Chapter 4
Application of LCA for the Short-Term Management of Electricity Consumption

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Abstract The application of LCA in the energy consumption management can address the sustainability of energy systems. The chapter first aims at summarizing general trends in addressing environmental implication of energy use. Second, LCA methodology is briefly introduced in order to clarify its potentialities and general use in the energy field area. In particular, LCA can contribute to select the best technological choices for an energy system. A challenge in the use of LCA is identified in the representation of a complex system in which the energy producers' contribution changes on a temporal basis. Two approaches are proposed for the LCA use in the short-term perspective: attributional LCA and consequential LCA. The proposed approach examines the application of LCA in a short-term perspective. Both approaches can be used to analyze an efficient configuration of the system. However, the more the temporal and geographical area is restricted, the more specific issues have to be adopted to provide a reliable analysis. In particular, consequential and attributional approaches should be used under different hypotheses and with proper adaptation. The proposed approach examines the application of consequential LCA in a short-term perspective, defined as the time span in which the market system has not reacted to a change yet. Moreover, it could claim environmental impact savings in the presence of an accurate model that is able to predict the hourly marginal technology of the near future (one day to 1 week). The future application of the pro-

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posed approach would be a tool that manages to assess the best hourly consumption trajectory in order to minimize environmental impacts.

Keywords Electricity · LCA · CLCA · ALCA

4.1 Introduction

The consideration of energy consumption as a dominant component of an organization's sustainability cost structure has progressively gained interest along years by including more precise and systematic approaches. Nowadays, the use of energy is considered one of the basic aspects of sustainable society (UN 2015). Indeed, for the first time, the United Nations Sustainable Development Goals (SDG) for 2030 include specific energy-related targets for affordable, reliable, and sustainable energy. In particular, the seventh SDG requires to enhance international cooperation to facilitate access to clean energy technology and promote investment in energy infrastructure and clean energy technology.

The sustainable energy concept requires compliance with two sub-objectives: the increase in energy efficiency by the reduction of the energy process intensity and the reduction of the related social and environmental impacts. The first objective can be performed by introducing technological systems that minimize the use of energy in relation to a set of target performances, re-utilizing energy through recovery systems, reducing dispersions and, where necessary, replacing power generation technologies with more efficient options. As far as the second objective is concerned, the minimization of social and environmental impacts requires to properly assess the effects of energy production and then the setup of systematic policy in order to efficiently reduce social and environmental burden. In particular, this second subobjective implies the replacement of more polluting energy sources, the adoption of end-of-pipe solutions to mitigate adverse effects (i.e., re-utilization of residual flows), and improvements of inefficient distribution methods by the use capillary management of the whole energy grid.

At the strategic level, some documents emphasize the importance of introducing systems for "sustainable energy" consumption. With this meaning, the European Community indicates in its strategic plan (EU-Strategic Plan 2016–2020 DG Energy) a production system able to satisfy social demand, supporting the economy, protecting the environment in the long term. This type of energy is pursued through the increase of renewable energy, the improvement of energy efficiency, and energy savings. The 2014–2018 strategic plan of the US Department of Energy (US Department of Energy 2014) further details the objectives for driving down the costs and improving the performance of clean energy technologies. In particular, in the fifth goal, explicit reference is made to smart grids for an optimal integration of clean electricity into intelligent grid, suggesting as main drivers the intra-hour variability and the demand response mechanisms. The same International Energy Agency (IEA) introduced in 2017 in its annual World Energy Outlook a Sustainable Development Scenario. In addition to the first target for universal access to modern energy services, it includes two targets on environmental effects of energy consumption both to mitigate peak in emissions according to Paris agreements and largely limit other energy-related pollutants (IEA 2017).

The need for more precise and refined tools for the assessment of impacts due to energy consumption is also identified by industrial policy agendas that emphasize the importance of smart sensing systems and inventory systemization of industrial aspects that are linked to the energy consumption. In the past, traditional strategic plans frequently aimed to focus on energy efficiencies along the energy life cycle as a prevalent part of environmental policy in the resource and cost perspective (ARC 2009). More recently, industry policy documents are introducing a focus on better calibration of the real environmental effects of energy systems in order to realize a fine-tuning of industrial policies (Siemens 2017). Energy objectives are linked with the UN SDGs and have been focused on environmental effects rather than just on environmental aspects (Siemens 2017). Finally, this objective is also pursued by the use of recent certification and energy audit schemes. In fact, energy management systems need of infrastructure system to collect, analyze, and report data-related energy consumption, and ensure correctness and integrity of that data in order to ensure minimum energy consumption for the current activity (Kahlenborn et al. 2012). Furthermore, the rise in concerns by new consumers about climate change can positively drive changes in demand toward certified green energy as rewarding criteria for producers. Such influence has been partially registered at global level in shifting energy demand toward renewable sources (Deloitte 2017).

4.1.1 The LCA Application in Analyzing Electricity Life Cycle

LCA has been frequently used as a tool to understand implications of energy management options. In particular, the electricity consumption constitutes a wide area of analysis ranging from energy power production to its distribution by national electricity grid. Such widespread use of the methodology can be linked to LCA intrinsic features. In particular, its inclusion of different impact indicators in the final assessment and its ubiquitous assessment of the effects along the whole energy life cycle can represent strength point in comparison to quantitative methods that are focused on site-specific environmental targets. Moreover, LCA allows to include additional mitigation phases, scenario approaches, sensitivity analyses, and consequential modification of the energy system due to assessed options (Fig. 4.1).

LCA applied to energy system is traditionally used to estimate the effect that a certain consumption of energy or an energy generation option produces in environmental terms. A brief qualitative analysis of the SCOPUS search engine emphasizes that scientific papers including LCA in the title and the abstract are increasing. Concurrently, papers including "LCA" and "Energy Systems" in the title and abstract also increase by representing a consistent part of the entire publications. Conversely, articles including "LCA" and "Power grids" represent a minimal percentage of such

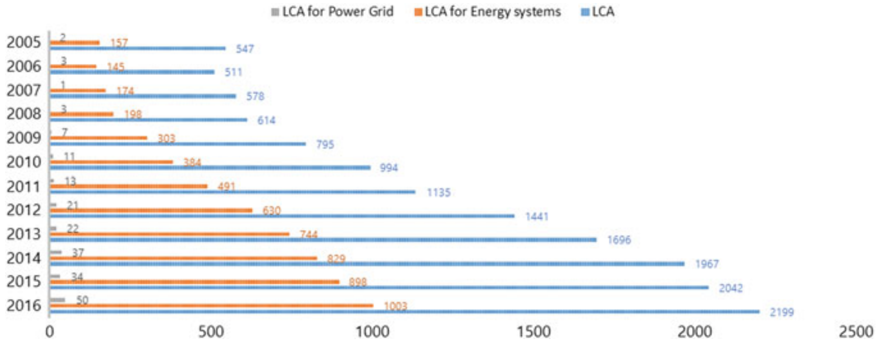


Fig. 4.1 Scopus papers related to LCA and energy (www.scopus.com)

publications. Such discrepancy could partially suggest that current LCA literature is less focused on actual electricity consumption at domestic or industrial level. According to a further in deep analysis, LCA seems to be widely used for the explicit aim to drive innovation in current energy systems by providing alternative solutions to current energy sources in order to identify environmental bottlenecks, to provide comparison and scenarios for technological implementation, and to identify environmental effects on a large scale including substitution of traditional technologies. In general, barriers and uncertainty in LCA study on a real electrical grid depend on the different focuses of the study.

In the Attributional LCA (ALCA), electricity is examined in terms of average impacts both at geographical and at temporal levels. Technological efficiency can be mirrored as average efficiency of a single technology rather than through the efficiency of the modeled plants. Meanwhile, the temporal variance in the environmental impact is assessed according to ex-post provided power in the same reference period. The more an attributional study is focused on a single plant or on a group of plants at regional level, the more LCA datasets may need to be adapted to better depict actual regional power systems and real efficiency of single plant. It must be taken into account though that the maximum detail on the geographical level should contemplate physical and technical limits due to the electricity market.

Main sources of uncertainty can be resumed as follows:

– Inventory methods: Process Chain Analysis (PCA) should be preferred to input–output approaches IOA that are based on monetary data for individual economic sector. In fact, PCA requires a bottom-up approach that uses engineering data and process-specific information preferably obtained directly from the plants. PCA is a time-consuming procedure, but it generally provides results that are more precise (Turconi et al. 2013).
– Efficiency variance: emission factors for the electricity generation are presented for single technology in stationary conditions. However, electricity is usually produced in dynamic conditions, and hence the same technology can change its efficiency according to its operational conditions. Moreover, multi-input and multi-output

systems often occur, i.e., co-combustion power plant is an example of a multi-input system in which a mix of fuels (e.g., coal–straw, waste-coal, etc.) is used as feedstock for the process.

- Change of technology mix: the single contribution of energy production by single technology can change along time according to market and operational constraints. The more the assessment is focused on a limited time span, the more such variability can infer the final assessment of environmental impacts due to the implementation of a certain technology mix. As an example, the contribution of solar and wind power sources can lie on electricity system majorly in certain hours during the day. Such variable contribution is expected to majorly affect grid power production for specific countries in the next decade (Galliani 2016).
- Technology characterization: The operational technology efficiency represents a baseline for the correct assessment of the environmental impact of a power plant. Such assessment tends to vary according to the extension of the assessment. In case the average contribution of technology is included in the assessment, the variance in real efficiency of the same technology has to be aggregated from different power plants. In such case, the age of the power plants assessed should be mirrored in the dataset building. The selection of inappropriate datasets not sufficiently reflecting the real system in focus may clearly result in a significant under or over-estimation of emissions. Conversely, the more the local contribution from single power plants in power supply became relevant, the more their specific features should be analyzed in the technology characterization (i.e., energy recovery efficiency of a plant, the reference year, and the geographical origin of the materials and energy used for the infrastructure).

In the Consequential LCA (CLCA), the marginal effects on existing electricity infrastructures are included in the final assessment as avoided or additional impact from the production of other energy sources. CLCA provides explicit reference on large-scale effects in order to majorly support policymaker and prospective studies (Lund et al. 2010; Olkkonen and Syri 2016). The following potential drawback in CLCA for electricity life cycle can be identified as follows:

- Double counting: CLCA should provide support at operational level to address decisions in a scenario perspective. Unlike an ALCA, a CLCA can overlap with the boundaries of other LCAs, meaning there would be double counting if multiple CLCAs were added together. The reuse of CLCA for different purposes can hardly provide support for large-scale assessment mining (Jones et al. 2017).
- Increased uncertainty: complex relationships (including difficult to model social and economic dynamics) between provided energy and a wider system mean that although a CLCA might be considered more comprehensive there is greater uncertainty in CLCA than in ALCA (Jones et al. 2017). It is therefore valuable to limit the expansion of system boundary to the most relevant processes within the system that are affected by changes in the key variable (i.e., distributed generation uptake) (Mathiesen et al. 2009).
- Approximation of marginal data: CLCA uses marginal data rather than average data to quantify changes within the boundary of the system resulting from the displacement and/or substitution of individual processes. Marginal data implies a

number of assumptions that require a deep knowledge of the electricity system. Such data can be based on perspective or standard impact for a certain technology rather than real substitution at regional or local level.

- Time-related effects: CLCA can include temporal assessments in the form of perspective changes in the electricity life cycle. Such scenarios could fail in the implicit assumption if the temporal scale is related to medium- or short-term changes in the energy supply. In fact, the more the CLCA tends to provide assessments for short-term policies, the more CLCA assume similarities in inventory data with ALCA and need to include bottom-up approaches and coherent substitution at geographic and temporal level (Amor et al. 2014).

  Both ALCA and CLCA can be adopted to assess effects in electricity infrastructure in the short term according to a specific technological option. Considering current bottlenecks, ALCA application to electricity life cycle needs to be compliant with application context while CLCA needs to guarantee reliability of assumptions for the estimation of substitution effects. Both prospective analyses can be useful tool for helping decisionmakers to think through future implications of particular technology pathways at a whole system level.

4.2 Short-Term LCA to Address Consumptions Within Electricity Systems

LCA can be used to evaluate the environmental impacts of a technological or operational choice within the electricity life cycle. The adaptation of this methodology to the context of existing electricity systems can support operational decisions in the short term and requires a series of important adaptations:

Temporal adaptation: In the short term, the environmental profile of a kWh supplied to the network becomes a time-varying vector. Such vector depends on the supply conditions of the system at a given instant t. As noted in literature studies, the environmental profile of a unit of energy supplied to the electricity system varies on a temporal basis throughout the day (Soimakallio et al. 2011; Weidema 2003). This aspect can introduce an error if this impact is replaced by the average environmental profile of a kWh on a national scale. Such error can involve remarkable deviations even when the period of analysis of an LCA regards short-term assessments, intended as that period in which it is realistic to hypothesize that the marked system has not yet reacted to possible changes. In fact, the environmental quality of energy can vary along the day so that the specific impact of energy consumption by a single consumer not only depends by the final quantity of consumed energy but also by consumption patterns along the time.

Geographical adaptation: The instant environmental profile is rebuilt considering the local state of the network, the location on the territory of the energy providers. In this sense, the approach of the calculation is more similar to a supply chain LCA in which single contribute from suppliers can change according to operational conditions in order to satisfy a certain demand of energy.

Technological constraints: The environmental profile should take into account the type of technology used and the effective efficiency of the technology within the same technological class. The technological features of the different energy providers should be modeled in order to represent hourly performance based on the different operating conditions. This means that modeling in the short-term perspective requires to introduce both variation in the effective provided power on the electric grid (i.e., efficiency of solar panels depending from solar radiation) and change in operational conditions (i.e., fuel type or efficiency in fuel consumption in a turbogas plant) that can vary the supplier's environmental profiles.

Market constraints: Such aspect needs to be considered in particular in the CLCA since the change in supply involves a previous market bidding phase. In most western markets, the hourly supply of energy is determined through complex mechanisms that include, in general, a programmed hourly power on the electrical grid and a variable ancillary power that depends on the real operating conditions of the electricity grid.

The application of these rules can be detailed from the perspective of the energy consumer. However, the key condition in LCA application depends on the possibility for consumers to be able to alter or not their consumption configuration of provided power on electricity grid by the variation of his demand.

A range of terminology can be used to identify targets for assessments. A number of terms and their definitions as in (Hawkes 2014) are as follows:

- Average Environmental Profile (AEP): The average environmental profile for an average unit of electricity delivered for an electricity system in a certain time span.
- Operating Marginal Environmental Profile (O-MEP): The change in single impact categories to a unit change in electricity demand, where there is no structural change in the electricity system being analyzed (i.e., no power station commissioning or decommissioning, no fuel price changes, etc.).
- Build Margin Environmental Profile (B-MEP): The environmental profile per unit of electricity produced for the next power station included in the market negotiation.
- Marginal Environmental Profile (MEP): The change in environmental profile to a unit change in electricity demand, calculated by weighting the O-MEP and B-MEP to arrive at a "combined" figure.

4.3 Attributional LCA to Analyze Electricity Consumptions in the Short Term

The LCA in an attributional perspective can be applied for ex-post analysis in order to assess the precise impact that a historical consumption of energy has produced in a given time. The application of an attributional approach according to a bottom-up scheme requires that the average national energy profile is replaced by a time-variant environmental profile that derives from the individual contribution of the energy providers and from the contribution of the distribution network. According to this

Table 4.1 Legend of equation system (1) and (2)

OEP(T)	Operating environmental profile of an electricity system that is composed by N supplier at the time $T + \Delta$
[EP_n]	Environmental impact matrix for the supplier N collecting environmental impact categories for single unit (e.g., 1 kWh of provided energy by the supplier n at the time t). Such matrix is time-variant and depends on technology efficiency features of the single provider
EP_{inf}	Additional environmental effects of energy distribution on the electricity grid (e.g., energy dissipation of the distribution network from the single provider to the distribution point and from distribution point to the consumer)
q	Energy in kWh provided by the single supplier at the time t
Q	Total energy provided by the electricity system at the time t
N	Total number of supplier composing the assessed energy system
$T + \Delta$	Time horizon in which energy supply on electricity system is considered

approach, the efficiency of individual providers as well as efficiency features of individual producer can be explicitly counted in the LCA calculation.

The following equation can represent contribution in environmental terms of single supplier from an operational perspective (Table 4.1):

$$\mathbf{OEP}_{\boldsymbol{N,T+\Delta}} = \frac{1}{Q}\left(\sum_{n=1}^{N} \mathbf{EP}_{\boldsymbol{n}}(\Delta T) + \mathrm{EP}_{\mathrm{inf}}(\Delta T)\right) \tag{1}$$

$$\mathbf{EP}_{\boldsymbol{n}}(\Delta T) = \int_{t=T}^{T+\Delta} \left[\mathrm{EP}_{e,t}\right] * q_{n,t} \tag{2}$$

The use of the attributional methodology allows a more precise understanding of the impact linked to the consumption of energy in the perspective of the single player. By applying such approach, it becomes possible to identify the qualitative change in the environmental profile on an hourly basis for a certain electricity system. Such figure provides the estimation of the CO_2-eq variation on the Italian electricity system on a specific day for high-voltage production. The main hypothesis in adopting ALCA implies that energy consumption of a single supplier does not alter the configuration of energy production from each producer in a given day. Furthermore, it becomes possible to calculate with more accuracy the measurement of the error compared to the data provided by the commercial databases. In particular, such error results from difference between national AEP and O-MEP as reported in Graph 1. The yellow

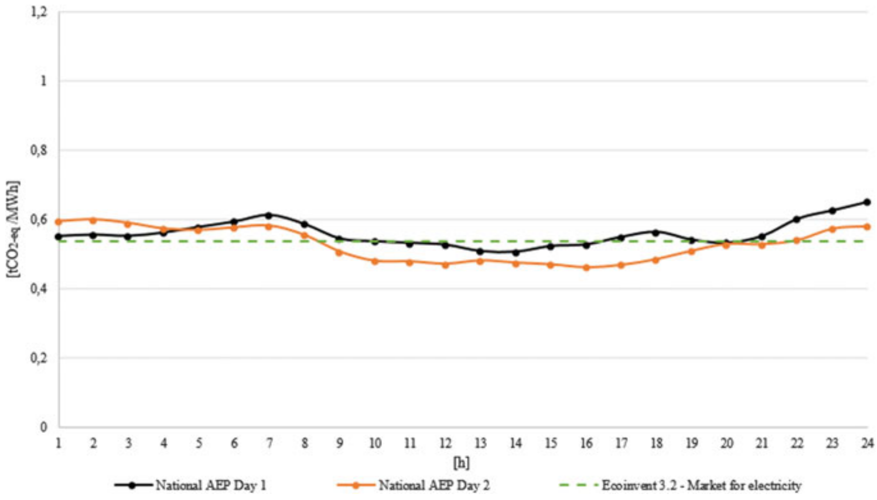
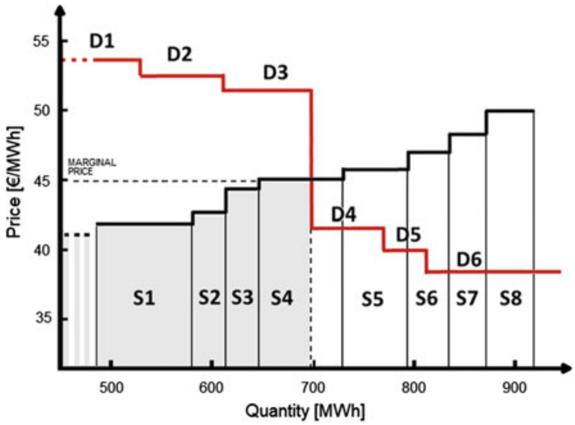


Fig. 4.2 Comparison among AEP CO_2-eq values for two specific days and the AEP provided in an LCA database, with reference to GWP100 values

line represents the value of the impact for the consumption of 1 MWh of electricity at high voltage, as provided by the LCA database (Ecoinvent 2017): the flat line shows that only an average value is provided since the impact is not dependent on the assessed time of the day. Such average data has been compared to hourly national average impacts that are calculated by using data from Italian electricity transmission system operator (Terna 2018) on power production of the represented days and LCA database on specific impacts by technological options for power production. Hence, time dependency introduces variability among different hours of the day. Given that this variability is assessed on data produced after the closure of the day-ahead market, it cannot be exploited in order to shift electricity-intensive productions toward hours characterized with lower than average impacts. Indeed, energy managers should decide energy consumption trajectories before the closure of the market so that the energy provider is able to make the correct bid. Then, once the market is closed, it is possible to use time-dependent impacts only for the already scheduled production, in an ALCA perspective (Fig. 4.2).

The ability to monitor O-MEP depends on the chance to effectively measure the environmental profile of the individual player and then on the related capillarity of the monitoring system. In general, the power and size of the energy production plant can enable a better monitoring at high level. Plants providing power on high-voltage grid and limited variability in power supply present features that facilitate the monitoring. Conversely, local plants for the production of distributed energy in low or medium voltage seem to involve a major complexity in their monitoring. Small-size PV energy productions can represent an example of calculation that can be based on an efficiency estimation rather than on actual measurements.

Fig. 4.3 Day-ahead market mechanism to determine energy supply in electric system



4.4 Consequential LCA to Analyze Electricity Consumptions in the Short Term

The consequential LCA appears to be a useful tool to assess the environmental impacts that the modification in electricity consumption produces in the short term. A proper use of the CLCA in the short-term perspective requires first the identification of the instantaneous environmental profile of the electricity system and then the inclusion of the marginal effect linked to energy consumption.

The general implicit hypothesis is that through shifting in time its electricity consumption a consumer can influence the environmental impact of the electrical power supply. In order to assess this shifting properly, the inventory phase has to incorporate market mechanisms: this implies the use of marginal data instead of averages.

- In most advanced countries (US, Canada, Europe, etc.), the prevailing market mechanism for determining both power supply and demand dispatch is the day-ahead market. Such market, divided into zonal sections, defines both the commitment of production units and the consumption profiles of aggregated end users for the following day, on an hourly basis, such as the economic merit is guaranteed. Indeed, the market aggregates both production bids by suppliers, sorting them from minor price to higher price (S bars in Fig. 4.3) and demand bids by users, sorting them in the opposite way (D lines in Fig. 4.3). A production bid is a couple of Q quantity [MWh] and P price [€/MWh] which states the availability of the producer to generate a specific amount Q of energy provided that the awarded price is at least equal to P. On the other hand, a consumption bid (Q', P') sets the availability of an aggregated user to pay at most P' for a specific amount Q' of energy. The interception between these two cumulated profiles addresses three key issues: The marginal price, which is the hourly and zonal value of electricity for both producers and consumers;

- The marginal supplier and the marginal consumer, respectively S4 and D3 in Fig. 4.3;
- The supply and demand power dispatch, defined as follows. Producer bids whose price is lower than the marginal price are accepted. Hence, those producers have the permission to generate the awarded quantity. Conversely, only consumer bids whose price is higher than the marginal allow these users to consume.

Such selection mechanism is performed for different geographical areas determining the power supply dispatch configuration of the electricity grid on an hourly basis. In the framework of the flexible power demand, the use of the CLCA therefore includes the assessment of the combined environmental impacts of the expected energy supply plus the marginal effect on the market.

As for the calculation of the environmental effects from planned supply, it can be calculated through the day-ahead market balance point. O-MEP can be calculated by identifying the technology type and efficiency features of the single supplier. In order to obtain a precise assessment of single impact category, the vector representing the O-MEP should be calculated according to an attributional perspective. This approach is justified by the reduced time margin of the analysis.

As regards the effects of marginal demand, first it is necessary to know the effective shift of the balance point that stems from a change in energy consumption. In general, the demand shift for a certain amount of energy from hour h to hour g produces a precise effect on the perspective of an individual consumer. The demand reduction in the hour h shift to the left the demand curve by excluding from production a certain number of marginal producers that are close to the equilibrium point. Similarly, the increase in demand in the hour g will shift the equilibrium point to the right by including the marginal producers who bid at that time. A greater additional demand for energy in a certain hour produces a greater number of marginal producers that are included in the electricity network configuration. Therefore, the avoided impact coincides with the cumulative B-MEP of the marginal energy producers that do not participate in the energy supply on the day fixed following the change in demand. Similarly, the additional impact coincides with the B-MEP of the marginal suppliers that have to plan an additional energy production for the hour g.

In Fig. 4.4, it is represented the O-MEP for CO_2-eq emissions of two Italian bidding zones, Zone A and Zone B corresponding to the North and to the continental South of Italy. Data on hourly and zonal marginal technology is available on the Italian Power Exchange manager (www.mercatoelettrico.org). As far as the technology-specific impact is concerned, Ecoinvent "At Point Of Substitution" 3.2 should be preferred to the "Consequential long-term" version of the database because of the short-term impact on the system that is needed to be assessed. As Fig. 4.4 shows, the variability of CO_2-eq emissions among different hours of the day is much higher than the one seen for the hourly national average in Fig. 4.2. Moreover, since the marginal technology is not mitigated by any average, the geographical parameter is fundamental: in general, two bidding zone trajectories may differ greatly during the same day. These trajectories were obtained ex-post but in order to be useful in a CLCA perspective, they should be representative of the expected near future.

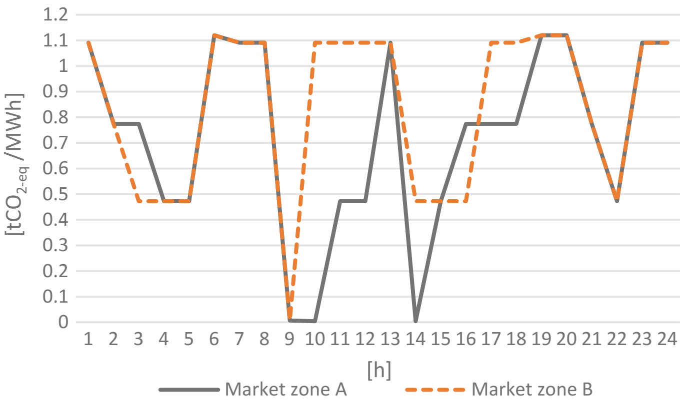


Fig. 4.4 GWP100 impact of two operational marginal environmental profiles representing two Italian bidding zones in the same day

Despite the prospect to accurately estimate the marginal effect that the consumption shift produces in the short term, several applicative and structural drivers can strongly influence the application of this approach.

Consumption-change effects to bid effect. As discussed, the effect of increasing or reducing demand produces a certain shift in the resulting equilibrium point of the day-ahead market. This further knowledge makes it possible to forecast those suppliers, with their environmental impacts, that would be either included or excluded by the variation in energy consumption.

Network monitoring. It is therefore necessary to negotiate energy on the basis of market criteria, knowing the environmental contribution of the different suppliers. As in the case of the OEP, it is therefore necessary to know the environmental profiles and the efficiency of the individual suppliers.

Data availability. The CLCA can be used to estimate the impact produced in the short term. However, the needed data may only be available with a delay of up to 24 h. The lower the time between the negotiation and the actual dispatching of the energy, the more forecast systems tend to mirror real-time systems.

Robustness. Although short-term CLCA requires less assumptions than long-term CLCA, there are three factors that limit its accuracy even in the absence of significant hypotheses. The first factor concerns the actual production of energy by a committed unit. In fact, the CLCA does not consider the ancillary production of energy and the dissipation of the distribution network that depends on the location of the dispatching of the energy in the considered market day. The second factor is that the displaced value of the supplied energy has to be assessed in advance through prediction systems because the shifted demand implicitly requires a modification in the provider bid in the day-ahead market. Indeed, every flexible consumers' bidding strategy has to be taken before knowing the actual market equilibrium. The high variability of MEP between one hour and another, however, means that small inaccuracies in the identification of the supplier can produce consistent shifts in the impact assessment. Finally, since the market sorts suppliers by an economic merit criterion, substituting the marginal supplier does not assure to include producers related to better environmental impacts or to exclude those with worse ones.

4.5 Conclusions

The present work focused on the implementation of the LCA for the analysis of the electric networks in the short-term perspective. In general, two different approaches have been used: the attributional LCA in the case the grid consumer is unable to influence the network configuration and the consequential LCA in the case the consumer can modify the hourly offer curve that is based on the bid market. According to preliminary results, the hourly profile of impact categories is remarkably different depending on the used approaches. More in general, a supplier-led assessment approach is preferred for scenario development where the primary goal of the assessment is to inform the choice between options, such as short-term approach can provide comparable representations on the basis of effective changes in electric networks that are related to consumer choice. The same assessment can be both applied for ex-post analysis in order to identify real decisional outcomes and for ex-ante analysis in the perspective to attain accurate forecasting. The central point for further developments regards the efficiency of data exchange between stakeholders of electric network as required by a number of different research agendas. It is possible to assume that any further improvement will contribute to reduce uncertainty and to improve economic and environmental effectiveness of single stakeholder. As second result, CLCA on the short term can relocate endogenous assumptions by researchers into a set of verifiable data.

A second relevant point regards the need to define further optimization policies in an LCA-based information system. The case presented refers to the monitoring of the produced CO_2-eq by the electric network on the basis of consumption choices of a single player that acts on the electricity system and can influence the day-ahead market. It therefore becomes possible for the consumer to perform policies that balance both the price effects and the environmental effects by managing the consumption of energy in a given time. This approach can produce relevant results in case the single player is an industry that has significant energy consumption and can shift this consumption through the management of hourly production. In this specific case, the player should have the possibility to know in a limited time horizon the precise effect of operational choices that are related to energy consumption. Even in this case, however, it is necessary to define appropriately the company's environmental strategy and the resulting optimization system. For example, the values of environmental impact categories may vary in different ways throughout the day and the introduction of weight systems should translate the relevance that these categories have in the optimization strategy. The concurrent application of LCA-based tool to control the real emissions produced by a company can support energy management tools to control the actual impact of business decisions and compliance with related environmental targets.

Such information framework can prospectively represent a test-case area for Cyber-Physical Systems (CPS) application (Ballarino et al. 2017). These CPSs can in fact exchange real-time information on the energy attributes and real-time demand in a coordinated way. The user company should implement a system of devices that can record energy consumption from electricity and the CPS system should be able to estimate the energy consumed for the work cycle, and the energy required for subsequent scheduling through a time-machine system. Unified to market or to network manager, but also provide distributed data in order to transfer to series of real-time information regarding its expected offer and its efficiency.

Such evolution in electricity management can be inferred by considering the contribution that technologies and the market are producing in the actual configuration of the electricity market system. On the one hand, the opening of the market has produced an increasing growth in the percentage of distributed energy sources and with an increasing variability in the hourly supply. Second, market mechanisms tend to reward power plants that are able to produce large quantities of energy by flexibly respond to the demand. Such selection produces high dynamism in the configuration of the hourly suppliers and in their consequent environmental contribution. A switch to distributed renewables therefore implies a shifting of resource use and environmental impacts both spatially and temporally (e.g., GHG emissions arising "upfront" in the country of product manufacture, rather than during the operational life in the country of deployment), and potential reconfiguration throughout the electricity system. These dynamics pose a challenge for the accounting of real environmental effects from efficiency industry policies in relation to environmental goals when new energy supplier type will replace the current generation.

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