilistic cost estimation is that it requires historical cost data to obtain the probability distribution. An example of probabilistic cost estimation for reverse osmosis plants is found in Park *et al.* (2010). The second approach is based on modeling the relationship between costs and some variables through regression models using historical data. The main drawbacks of this method are the need for a high quantity of data and the difficulties in forecasting long lifespans.

Risk assessment

In the urban water cycle, some of the most important risks may be pollution episodes, floods, droughts and extreme events. In the long term, changes in technologies and demand patterns should be considered.

Due to the identification of potential causes of risk in the LCC assessment, it will be necessary to assess their potential likelihood and extent. In order to quantify the risk of hazardous events, it is necessary to predict damage in case of potential hazard scenarios. The 'frequency' is derived from probability of occurrence of the potential hazard scenarios. Results obtained from risk assessment should be added as a complement to LCC results.

Structural and non-structural responses can be adopted to manage risks. LCC is a useful approach to assess both types of measures. In this context, Viavattene & Faulkner (2012) developed a qualitative method to assess the feasibility of non-structural responses for flood risk management. Monte Carlo simulation is a more traditional approach to integrate risks in LCC results, see Lauria *et al.* (2004), Sarang *et al.* (2008) and Brouwer & De Blois (2008).

Uncertainty assessment

As stated above, values in many components of LCC may suffer great variability. For this reason, an analysis of the variability of input prices must be carried out in order to assess the uncertainty of the final results. It is recommended to analyse how final results may vary in different scenarios.

There are several advantages of performing a sensitivity analysis (Marshall 1988):

- It shows how significant a single input variable is in determining project outcomes.
- It helps to identify the uncertainty associated with the input.
- It gives information about the range of output variability.
- It identifies critical input values in LCC.
- It finds out trade-offs between costs and environmental effects.

Based on the methodologies collected by Chowdhury *et al.* (2009), Hutton *et al.* (2011) and Bullene *et al.* (2013), the following approach is suggested to perform a sensitivity analysis for the LCC obtained in bottom-methodologies.

Step 1: Select the factors with a greater weight in costs. In doing so, the Pareto's 80/20 rule might be used. In this sense, discount rate value is a factor always to be considered in the sensitivity analysis.
Step 2: Recalculate the LCC taking into account the increase or decrease in the selected factors (more than one scenario).
Step 3: Compare the percentage changes in LCC for different cases assessed.
Step 4: Display the results of the sensitivity analysis in a graphical format, for example in a 'spider diagram'.

Environmental impacts accounting

Besides the obvious benefits of water activities, all processes involved in the urban water cycle also have induced environmental impacts along their life cycle, as they consume electricity and chemicals, generate waste, etc. Therefore, there is a need for integrating economic externalities in the assessment of costs. In this context, the so-called 'environmental LCC' has been developed as a supplement to the conventional LCC.

This novel approach was developed by a scientific working group within the Society of Environmental Chemistry and Toxicology (SETAC), running from 2002 to 2007, and a code of practice has been published in 2011 by the United Nations Environment Programme. Nevertheless, incorporating external effects in LCC is not an easy issue to deal with.

Environmental LCC considers costs supported by society as a whole, and there is not a similar market system that defines a value for them. Nevertheless, there is a need to include sustainability in LCC in order to obtain a tool that helps to make more consistent decisions about investment in urban water cycle technologies. There are different approaches to face this challenge:

- Including costs related to externalities which may be internalized inside the system through environmental taxes, costs related to environmental management, etc. (Hunkeler *et al.* 2008).
- LCC can be complemented by Life Cycle Analysis (LCA) with an equivalent system boundary and functional unit. It is very important that there is no double counting between LCC and LCA, so impact elements considered in LCA should not be included in LCC. Then, costs described above related to externalities already considered in LCA will not be included in environmental LCC.

In the European context, the cost recovery principle stated at the Water Framework Directive has to take into account 'the polluter pays principle'. Thus a Life Cycle Thinking provides a step forward for an analysis of external costs. Environmental LCC provides additional information to conventional LCC results since it includes external costs related to environmental effects due to water activities. So components related to sustainability are taken into account to decide from an economic point of view.

Monetization of externalities may be calculated as complementary information to environmental LCC. It is a major difficulty since there are many impact factors to be calculated and it is very difficult to obtain a value. In this context, several methodologies might be used. Traditional techniques are based on the demand approach being stated preference methods the most common for valuating externalities. They are based on the simulation of a hypothetical market through surveying processes. Hence, the willingness to pay for a particular good or service or the willingness to accept payments in exchange for bearing a particular lost is estimated. Färe *et al.* (1993) developed an alternative approach based on the concept of distance function. It allows undesirable outputs arising from activities that have no market value to be valued. Unlike traditional methods, it is based on the cost production perspective. In the context of wastewater treatment, several empirical applications have been developed aimed at estimating the shadow prices of the pollutants removed from wastewater treatment (Hernández-Sancho *et al*. 2010; Molinos-Senante *et al.* 2011b). Shadow prices have been considered as a proxy to the environmental benefits from wastewater treatment.

The difficulty of considering all the externalities involved in urban water cycle activities should be emphasized. However, the internalization of the most number of environmental impacts as is possible provides useful information for the decision making process.

The last issue analysed in this paper refers to how environmental impacts can be incorporated in the LCC assessment. In this sense, two main approaches have been identified. The first one involves the complementarity of the LCC with the LCA while the second one refers to the economic valuation of the externalities from a demand perspective or cost production approach.

The paper illustrates the different elements that might influence the LCC assessment and how they can be considered in order to increase the usefulness of this methodology in the framework of the decision making process.

CONCLUSIONS

LCC has been proven to be a useful methodology to assess the costs of the whole urban water cycle activities. However, there are several elements that may influence the results of the LCC assessment in the framework of the urban water cycle.

It has been identified that the definition of the goal of the study and the description of the system play a key role since they influence the subsequent steps in the LCC assessment. Another factor that should be stressed is the definition of the costs categories since it affects not only LCC results but also the study's comparability.

Regarding methodology issues, two main approaches can be followed: engineering and parametric methods. It has been illustrated that they are not exclusive but complementary. Hence, both engineering and parametric methods should be used in order to provide the richest cost description as possible.

The temporal component of the LCC might influence the results through two main parameters which are the lifespan of each process and the discount rate used to update costs to present value.

One issue that should be remarked is the comparability of the results achieved when LCC assessments are carried out. Since there are not two identical urban water cycles, technical and geographical differences among case studies must be taken into account for comparability purposes.

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