Journal of Energy Storage 58 (2023) 106344

Contents lists available at ScienceDirect

Journal of Energy Storage

journal homepage: www.elsevier.com/locate/est

Research Papers

Thermal energy storage co-benefits in building applications transferred from a renewable energy perspective

David Vérez, Emiliano Borri, Gabriel Zsembinszki, Luisa F. Cabeza *

GREiA Research Group, Universitat de Lleida, Pere de Cabrera s/n, 25001 Lleida, Spain

ARTICLE INFO

Keywords:
Co-benefits
Renewable energy
Thermal energy storage
Buildings
Cross-sectorisation

ABSTRACT

Although one of the main aims of using renewable energy sources in building applications is to reduce the environmental impact caused by the high global energy demand of buildings, it can also produce other positive effects, known as co-benefits. Thermal energy storage technologies are often used in building applications, either integrated into the renewable system or independently, for *energy savings* or *energy efficiency* reasons. This paper demonstrates that it is possible to identify the co-benefits of the use of thermal energy storage in buildings by cross-sectorizing the renewable energy and thermal energy storage sectors. To this end, this article first reviews the literature on the co-benefits of renewable energy for building applications, followed by an evaluation on how these co-benefits can be attributed to thermal energy storage in buildings. As a result of a keywords analysis, the main co-benefits of thermal energy storage were identified related to *environmental*, *health*, *economic*, *cost*, and *policies* aspects.

1. Introduction

Any action in buildings may have substantial value beyond the direct impact looked for; that is, any action has multiple impacts, which can affect the economy, society, or end user [1]. These impacts are related to health (*better indoor conditions, energy poverty alleviation, better ambient air quality, reduction of the heat island effect*), environment (*reduced local air pollution, reduced sewage production*), resource management (*including water and energy*), social well-being (*increase productivity for women*, *fuel poverty alleviation*, *decrease in energy expenditure*), microeconomic effects (*increase productivity in non-residential buildings*), macroeconomic effects (*creation of jobs*), and *energy security*.

These impacts that are not related to the direct objective of study are known as co-benefits. According to the IPCC AR6 [2], *co-benefit* is “a positive effect that a policy or measure aimed at one objective has another objective, thereby increasing the total benefit to society on the environment”. Another definition of co-benefit related to climate states that “climate co-benefits are beneficial outcomes from action that are not directly related to climate change mitigation” [3].

Moreover, the term co-benefits refers to simultaneously meeting several interests or objectives resulting from a political intervention, private sector investment or a mix thereof [4].

Thermal energy storage (TES) in buildings is a technology used for *energy savings*, *energy conservation*, and *energy efficiency* [5]. TES is the technology to overcome any mismatch between energy generation and energy use (in time, temperature, power, or location) [6]. TES can be used to convert an intermittent energy source, such as solar energy, in meeting the demand profile. For instance, TES can be used for free-cooling in buildings, or to increase the thermal inertia of the building (by integrating TES materials, such as phase change materials, into the building materials or into the building structure) [7].

Highlighting co-benefits of TES technologies, such as with any other technology, contributes to social acceptance of such technologies [3]. Since literature agrees [8] that one of the main barriers for TES implementation is the lack of knowledge about these systems, dissemination of their co-benefits, especially those related to health and environment, can help in the knowledge deployment. Moreover, literature states that local climate actions would potentially occur faster and at a higher level if they generate co-benefits, such as *environmental, public health, or economic development* benefits, on top of *energy efficiency* and *cost savings*, although usually the last two are already powerful motivators [9].

The literature highlights the advantages of using TES in buildings (i.e., *increasing efficiency and reliability of energy systems, better economic feasibility, reducing investment and costs, reducing pollution, reducing CO_2 emissions*) [6,10,11], but these advantages have never been identified as co-benefits. Therefore, this paper aims at filling up this literature gap by

* Corresponding author.
E-mail address: luisaf.cabeza@udl.cat (L.F. Cabeza).

https://doi.org/10.1016/j.est.2022.106344
Received 6 May 2022; Received in revised form 2 December 2022; Accepted 4 December 2022
Available online 13 December 2022
2352-152X/

evaluating the potential co-benefits of TES in buildings. To this end, this article first reviews the literature on the co-benefits of renewable energy for building applications, and then evaluates how these co-benefits can be attributed to thermal energy storage in buildings.

2. Methodology

This section describes the methodology adopted (Fig. 1) to prepare the bibliographic and bibliometric analysis presented in the following sections. In this study, the Scopus database was used as a reference, since it includes a large number of papers referring to technological topics compared to other databases such as Web of Science [12]. Databases such as Google Scholar or ResearchGate were excluded due to their low reliability of bibliometric results [13]. Moreover, the data on world population was obtained from the United Nations 2019 Revision of World Population Prospects [8].

This study was carried out with the following query:

(TITLE-ABS-KEY ("renewable energ*") AND TITLE-ABS-KEY ("co-benefit*" OR "cobenefit*")) AND (EXCLUDE (PUBYEAR,2022))

In order to obtain a clear picture of research topics, similar keywords were groups using a thesaurus file into the VOSViewer software. Moreover, this avoids having a dispersion of keywords with low relevance and highlights the macro-area of research.

3. State-of-the-art of renewable energy co-benefits

3.1. Bibliometric analysis

The present study was conducted in May 2022; therefore, the time frame was established in the query, considering all historical publications on the subject up to 2021.

Fig. 2a shows that around 70 % of publications on the topic are articles/papers and the other 30 % are reviews, conference papers, with a small number of books chapters. Moreover, when analyzing the number of publications by countries, Fig. 2b indicates that the United States is the country with more publications, having published more than twice compared to the next two countries in line United Kingdom and China.

The trends in the number of publications are shown in Fig. 3. The figure indicates that renewable energy co-benefits started to be mentioned in research papers in 2006, with continuous interest in the peer-reviewed literature until today. The trends of paper published by the main countries that are interested in the studies of co-benefits in renewable energy is presented in Fig. 3b. The figure shows that United States is one of the countries that started to publish on the topic and that today has the highest research output followed by United Kingdom.

The authors with more publications that are related to the co-benefits of renewable energy are listed in Table 1. In this case it is interesting to notice that there is only one scholar from United States and that the first author publishing in the topic is B. Limmeechokchaiai, from Thammasat University located in Thailand. The first paper from this author was published in 2012 on the assessment of Thailand energy policies on renewable electricity generation and energy efficiency in industries and buildings evaluating also the CO_2 emissions from power generation expansion plans [14]. The most cited paper was then published in 2013 on the analysis of the mitigation measures in Thailand with emission trading and carbon capture and storage (CCS) using a computable general equilibrium (CGE) model (AIM/CGE) [15]. From the co-authors of this paper is worth to mention R. Shrestha, and T. Masui which is also in list of top authors. In particular R. Shrestha is author of one of the first paper published on the topic in 2010 on the co-benefits of CO_2 emissions reduction in Thailand [16]. From the authors listed in the table the most cited papers was published by Dai, H. in 2016 on the economic and

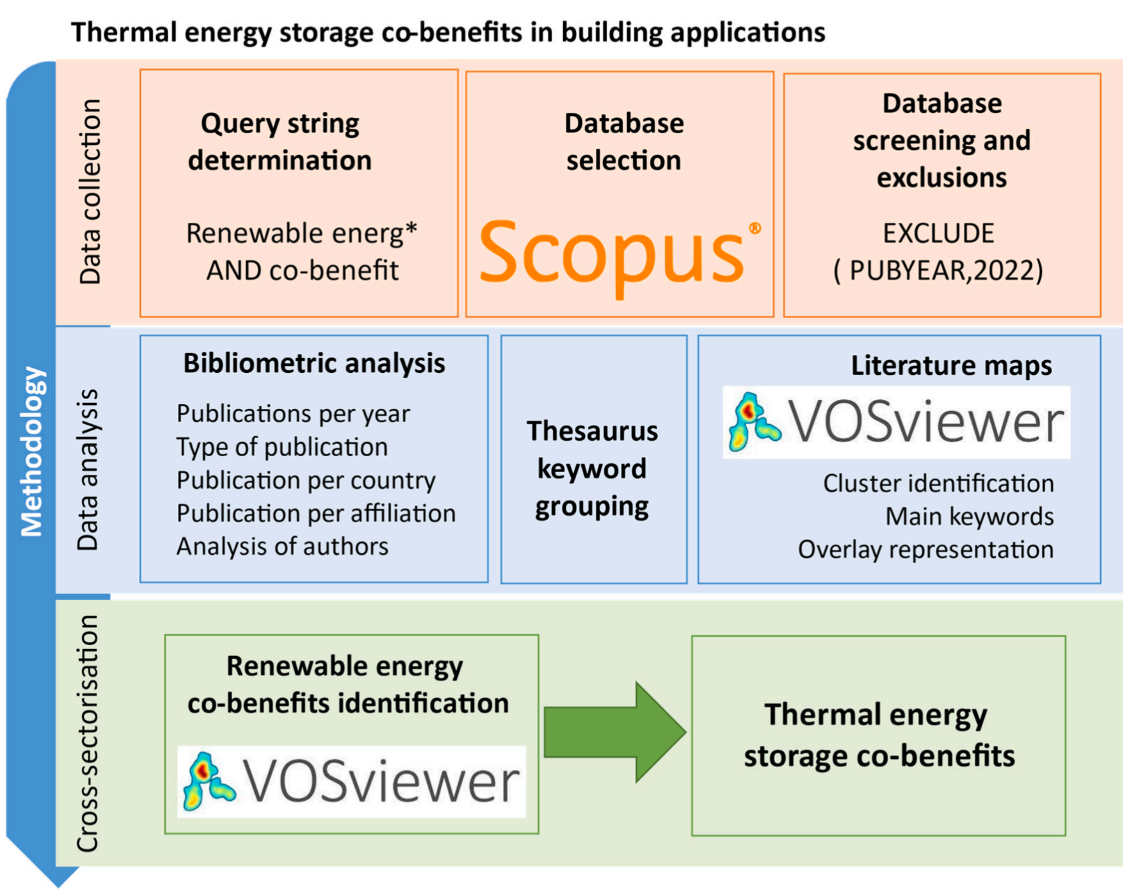

Fig. 1. Methodology followed in the bibliometric analysis.

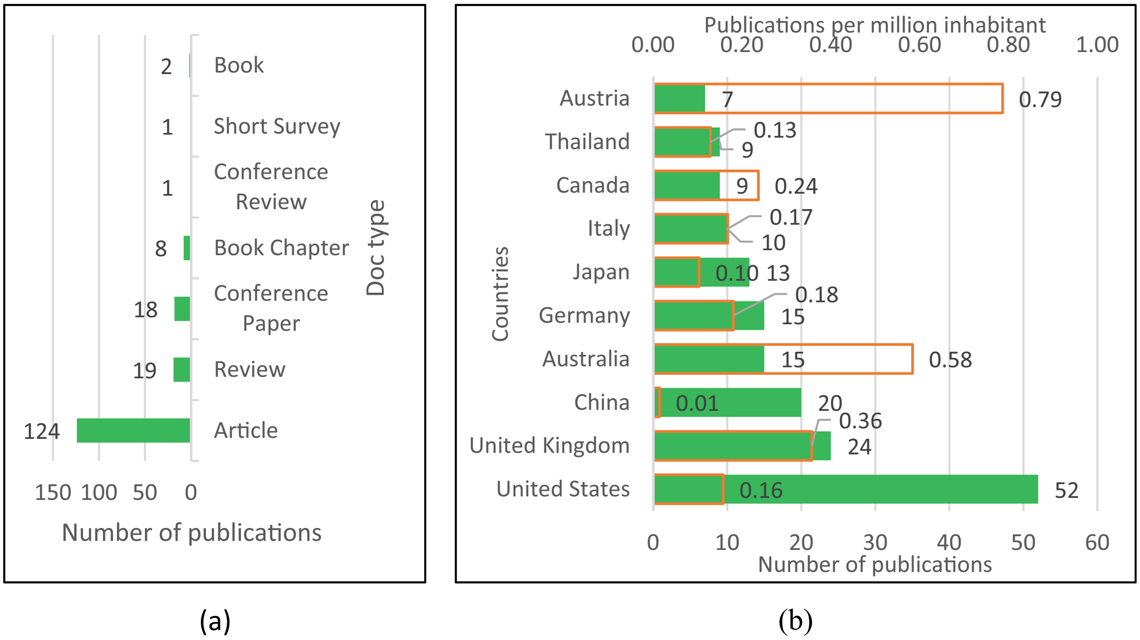

Fig. 2. Distribution of documents by (a) type of documents (b) country/region of publication and in the orange bars publications per million inhabitants.

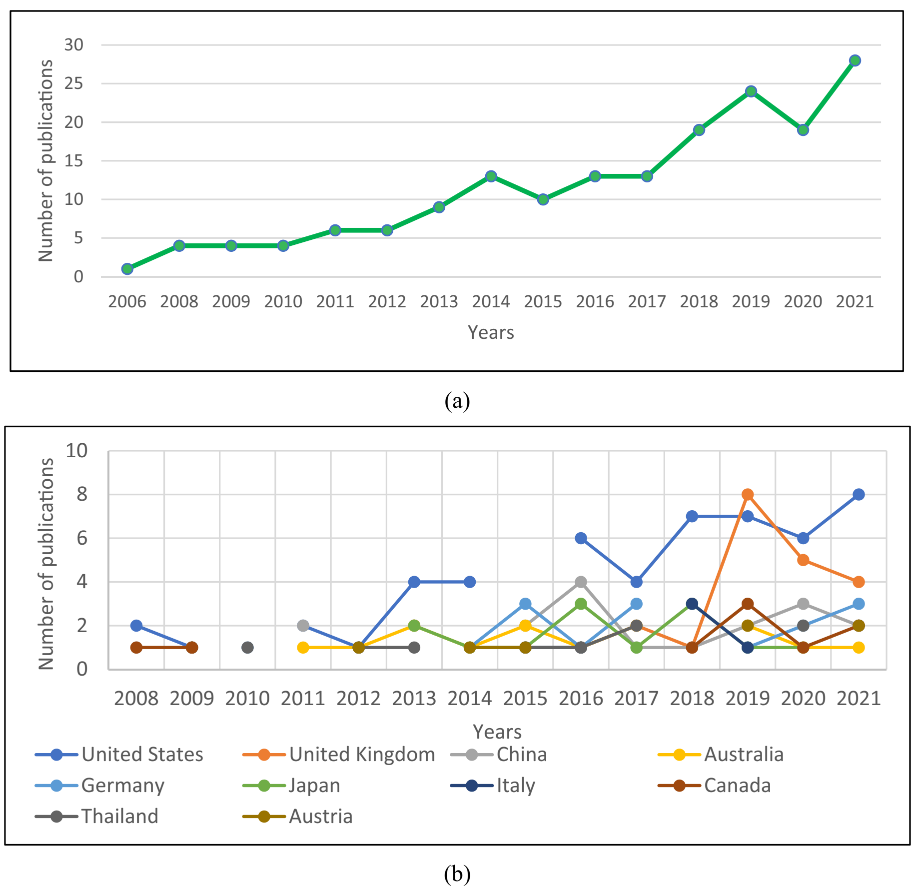

Fig. 3. Trends in the number of publications in the area of study (a) worldwide (b) per country.

environmental impact assessment of large-scale renewable energy development in China [17]. B.K. Sovacook is also author of highly cited papers including a study on energy justice of low-carbon transition in Europe [18] and a study on the o-benefits of electric vehicles and vehicle-to-grid [19]. The main journals that contain publications related to co-benefits of renewables are indicated in Fig. 4 and details listed in Table 2, where the most targeted journal in this case is *Energy Policy*. From the bibliometric data is possible to notice that most of journals are

Table 1
Authors with more publications in the field of study.

Author	Institution	Country	Number documents search	Number documents total	h-Index total
Limmeechokchai, B.	Thammasat University	Thailand	6	132	19
Almeida, M.	Universidade do Minho	Portugal	3	76	18
Armstrong, A.	Energy Lancaster	United Kingdom	3	41	19
Becchio, C.	Politecnico di Torino	Italy	3	53	17
Dai, H.	Peking University	China	3	86	32
Ferreira, M.	Universidade do Minho	Portugal	3	16	12
Holloway, T	University of Wisconsin-Madison	United States	3	73	31
Masui, T.	National Institute for Environmental Studies of Japan	Japan	3	176	47
Shrestha, R	Asian Institute of Technology Thailand	Thailand	3	92	25
Sovacool, B.K.	Aarhus Universitet	Denmark	3	508	74

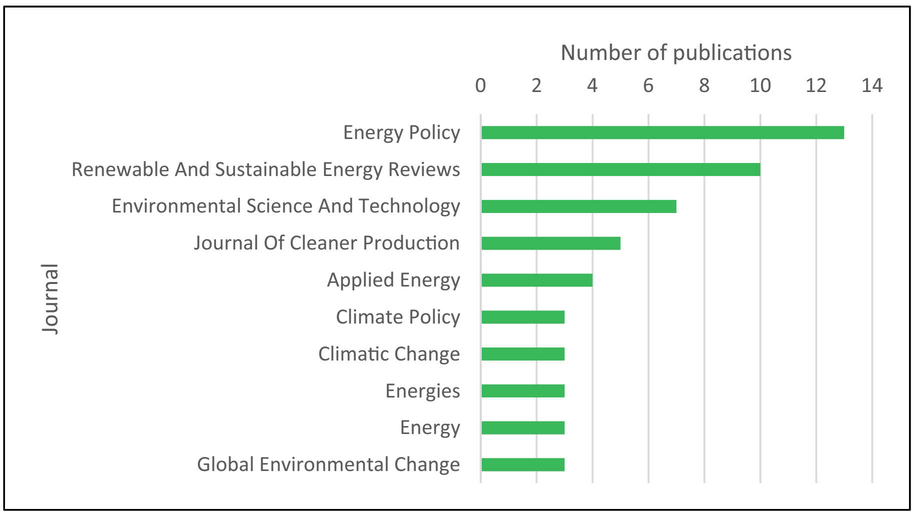

Fig. 4. Journals where the documents are published.

Table 2
The journals most used and their impact.

Journal	Number documents search	Total h-Index (2022)	Category	Open Access
Energy Policy	13	6.142	Q1	Hybrid
Renewable and Sustainable Energy Reviews	10	14.982	Q1	Hybrid
Environmental Science and Technology	7	9.028	Q1	No
Journal of Cleaner Production	5	9.297	Q1	Hybrid
Applied Energy	4	9.746	Q1	Hybrid
Climate Policy	3	5.085	Q1	Yes
Climatic Change	3	4.743	Q2	Hybrid
Energies	3	3.004	Q2	Yes
Energy	3	7.147	Q1	Hybrid
Global Environmental Change	3	9.523	Q1	Hybrid

classified as Q1 and only few of them are full open access. Nevertheless, almost half of documents published in the topic are available in hybrid gold, bronze, or green in open access.

3.2. Keyword analysis

The data extracted from the Scopus database were implemented in a bibliographic mapping (Fig. 5). This figure shows the relationships among the keywords extracted from each document. The size of the bubbles represents the occurrence of the keywords and the colours represent groupings in clusters. Given the high number of keywords found, and that the main objective of the paper is not to analyse the relationship between the keywords of renewable energy but to identify its co-benefits, the figure is not analysed in detail. However, it is interesting to highlight that the keyword “co-benefit” contains a total of 49 occurrences, which places it outside the top 10 % keywords with the highest number of occurrences, which exemplifies that the study of co-benefits represents a large gap in the scientific literature.

To identify that relationship, all keywords related to one specific area were joined using the thesaurus technique to be able to analyse the relation between the co-benefit areas (e.g., *environment*, *health*, *policy*). 200 of the 231 keywords presented in Fig. 5 were grouped into 100 main keywords groups (Fig. 6). This main groups were: those related to the *energy sector*; to *health impact*; to *carbon dioxide (emissions, carbon sequestration)*; to *air pollution* and *air quality*; to *the environmental impact management and protection*; economic aspects such as *cost* and *green economy*; biomass including bioenergy and biofuels; buildings; waste management and waste treatments; and finally, policy related keywords. The results after such grouping are shown in Fig. 7.

Fig. 7 shows a first cluster in green where carbon dioxide-related keywords are linked to biomass and waste management groups; other keywords also included in this cluster are climate change, landfill, nuclear energy, and electricity. Another cluster in light blue relates those keywords group in air pollution very strongly with those related to *health impact*; other keywords appearing in this cluster are fossil fuels, coal, and *employment*. The third cluster in red relates those keywords included in *policy* with other keywords such as renewable energy, *environmental impact*, *sustainability*, water, biodiversity, and conservation; and more interestingly in social aspects. Other renewable energy keywords (such as solar energy, photovoltaics) are linked in the cluster in purple with keywords co-benefits, *climate change mitigation*, and

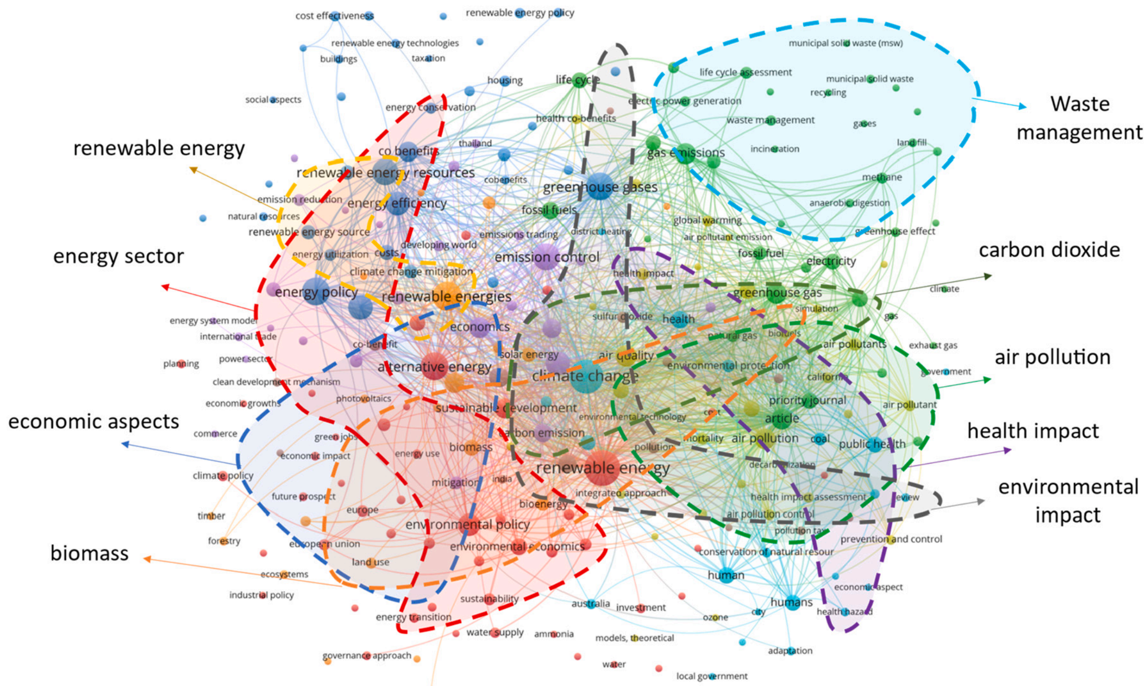

Fig. 5. Keywords co-occurrences bibliographic mapping.

developing countries. Finally, the cluster in yellow groups keywords such as energy sector and economic aspects with renewable energy sources, *energy efficiency*, *emission reduction*, and building.

4. Cross-sectorisation to thermal energy storage

This section presents the cross-sectorisation to thermal energy storage of the renewable energy co-benefits presented in Section 3.

Environmental co-benefits

Reduction of indoors and outdoors air pollution is an identified co-benefit of local climate actions in the area of transportation (vehicle efficiency), energy efficiency (green buildings), and the use of renewable energy in cities [9,21,22]. This co-benefit is also related to TES as indicated, for example, by Xie et al. [23] who demonstrated that TES has great potential in improving the energy efficiency of electric vehicles (i.e., cars, buses), specially low- and medium-temperature phase change materials (PCM) technology. On the other hand, electric vehicle efficiency is highly improved with a correct thermal management using TES technologies [24].

If green buildings are understood as a building that includes sustainable and energy efficient concepts and technologies, reduction of indoors and outdoors air pollution are co-benefits of TES systems demonstrated widely in the literature. For example, Palanisamy et al. [25] studied the use of a TES module in an air conditioning system to improve *indoor air quality*. Wang et al. [26] used a TES module in a biomass boiler to reduce the number of boiler cycles and, therefore, reduce indoors air pollution.

Using renewable energies instead of fossil fuels would reduce the *air pollution* remarkably. The literature shows that adding TES in renewable energy systems increases its *energy efficiency*, therefore contributing again to this co-benefit. Examples of this are the increase of efficiency of photovoltaic panels when adding TES [27], the use of TES in low-temperature thermal solar systems [28], or the hybridization of a solar/geothermal system using TES [29].

Another environmental co-benefit of local climate actions is *biodiversity conservation* (habitat conservation) [9,30]; this co-benefit is classified in the area of land use and carbon offsets. An example where this co-benefit can be transferred to TES is the biodiversity conservation achieved when green roofs and green facades are used as passive TES technology [31].

Water as co-benefit

Water use efficiency, *water reduction and recycling*, *watershed health*, and *water savings* are co-benefits of local climate actions [9]. Managing the level of storage in the water damp is a potential source of hydroelectric power [32]. An example of *water management* and *water use efficiency* is the technology aquifer TES (ATES), where underground water is used for heating and/or cooling of buildings among other uses [33].

Health co-benefits

Public health is identified as co-benefit of local climate actions in the area of land use [9]. Offshore wind installations also contribute to the health and climate benefits of cities [34]. The 2015 Lancet Commission concluded that "tackling climate change could be the greatest global health opportunity of the 21st century" [35]. Several modelled scenarios suggest that the commitment to reduce 80 % of greenhouse gas (GHG) emissions by 2050 compared to 1990 brought *health* as a co-benefit [36–38]. Therefore, transferring health co-benefits from renewable energies to TES are related to the *reduction of* CO_2 and *GHG emissions* [39,40].

Economic co-benefits

Economic growth is a co-benefit of local climate actions in the area of energy efficiency (green buildings) and the use of renewable energy in cities [9]. *New jobs opportunities* and establishment of *new economy sectors* are also co-benefits from investments in renewable energy sector [41]. Similarly and according to IRENA [42], a growing business case lies ahead for TES technologies, projections show that in the next decade investment in the range of US$ 12.8 billion to US$ 27.22 billion is foreseen for power and cooling TES applications.

Policy co-benefits

Energy security is a co-benefit of local climate actions when integrating renewable energy in cities [9]. *Employment* is another co-benefit of renewable energy integration in both the power and buildings sectors [43]. Furthermore, local municipalities besides feeling motivated to collaborate with the energy transition of the country, and the economic advantages it could bring to the municipality, also look at other co-benefits such as *enhancing the image of the town* and *strengthening community life* [10]. Moreover, TES plays a fundamental role in the

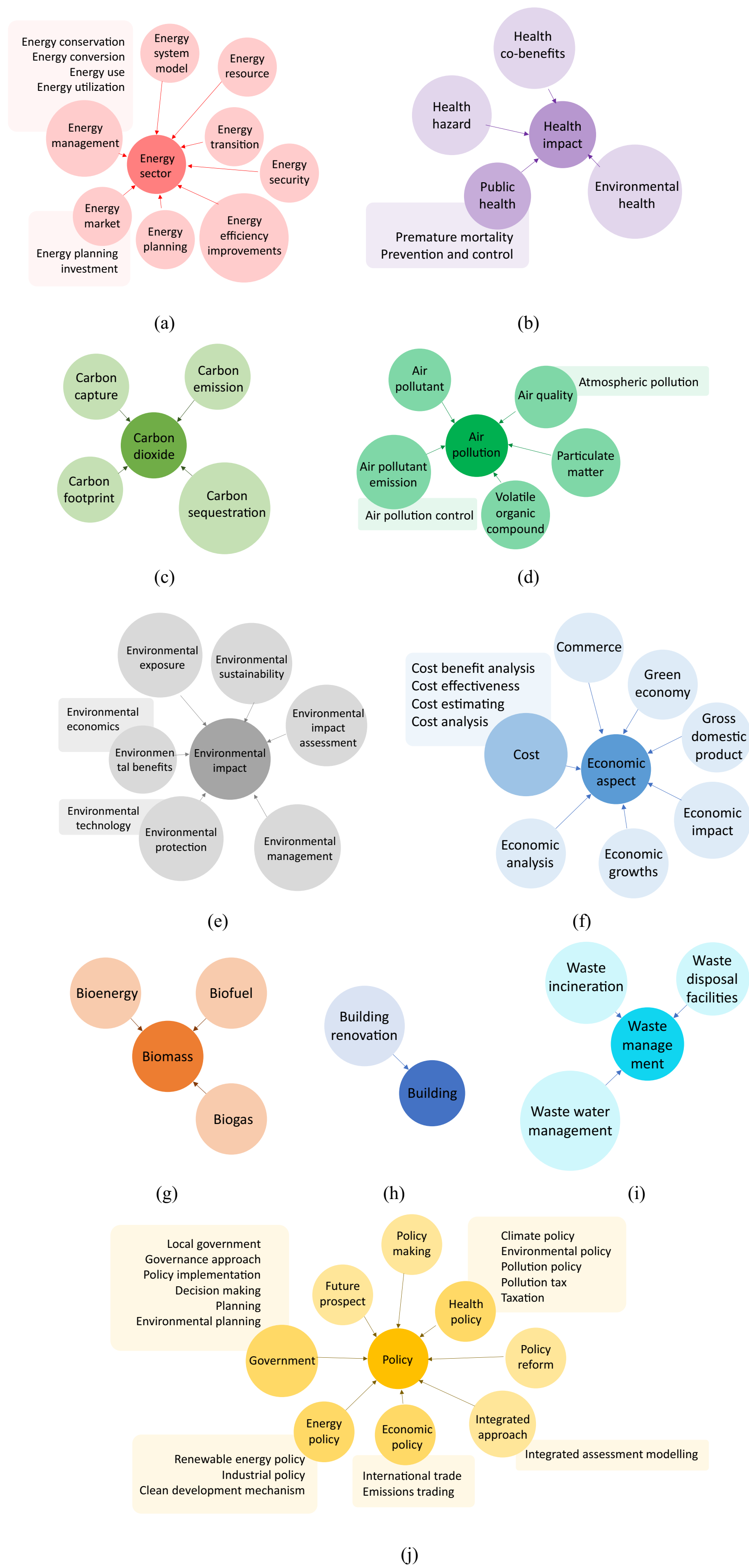

Fig. 6. Keywords linked by means of thesaurus, (a) keywords related to the energy sector, (b) keywords related to the health impact, (c) keywords related to carbon dioxide, (d) keywords related to air pollution, (e) keywords related to the environmental impact, (f) keywords related to the economic aspects, (g) keywords related to the biomass, (h) keywords related to the buildings, (i) keywords related to waste management, (j) keywords related to policies.

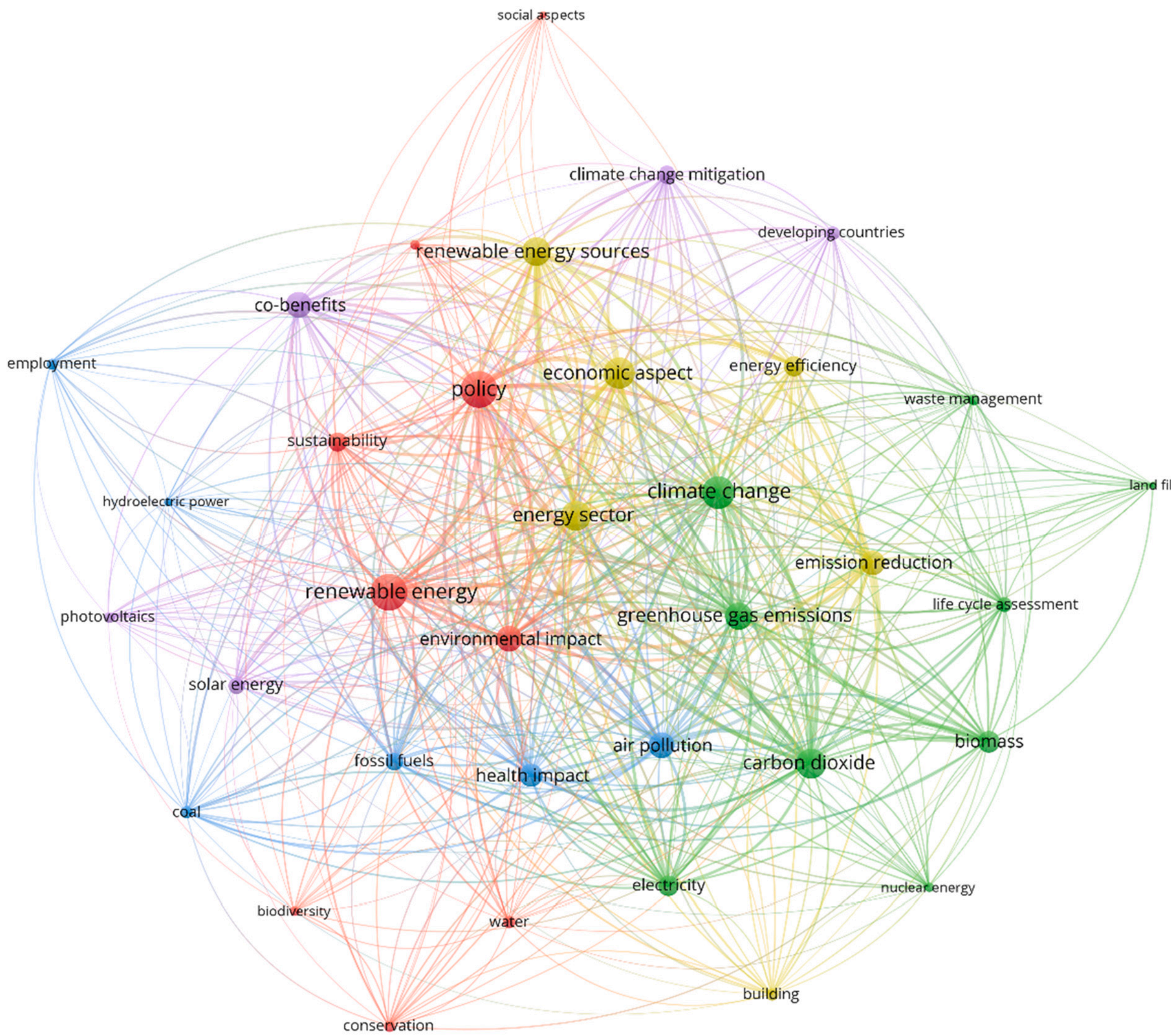

Fig. 7. Keywords linked by means of thesaurus grouped by main topic.

implementation of renewable energies and is therefore also an important component in energy security [44].

5. Conclusions

The term *co-benefit* related to renewable energy started to be mentioned in research papers only in 2006, with a rising interest literature. The evaluation of the main keywords related to co-benefits of renewable energies assess in this paper, shows that all terms are strongly interrelated. For example, *climate change mitigation* is mostly related to renewable energy sources, economic aspects, but also to developing countries. On the other hand, all keywords related to policies has a strong relation with the energy sector and *environmental impact*. Keywords related to the *health impact* present a strong relation with air pollution. And finally, the keyword carbon dioxide has strong relationship with health impact, renewable energies, and sustainability.

This paper demonstrates that by cross-sectorizing the renewable energy and thermal energy storage (TES) sectors it is possible to identify the co-benefits of thermal energy storage in buildings. When focusing on TES, co-benefits identified in the literature are those related to *environmental* co-benefits, *water* co-benefits, *health related* co-benefits, *economic* and *cost related* co-benefits, and benefits related to *policies.* The co-benefit of TES identified in the literature highlight that TES is a fundamental technology in the *energy transition* not only to increase the efficiency of energy systems and allow a better integration of renewables but also to provide benefits to *health impact*, *economic growth* and *energy security*. Nevertheless, economic investments in the technological development of TES together with targeted energy policy is fundamental to overcome the actual barriers and enhance the integration of this technology in the actual energy system.

CRediT authorship contribution statement

Term/author	David Vérez	Emiliano Borri	Gabriel Zsembinszki	Luisa F. Cabeza
Conceptualization	x			x
Methodology	x			x
Software				
Validation				
Formal analysis		x	x	
Investigation	x	x		
Resources				x
Data curation				x
Writing – Original draft	x	x		
Writing – Review & Editing	x		x	x
Visualization	x			
Supervision			x	x
				x

(*continued on next page*)

(*continued*)

Term/author	David Vérez	Emiliano Borri	Gabriel Zsembinszki	Luisa F. Cabeza
Project administration				
Funding acquistion				x

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

Acknowledgements

This work was partially funded by the Ministerio de Ciencia, Innovación y Universidades de España (RTI2018-093849-B-C31 - MCIU/AEI/FEDER, UE) and by the Ministerio de Ciencia, Innovación y Universidades - Agencia Estatal de Investigación (AEI) (RED2018-102431-T). The authors would like to thank the Catalan Government for the quality accreditation given to their research group GREiA (2017 SGR 1537). GREiA is a certified agent TECNIO in the category of technology developers from the Government of Catalonia. This work is partially supported by ICREA under the ICREA Academia programme.

References

[1] D. Ürge-Vorsatz, A. Kelemen, S. Tirado-Herrero, S. Thomas, J. Thema, N. Mzavanadze, D. Hauptstock, F. Suerkemper, J. Teubler, M. Gupta, S. Chatterjee, Measuring multiple impacts of low-carbon energy options in a green economy context, Appl. Energy 179 (2016) 1409–1426, https://doi.org/10.1016/j.apenergy.2016.07.027.
[2] IPCC, AR6 - Annex: Glossary, 2022.
[3] Tyndall Centre for Climate Change Research, Centre for Climate Change and Social Transformations, CDP Worldwide, The Co-benefits of Climate Action. Accelerating City-level Ambition, 2020.
[4] S. Helgenberger, M. Jänicke, K. Gürtler, in: Co-benefits of Climate Change Mitigation, 2019, pp. 1–13, https://doi.org/10.1007/978-3-319-71063-1_93-1.
[5] A. De Gracia, L.F. Cabeza, Phase change materials and thermal energy storage for buildings, Energy Build. 103 (2015) 414–419, https://doi.org/10.1016/j.enbuild.2015.06.007.
[6] L. Navarro, A. de Gracia, S. Colclough, M. Browne, S.J. McCormack, P. Griffiths, L. F. Cabeza, Thermal energy storage in building integrated thermal systems: a review. Part 1. Active storage systems, renewEnergy 88 (2016) 526–547, https://doi.org/10.1016/j.renene.2015.11.040.
[7] L. Navarro, A. de Gracia, D. Niall, A. Castell, M. Browne, S.J. McCormack, P. Griffiths, L.F. Cabeza, Thermal energy storage in building integrated thermal systems: a review. Part 2. Integration as passive system, Renew. Energy 85 (2016) 1334–1356, https://doi.org/10.1016/j.renene.2015.06.064.
[8] M. Simó-Solsona, M. Palumbo, M. Bosch, A.I. Fernandez, Why it's so hard? Exploring social barriers for the deployment of thermal energy storage in Spanish buildings, Energy Res. Soc. Sci. 76 (2021), 102057, https://doi.org/10.1016/j.erss.2021.102057.
[9] L.W. Bedsworth, E. Hanak, Climate policy at the local level: insights from California, Glob. Environ. Chang. 23 (2013) 664–677, https://doi.org/10.1016/j.gloenvcha.2013.02.004.
[10] D. Lee, R. Ooka, Y. Matsuda, S. Ikeda, W. Choi, Experimental analysis of artificial intelligence-based model predictive control for thermal energy storage under different cooling load conditions, Sustain. Cities Soc. 79 (2022), 103700, https://doi.org/10.1016/j.scs.2022.103700.
[11] E. Borri, G. Zsembinszki, L.F. Cabeza, Recent developments of thermal energy storage applications in the built environment: a bibliometric analysis and systematic review, Appl. Therm. Eng. 189 (2021).
[12] L.F. Cabeza, M. Chàfer, É. Mata, Comparative analysis of web of science and scopus on the energy efficiency and climate impact of buildings, Energies. 13 (2020) 409, https://doi.org/10.3390/en13020409.
[13] M.E. Falagas, E.I. Pitsouni, G.A. Malietzis, G. Pappas, Comparison of PubMed, scopus, web of science, and Google scholar: strengths and weaknesses, FASEB J. 22 (2008) 338–342.
[14] K. Promjiraprawat, B. Limmeechokchai, Assessment of Thailand's energy policies and CO2 emissions: analyses of energy efficiency measures and renewable power generation, Energies. 5 (2012) 3074–3093, https://doi.org/10.3390/en5083074.
[15] P. Thepkhun, B. Limmeechokchai, S. Fujimori, T. Masui, R.M. Shrestha, Thailand's low-carbon scenario 2050: the AIM/CGE analyses of CO2 mitigation measures, Energy Policy 62 (2013) 561–572, https://doi.org/10.1016/j.enpol.2013.07.037.
[16] R.M. Shrestha, S. Pradhan, Co-benefits of CO2 emission reduction in a developing country, Energy Policy 38 (2010) 2586–2597, https://doi.org/10.1016/j.enpol.2010.01.003.
[17] H. Dai, X. Xie, Y. Xie, J. Liu, T. Masui, Green growth: the economic impacts of large-scale renewable energy development in China, Appl. Energy 162 (2016) 435–449, https://doi.org/10.1016/j.apenergy.2015.10.049.
[18] B.K. Sovacool, M. Martiskainen, A. Hook, L. Baker, Decarbonization and its discontents: a critical energy justice perspective on four low-carbon transitions, Clim. Chang. 155 (2019) 581–619, https://doi.org/10.1007/s10584-019-02521-7.
[19] L. Noel, G. Zarazua de Rubens, J. Kester, B.K. Sovacool, Beyond emissions and economics: rethinking the co-benefits of electric vehicles (EVs) and vehicle-to-grid (V2G), Transp. Policy 71 (2018) 130–137, https://doi.org/10.1016/j.tranpol.2018.08.004.
[21] Y. Ou, J.J. West, S.J. Smith, C.G. Nolte, D.H. Loughlin, Air pollution control strategies directly limiting national health damages in the US, Nat. Commun. 11 (2020) 957, https://doi.org/10.1038/s41467-020-14783-2.
[22] C. Zapata, N. Muller, M.J. Kleeman, PM2.5 co-benefits of climate change legislation part 1: California's AB 32, Clim. Chang. 117 (2013) 377–397, https://doi.org/10.1007/s10584-012-0545-y.
[23] P. Xie, L. Jin, G. Qiao, C. Lin, C. Barreneche, Y. Ding, Thermal energy storage for electric vehicles at low temperatures: concepts, systems, devices and materials, Renew. Sust. Energ. Rev. 160 (2022), 112263, https://doi.org/10.1016/j.rser.2022.112263.
[24] L.F. Cabeza, A. Frazzica, M. Chàfer, D. Vérez, V. Palomba, Research trends and perspectives of thermal management of electric batteries: bibliometric analysis, J. Energy Storage. 32 (2020), 101976, https://doi.org/10.1016/j.est.2020.101976.
[25] D. Palanisamy, B.K. Ayalur, Development and testing of condensate assisted pre-cooling unit for improved indoor air quality in a computer laboratory, Build. Environ. 163 (2019), 106321, https://doi.org/10.1016/j.buildenv.2019.106321.
[26] K. Wang, S. Nakao, D. Thimmaiah, P.K. Hopke, Emissions from in-use residential wood pellet boilers and potential emissions savings using thermal storage, Sci. Total Environ. 676 (2019) 564–576, https://doi.org/10.1016/j.scitotenv.2019.04.325.
[27] H. Akbari, M.C. Browne, A. Ortega, M.J. Huang, N.J. Hewitt, B. Norton, S. J. McCormack, Efficient energy storage technologies for photovoltaic systems, Sol. Energy 192 (2019) 144–168, https://doi.org/10.1016/j.solener.2018.03.052.
[28] S. Gorjian, H. Ebadi, F. Calise, A. Shukla, C. Ingrao, A review on recent advancements in performance enhancement techniques for low-temperature solar collectors, Energy Convers. Manag. 222 (2020), 113246, https://doi.org/10.1016/j.enconman.2020.113246.
[29] J.D. McTigue, D. Wendt, K. Kitz, J. Gunderson, N. Kincaid, G. Zhu, Assessing geothermal/solar hybridization – integrating a solar thermal topping cycle into a geothermal bottoming cycle with energy storage, Appl. Therm. Eng. 171 (2020), 115121, https://doi.org/10.1016/j.applthermaleng.2020.115121.
[30] R.J. Randle-Boggis, P.C.L. White, J. Cruz, G. Parker, H. Montag, J.M.O. Scurlock, A. Armstrong, Realising co-benefits for natural capital and ecosystem services from solar parks: a co-developed, evidence-based approach, Renew. Sust. Energ. Rev. 125 (2020), 109775, https://doi.org/10.1016/j.rser.2020.109775.
[31] A. de Gracia, L. Navarro, J. Coma, S. Serrano, J. Romaní, G. Pérez, L.F. Cabeza, Experimental set-up for testing active and passive systems for energy savings in buildings – lessons learnt, Renew. Sust. Energ. Rev. 82 (2018) 1014–1026, https://doi.org/10.1016/j.rser.2017.09.109.
[32] O. Sahin, R.A. Stewart, D. Giurco, M.G. Porter, Renewable hydropower generation as a co-benefit of balanced urban water portfolio management and flood risk mitigation, Renew. Sust. Energ. Rev. 68 (2017) 1076–1087, https://doi.org/10.1016/j.rser.2016.01.126.
[33] B. Nordell, A. Snijders, L. Stiles, The use of aquifers as thermal energy storage (TES) systems, in: Adv. Therm. Energy Storage Syst, Elsevier, 2015, pp. 87–115, https://doi.org/10.1533/9781782420965.1.87.
[34] J.J. Buonocore, P. Luckow, J. Fisher, W. Kempton, J.I. Levy, Health and climate benefits of offshore wind facilities in the mid-Atlantic United States, Environ. Res. Lett. 11 (2016), https://doi.org/10.1088/1748-9326/11/7/074019.
[35] N. Watts, W.N. Adger, S. Ayeb-Karlsson, Y. Bai, P. Byass, D. Campbell-Lendrum, T. Colbourn, P. Cox, M. Davies, M. Depledge, A. Depoux, P. Dominguez-Salas, P. Drummond, P. Ekins, A. Flahault, D. Grace, H. Graham, A. Haines, I. Hamilton, A. Johnson, I. Kelman, S. Kovats, L. Liang, M. Lott, R. Lowe, Y. Luo, G. Mace, M. Maslin, K. Morrissey, K. Murray, T. Neville, M. Nilsson, T. Oreszczyn, C. Parthemore, D. Pencheon, E. Robinson, S. Schütte, J. Shumake-Guillemot, P. Vineis, P. Wilkinson, N. Wheeler, B. Xu, J. Yang, Y. Yin, C. Yu, P. Gong, H. Montgomery, A. Costello, The lancet countdown: tracking progress on health and climate change, Lancet 389 (2017) 1151–1164, https://doi.org/10.1016/S0140-6736(16)32124-9.
[36] C. Becchio, M.C. Bottero, S.P. Corgnati, F. Dell'Anna, Evaluating health benefits of urban energy retrofitting: an application for the city of Turin, Green Energy Technol. (2018) 281–304, https://doi.org/10.1007/978-3-319-75774-2_20.
[37] I. Partridge, S. Gamkhar, A methodology for estimating health benefits of electricity generation using renewable technologies, Environ. Int. 39 (2012) 103–110, https://doi.org/10.1016/j.envint.2011.10.003.
[38] F. Monforti-Ferrario, A. Kona, E. Peduzzi, D. Pernigotti, E. Pisoni, The impact on air quality of energy saving measures in the major cities signatories of the covenant of

mayors initiative, Environ. Int. 118 (2018) 222–234, https://doi.org/10.1016/j.envint.2018.06.001.

[39] P. Arce, M. Medrano, A. Gil, E. Oró, L.F. Cabeza, Overview of thermal energy storage (TES) potential energy savings and climate change mitigation in Spain and Europe, Appl. Energy 88 (2011) 2764–2774, https://doi.org/10.1016/j.apenergy.2011.01.067.

[40] L.F. Cabeza, L. Miró, E. Oró, A. de Gracia, V. Martin, A. Krönauer, C. Rathgeber, M. M. Farid, H.O. Paksoy, M. Martínez, A.I. Fernández, CO2 mitigation accounting for thermal energy storage (TES) case studies, Appl. Energy 155 (2015) 365–377, https://doi.org/10.1016/j.apenergy.2015.05.121.

[41] P. Dvořák, S. Martinát, D. Van der Horst, B. Frantál, K. Turečková, Renewable energy investment and job creation; a cross-sectoral assessment for the Czech Republic with reference to EU benchmarks, Renew. Sust. Energ. Rev. 69 (2017) 360–368, https://doi.org/10.1016/j.rser.2016.11.158.

[42] IRENA, Innovation Outlook: Thermal Energy Storage, Abu Dabhi, 2020, 2020. https://www.irena.org/publications/2020/Nov/Innovation-outlook-Thermal-energy-storage.

[43] C. Wang, W. Zhang, W. Cai, X. Xie, Employment impacts of CDM projects in China's power sector, Energy Policy 59 (2013) 481–491, https://doi.org/10.1016/j.enpol.2013.04.010.

[44] A. Azzuni, C. Breyer, Energy security and energy storage technologies, in: Energy Procedia, 2018, pp. 237–258, https://doi.org/10.1016/j.egypro.2018.11.053.