ATTI

XIV Convegno della rete Italiana LCA
IX Convegno dell'Associazione Rete Italiana LCA

La sostenibilità della LCA tra sfide globali e competitività delle organizzazioni

Cortina d'Ampezzo
9-11 dicembre 2020

A cura di Erika Mancuso, Sara Corrado, Arianna Dominici Loprieno, Laura Cutaia

1222·2022 800 ANNI

Università
degli Studi
di Padova

ENEA
AGENZIA NAZIONALE PER LE NUOVE TECNOLOGIE,
L'ENERGIA E LO SVILUPPO ECONOMICO SOSTENIBILE

Rete Italiana LCA

Rete Italiana LCA

ENEA
AGENZIA NAZIONALE PER LE NUOVE TECNOLOGIE,
L'ENERGIA E LO SVILUPPO ECONOMICO SOSTENIBILE

800 ANNI 1222·2022
UNIVERSITÀ
DEGLI STUDI
DI PADOVA

La sostenibilità della LCA tra sfide globali e competitività delle organizzazioni

ATTI
del XIV Convegno della rete Italiana LCA -
IX Convegno dell'Associazione Rete Italiana LCA

Cortina d'Ampezzo
9-11 dicembre 2020

A cura di Erika Mancuso, Sara Corrado, Arianna Dominici Loprieno, Laura Cutaia

La sostenibilità della LCA tra sfide globali e competitività delle organizzazioni

Atti del del XIV Convegno della rete Italiana LCA - IX Convegno dell'Associazione Rete Italiana LCA
Cortina d’Ampezzo 9-11 dicembre 2020

A cura di Erika Mancuso, Sara Corrado, Arianna Dominici Loprieno, Laura Cutaia

ISBN: 978-88-8286-416-3

2021 ENEA
Agenzia nazionale per le nuove tecnologie, l’energia e lo sviluppo economico sostenibile

Copertina: Flavio Miglietta
Stampa: Laboratorio Tecnografico ENEA - Centro Ricerche Frascati

Temporal variability and Battery Electric Vehicles influence on LCA impacts of marginal electricity consumption in Italy

Davide Rovelli[1], Pietro Scaglia[2], Simone Cornago[3,4], Carlo Brondi[1], Giovanni Dotelli[2]

[1]STIIMA-CNR - Institute of Intelligent Industrial Technologies and Systems for Advanced Manufacturing, Via Alfonso Corti 12, Milan 20133, Italy

[2]Politecnico di Milano, Dipartimento di Chimica, Materiali e Ingegneria Chimica "G. Natta", Piazza Leonardo da Vinci 32, Milan 20133, Italy

[3]Singapore Institute of Manufacturing Technology, 2 Fusionopolis Way,

Singapore 138634, Singapore

[4]National University of Singapore, 21 Lower Kent Ridge Road, Singapore 119077, Singapore

Email: davide.rovelli@stiima.cnr.it

Abstract

The electricity process is recognized to be one of the main drivers of LCA results for Battery Electric Vehicles (BEVs). Moreover, the spreading of BEVs is projected to significantly increase electricity demand, with repercussions on the electricity mix as well. The present paper aims at analysing the variability of the LCA results of the electricity consumption, both across the different months of the year and among different scenarios of BEV penetration in Italy. This paper presents a white box model of the Italian electricity system, coupled with a consequential LCA model between 2016 and 2030. The analysis indicates that the deviations of impact indicators with respect to the yearly average results may be up to 30% across summer and winter months, while increasing the number of BEVs up to 50% of the circulating fleet may further shift monthly results by 60%, with respect to the reference scenario.

1. Introduction

The substitution of Internal Combustion Engine vehicles by Battery Electric Vehicles (BEVs) constitutes a pathway for the decarbonisation of the transport sector. Due to the interest generated by this technology, an extensive literature of life cycle assessments (LCAs) of BEVs has been created throughout the most recent years. Yet such a wide number of studies sometimes generated conflicting results, too (Marmiroli et al., 2018). Thus, several reviews attempted to develop a deep understanding of the main drivers of LCA results, which is key to the development of policies on the future products life cycle in order to make the transport sector more sustainable. Within this context, several authors outlined the relevance of the electricity production process as one of the key drivers of environmental impacts of BEVs (Doucette and McCulloch, 2011). In particular, (Marmiroli et al., 2018) outlined how for the climate change indicator the specific carbon intensity of the country electricity mix can influence up to the 70% of its variability. Therefore, we intend to quantify the monthly variability of the carbon intensity of the country electricity mix with contrast to current LCAs that are performed at the yearly level.

This paper aims to provide indications in order to support decision-makers at at the Italian level. The same perspective was adopted by (Bohnes et al., 2017), in a study on electric vehicles diffusion in the urban context of Copenhagen, outlining the need to include the consequences lead by BEVs fleet by the interactions with other systems. Another fleet-based study, in which the LCA model was coupled with a transport model was proposed by (Garcia et al., 2015), addressing life-cycle Greenhouse Gases (GHGs) emissions up to 2030 across different scenarios in Portugal.

In addition to this perspective, (Girardi et al., 2015) provided a further focus on the electricity mix supplied to the fleet of BEVs. Such work coupled an LCA model with an energy system model, capable of analysing the Italian electricity mix on an hourly base, thus highlighting the importance of such a small temporal detail.

Hence, starting from the work developed in (Marmiroli, 2020), the present paper aims at analysing how the LCA results of the electricity mix vary as a consequence of the highlighted key factors:

- temporal resolution: monthly variability;
- interaction between BEVs diffusion and the increase of electricity demand, which eventually makes the electricity mix vary, too.

Italy offers an interesting case study, due to the diversity and variability in its marginal electricity mix.

2. Methods

Concerning the aims of the paper, there was a need of a model capable of simulating the Italian electricity system and BEVs penetration in an aggregated way. Then, the model results were to be coupled with the LCA model. Thus, the EnergyPLAN model was chosen. This is an input/output deterministic bottom up model that aims to identify optimal energy system designs and operation strategies looking at the complete energy system. It is based on a series of hourly simulations over a one-year time period (Lund, 2014). This model offers sufficient details concerning the time resolution over a year, while keeping a relatively simple and aggregated structure. The model is able to integrate projections developed by national research institutes.

a. The Energy system model

Demand

Coherently with the goal of the study, different future scenarios for the year 2030 have been defined varying the size of the circulating electric fleet, and the evaluation of the different marginal mixes is carried out referring to a reference-year scenario, namely the 2016. Data about the 2016 Italian electricity demand, together with the hourly distributions, are available from yearly reports provided by Terna (Terna, 2020), the transmission system operator. The overall electricity demand was 325 TWh, with a net import of 37 TWh.

The operation of the energy system in year 2030 is modelled according to the latest orientation paper regarding national energy strategy: the “National Energy and Climate Plan” (Piano Nazionale Integrato Energia e Clima, PNIEC) (MiSE et al., 2018), the proposal submitted to the European Commission in 2019. The electricity demand in 2030 is expected to be 337 TWh. The net import value decreases with respect to 2016 and is expected to be 29 TWh.

Electric transportation

Concerning the charging infrastructure of BEVs, the model allows to differentiate between *Dump* and *Smart* charge modality. The *Dump* charge is modelled as a traditional uncontrolled plug-in charge, in wich the user recharges the battery whenever it is needed. With the *Smart* charge, on the other hand, battery charging is used aiming at decreasing excess electricity production and battery storage is used to achieve the lowest market price of the electricity consumed (Lund, 2014).

The amount of BEVs in Italy during 2016 was 5743 modelled with the *Dump* charge modality, resulting in an electricity demand of 0.014 TWh/y (Marmiroli, 2020). As for the future scenarios, BEVs diffusion was modelled with the *Smart* charge modality. The number of BEVs was varied assuming the total passenger car fleet to remain constant with respect to 2016 at 38 million vehicles (ACI, 2017). Consequently, the demand of the transportation sector increases as follows:

Table 1: BEVs features in the future scenarios for 2030

Scenario	**BEVs**	**BEVs electricity demand [TWh]**	**Source**
Base – 4.75% BEV	1.8 million	4.2	(Energy and Strategy group, 2018)
25% BEV	9.5 million	21.4	(Marmiroli, 2020)
50% BEV	19 million	42.7	(Marmiroli, 2020)

Condensing power plants supply

The distributions of fuels for the power plant plants for 2016 and 2030 are reported in Table 2. Following the decarbonisation goals set by the European

Community, the phase-out of coal and fuel oil, the fuel distribution for the power plants changes as follows:

Table 2: Fuel distribution for Power Plants in Italy in 2016 and 2030

	Coal	**Oil**	**Natural gas**	**Biomass**	**Source**
2016	19.46%	2.16%	68.11%	10.27%	(Gestore Servizi Energetici (GSE), 2016)
2030	0%	1.48%	87.4%	11.1%	(MiSE and MATTM, 2017)

Renewable sources supply

Renewable Energy Sources (RES) production is forecast to grow due to the increase of the installed capacity of PV, wind, run-of-river hydro and concentrated solar power (CSP) plants, according to the projections reported in the PNIEC:

Table 3: electricity production from renewable sources in Italy

	2016 electricity production [TWh]	**2030 electricity production [TWh]**	**Source (2016; 2030)**
PV	22.1	71.25	(GSE, 2016; MiSE et al., 2018)
Wind, onshore	16.5	36.95	(GSE, 2016; MiSE et al., 2018)
Wind, offshore	0	3.15	(GSE, 2016; MiSE et al., 2018)
Hydro, Run-of-river	21.35	24.85	(Terna, 2016; MiSE et al., 2018)
Hydro, Dammed	22.90	26.40	(Terna, 2016; MiSE et al., 2018)
Geothermal	6.3	7	(GSE, 2016; MiSE et al., 2018)
Concentrated Solar Power, CSP	0	3.25	(MiSE et al., 2018)

b. The LCA model

According to the ILCD recommendations for Life Cycle Inventory (LCI) modelling choices, the consequential, long-term modelling was adopted. In particular, the electricity process, here analysed in terms of its structural response to changes, will be modelled as a mix of long-term marginal processes.

This poses the problem of determining the correct marginal electricity mix. In this regard, (Vandepaer et al., 2019) already introduced the integration of long-term marginal electricity supply mixes in the ecoinvent consequential database, based on publicly available projections for 2030 electricity generation. Another approach was followed by (Dandres et al., 2017; Roux et al., 2017) which computed marginal electricity mixes by coupling the LCA model with an energy system model. The same approach was followed in this paper. Thus, the marginal electricity productions by source, for each single month across the 3 analysed scenarios of 2030 were computed as the difference with 2016 values, setting to

0 every negative value, in accordance to the indications provided in (Vandepaer et al., 2019). In accordance to the ecoinvent 3.6 consequential database the consumption mix of the country was modelled. Due to the penetration of Variable Renewable Electricity Sources (VRES) (i.e. PV, wind and run-of-river hydro), excess electricity production arises in the energy system scenarios for 2030. This excess electricity, which can firstly be exported and then curtailed, is not actually consumed within the country, thus it had to be subtracted from the electricity mix.

Hence, the monthly values of excess electricity were subtracted from the electricity production of VRES, thus diminishing their production. The subtraction is weighted on the monthly electricity production of each of these 3 sources. CSP is excluded due to the possibility to store thermal energy, thus allowing for a higher degree of flexibility of electricity production. In order to obtain the LCI and LCIA results related to every month and scenario, the selected mixes were inputted to the Italian electricity mix dataset of the ecoinvent 3.6 consequential database. All the calculations were made by means of the brightway2 software (Mutel, 2017). The selected LCIA method is ILCD 2.0 midpoint.

3. Results and discussion

Figure 1 displays the computed marginal electricity mixes: they are dominated by natural gas plants, PV and wind production, which together account for approximately 80% of the electricity mix across the 3 analysed scenarios. In particular, PV electricity production increases when moving towards spring and summer seasons, while the opposite happens for wind and natural gas.

When increasing the number of circulating BEV in the fleet, two main trends can be outlined. During months in which the additional electricity demand is covered by exploiting excess electricity production by VRES, the electricity mix remains stable across the 3 scenarios. This is especially the case for summer months. Instead, during winter months, the additional electricity demand is covered by natural gas and accordingly, the share of this technology increases.

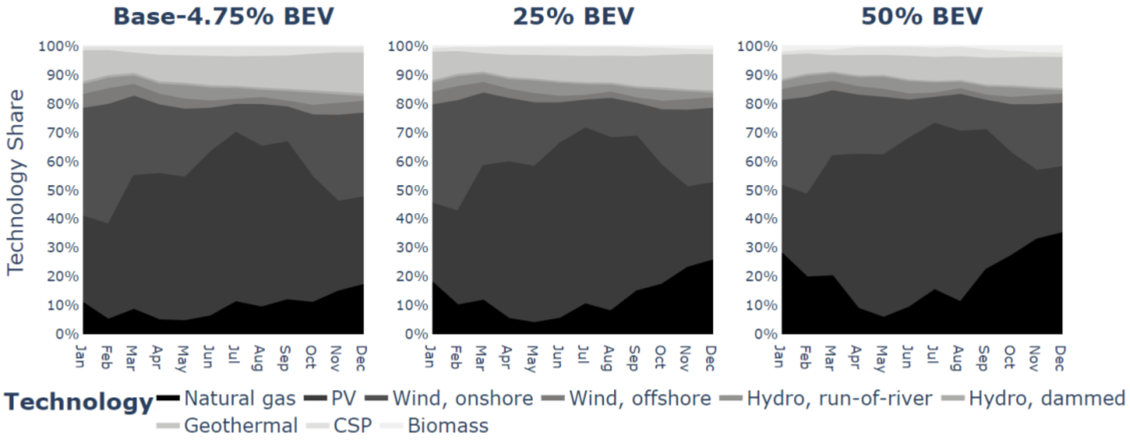

Figure 1: monthly marginal electricity mixes, by technology source, across the 3 analysed scenarios. Technologies are displayed in the same order of the legend, moving from the bottom to the top of the figure

Indeed, as Figure 2 shows, in winter months the increase of electricity produced by natural gas fuel is higher than the increases related to PV and wind sources, which constitute the dominant electricity sources in the 2030 italian marginal mix. The opposite happens in summer months.

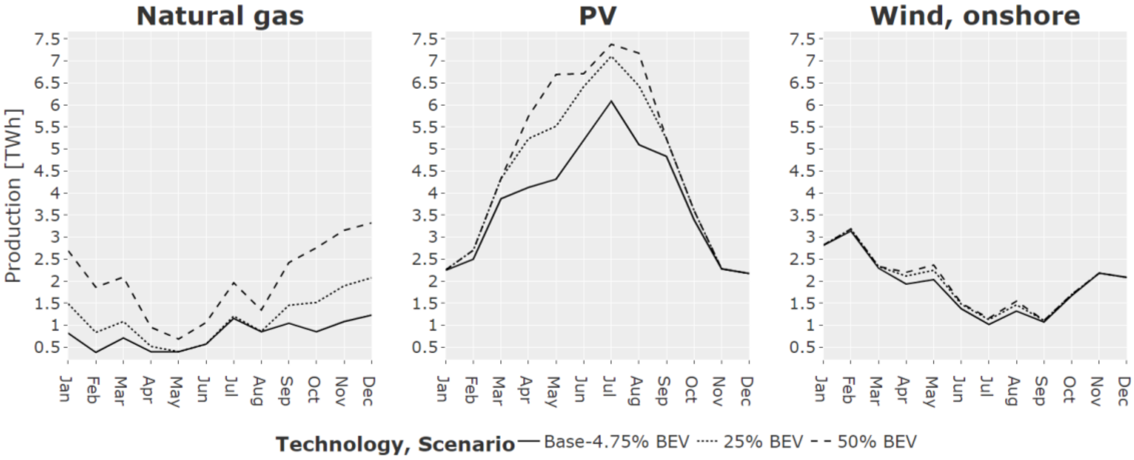

Figure 2: monthly marginal electricity production, across the 3 analysed scenarios, for the 3 dominant sources in the electricity mix. From left to right: natural gas, photovoltaic and wind electricity production. Dashed, dotted and solid lines respectively correspond to the 50% BEV, 25% BEV and base case scenarios

Among the 19 impact indicators, we selected the 2 categories with the highest degree of variability, both across months and scenarios, with respect to the yearly average value. Figure 3 and 4 summarize the resulting LCIA indicators, which indicate two different patterns: *minerals and metals* impact indicator increases during the summer months due to a higher VRES penetration, while the opposite happens for the *climate change total* impact indicator. Concerning other impact categories, *fossils*, *freshwater and terrestrial acidification* and *ozone layer depletion* show a trend which is very close to *climate change*, but with lower relative variations. Fig. 3 also shows two dashed lines. The dashed line with markers represents the impact indicator associated to a consequential LCA between 2016 and 2030 for the *Base* scenario. The dashed line without markers stands as reference from the ecoinvent 3.6 consequential Italian dataset for electricity. The largest deviations across scenarios are found in winter months, in accordance with the related monthly mixes variation.

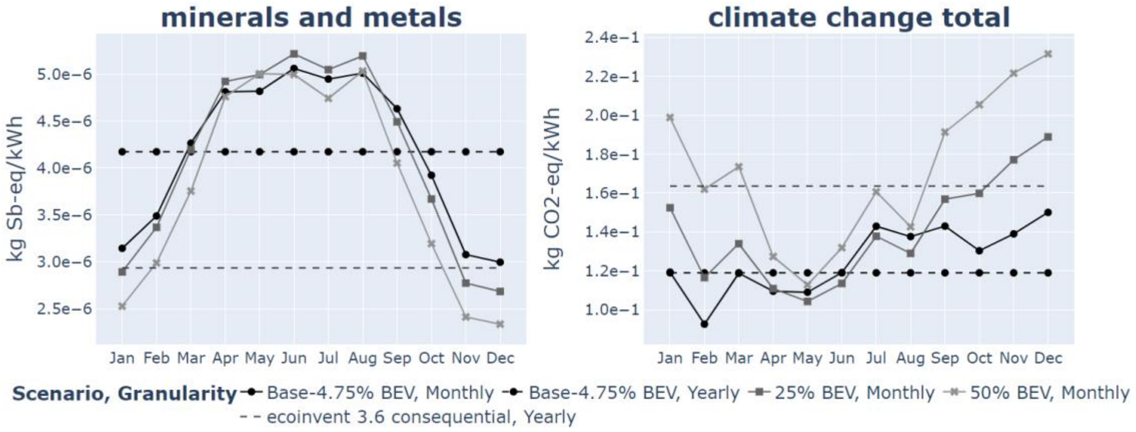

Figure 3: comparison of the monthly LCIA results for the 3 analysed scenarios (solid lines) with respect to the average yearly LCIA result for the Base scenario (dashed line with markers) and for the yearly ecoinvent 3.6 consequential original dataset (dashed line without markers), for two representative impact categories

Figure 4 shows the monthly LCIA results variations, relatively to the consequential LCA result performed at the yearly level (see the dashed line with markers in fig. 3). Indeed, deviations span across (-30%; +20%) and (-20%; +25%) intervals, respectively for the *minerals and metals* and *climate change total* impact indicators for the *Base* scenario. Variations of the other two scenarios on the same reference value span across (-40%; +20%) and (-10%; +90%) intervals, respectively for the *minerals and metals* and *climate change total* impact indicators. For the latter category, moving between *Base* and *50% BEV* scenarios makes LCIA results vary by up to 60%, depending on whether the additional electricity demand is covered by VRES or by natural gas.

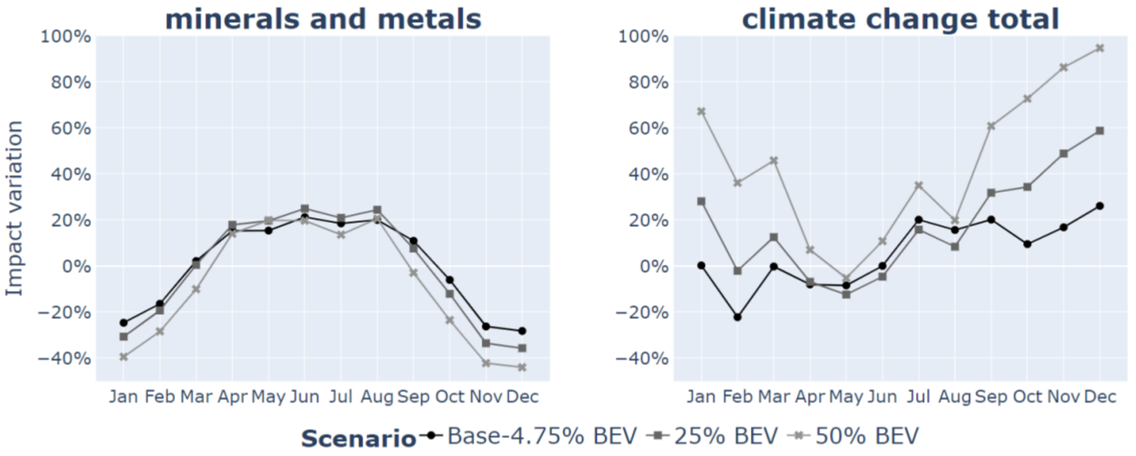

Figure 4: relative variation of monthly LCIA results for the 3 analysed scenarios with respect to the average yearly LCIA result of the base case scenario, for two representative impact categories

4. Conclusions

Here we aimed to analyse the influence of two key factors on the LCA impacts of the electricity consumption. The first factor is related to the timeframe of assessment of the electricity mix, while the second one is linked to the interaction between BEVs and the energy system in Italy. The analysis showed that among the 19 ILCD 2.0 midpoint categories, *minerals and metals* and *climate change total* impact indicators vary the most, from -30% to +25% when assessing the same scenario, but with monthly averages. Furthermore, the same impact indicators show a deviation of up to 60% when moving between *Base* and *50% BEV* scenarios, with the sign of the variation depending on the specific impact category.

Future works are related to a deeper contextualisation of the current results into the landscape of LCAs of BEVs. On one hand, the temporal variability of LCIA results can have important consequences on LCAs of the use phase of BEVs, assuming inhomogeneous driving patterns across the year. On the other hand, the interaction between BEVs and the energy system of the country may influence the other phases of BEVs LCAs as well, assuming that production and end-of-life phases are carried out in the analysed country. On top of this, the temporal resolution of the EnergyPLAN model could be further exploited, by means of an analysis at the hourly level. Thus, the distributions of hourly marginal electricity mixes will be computed in order to outline the underlying variability associated to each of the monthly LCIA results.

5. Bibliography

ACI (2017) *Annuario Statistico ACI*.

Bohnes, F. A., Gregg, J. S. and Laurent, A. (2017) ‘Environmental Impacts of Future Urban Deployment of Electric Vehicles: Assessment Framework and Case Study of Copenhagen for 2016-2030’, *Environmental Science and Technology*, 51(23), 13995–14005.

Dandres, T. *et al.* (2017) ‘Consequences of Future Data Center Deployment in Canada on Electricity Generation and Environmental Impacts: A 2015–2030 Prospective Study’, *Journal of Industrial Ecology*, 21(5), 1312–1322.

Doucette, R. T. and McCulloch, M. D. (2011) ‘Modeling the CO2 emissions from battery electric vehicles given the power generation mixes of different countries’, *Energy Policy*. Elsevier, 39(2), 803–811.

Energy and Strategy group (2018) ‘E-Mobility Report 2018’.

Garcia, R., Gregory, J. and Freire, F. (2015) ‘Dynamic fleet-based life-cycle greenhouse gas assessment of the introduction of electric vehicles in the Portuguese light-duty fleet’, *International Journal of Life Cycle Assessment*, 20(9), 1287–1299.

Gestore Servizi Energetici (GSE) (2016) *Rapporto Statistico: Energia da fonti* *rinnovabili in Italia*.

Girardi, P., Gargiulo, A. and Brambilla, P. C. (2015) ‘A comparative LCA of an electric vehicle and an internal combustion engine vehicle using the appropriate power mix: the Italian case study’, *International Journal of Life Cycle Assessment*, 20(8), 1127–1142.

Lund, H. (2014) *Renewable Energy Systems: A Smart Energy Systems Approach to the Choice and Modeling of 100% Renewable Solution*.

Marmiroli, B. *et al.* (2018) ‘Electricity generation in LCA of electric vehicles: A review’, *Applied Sciences (Switzerland)*, 8(8).

Marmiroli, B. (2020) *Sustainability Assessment of Electric Mobility*. PhD Thesis.

Ministero dello Sviluppo Economico (MiSE) and Ministero dell’Ambiente e della Tutela del Territorio e del Mare (MATTM) (2017) *Strategia Energetica Nazionale (SEN)*.

Ministero dello Sviluppo Economico (MiSE), Ministero dell’Ambiente e della Tutela del Territorio e del Mare (MATTM) and Ministero delle Infrastrutture e dei Trasporti (MIT) (2018) *Proposta di Piano Nazionale Integrato per l’Energia e il Clima (PNIEC)*.

Mutel, C. (2017) ‘Brightway: An open source framework for Life Cycle Assessment’, *The Journal of Open Source Science*, 2(12), 1–2.

Roux, C., Schalbart, P. and Peuportier, B. (2017) ‘Development of an electricity system model allowing dynamic and marginal approaches in LCA—tested in the French context of space heating in buildings’, *International Journal of Life Cycle Assessment*. The International Journal of Life Cycle Assessment, 22(8), 1177–1190.

Terna (2016) *Impianti di generazione*.

Terna (2020) *Transparency Report*. Available at: https://www.terna.it/it/sistema-elettrico/transparency-report (Accessed: 31 August 2020).

Vandepaer, L. *et al.* (2019) ‘The integration of long-term marginal electricity supply mixes in the ecoinvent consequential database version 3.4 and examination of modeling choices’, *The International Journal of Life Cycle Assessment*, 1409–1428.

Con il patrocinio di:

COMUNE DI CORTINA D'AMPEZZO

MINISTERO DELL'AMBIENTE
E DELLA TUTELA DEL TERRITORIO E DEL MARE

SETAC®
Italian Language Branch

ENEA

ISBN 978-88-8286-416-3