**UNIVERSITY OF SÃO PAULO**
**INSTITUTE OF ENERGY AND ENVIRONMENT**
**GRADUATION PROGRAM IN ENERGY**

**ALEXANDRE DE BARROS GALLO**

# COMBINING GREENHOUSE GAS ACCOUNTING AND ENERGY PERFORMANCE INDICATORS TO IMPROVE ENERGY-RELATED CARBON EMISSIONS REPORTING

**SÃO PAULO**
**2023**

ALEXANDRE DE BARROS GALLO

# COMBINING GREENHOUSE GAS ACCOUNTING AND ENERGY PERFORMANCE INDICATORS TO IMPROVE ENERGY-RELATED CARBON EMISSIONS REPORTING

PhD Thesis presented at the Graduation Program in Energy of the Institute of Energy and Environment of the University of São Paulo to obtain a Doctor in Sciences (DSc) degree.

Supervisor: Prof. Dr. Edmilson Moutinho dos Santos

Revised version

SÃO PAULO
2023

FICHA CATALOGRÁFICA

Gallo, Alexandre de Barros.
Combining greenhouse gas accounting and energy performance indicators to improve energy-related carbon emissions reporting. / Alexandre de Barros Gallo; orientador: Edmilson Moutinho dos Santos. – São Paulo, 2023.
256 f.: il; 30 cm.

Tese (Doutorado em Ciências) – Programa de Pós-Graduação em Energia – Instituto de Energia e Ambiente da Universidade de São Paulo.

1. GHG emission. 2. Energy performance evaluation. 3. Energy models.
. I. Título.

Elaborado por Maria Penha da Silva Oliveira CRB-8/6961

## ACKNOWLEDGEMENTS

Starting with my academic mentors, I would like to thank my supervisor Prof. Dr. Edmilson Moutinho dos Santos at the Institute of Energy and Environment of the University of São Paulo (Brazil), my supervisor since my Master's, for guidance and support, but above all, for the confidence in me. Dr. Adam Hawkes, thank you for friendly accepting to work with me as my supervisor during my research period at the Imperial College London (United Kingdom).

Moving to the academic institutions that supported and received me during my PhD, I would like to genuinely thank my colleagues, professors, and staff from the Institute of Energy and Environment of the University of São Paulo, the Imperial College of London, and the Research Centre for Greenhouse Gas Innovation (RCGI).

I acknowledge and sincerely thank my funding institutions, the National Council for Scientific and Technological Development (CNPq), Support Foundation for the University of São Paulo (FUSP), Foundation for the Technological Development of Engineering (FDTE), and the Gas Innovation Fellowship Programme (GIFP).

As a participant in standardization forums, I would like to acknowledge the work done by staff and voluntary experts from ISO/TC 301, ISO/TC 207/SC 7, ABNT/CB-116, and ABNT/CB-038. In particular, I would like to recognize their respective chairs, Mr. Roland Risser, Ms. Sara Jane Snook, Dr. Alberto José Fossa, and Mr. Ranilson Coutinho Prestrelo, for keeping their standardization groups consistent and mobilized.

I imagine several acknowledgments of recently produced thesis and dissertations, and probably others in following years, will mention at least one impact of the COVID-19 pandemic. In my case would not be different. The pandemic hit me during my research period at Imperial College London. I would like to thank Denis Fraga, my flatmate in London, as his friendship was fundamental so I could pass through these challenging times away from my family without mental health issues.

Finally, I would like to thank my family, who supports me in all my decisions, cheers me up in every challenge, celebrates each accomplishment, and whose emotional support is fundamental. For always being there for me, I dedicate this work to you, my father, Carlos, my mother, Maria da Consolação, and my sisters, Camila e Luciana.

# ABSTRACT

GALLO, Alexandre de Barros. **Combining greenhouse gas accounting and energy performance indicators to improve energy-related carbon emissions reporting**. 2023. 256p. PhD Thesis – Graduate Program in Energy, University of São Paulo. São Paulo. 2023.

Climate change is one of the most significant sustainability challenges of our times. Improvements in GHG emissions reporting can increase credibility in GHG emission reduction claims, which is fundamental for combating climate change and promoting carbon neutrality. This thesis's main objective is to improve energy-related GHG emission reporting, methodologically and through standardization, by combining GHG emission accounting and energy performance evaluation with indicators, considering their underlying strengths and challenges. Two systematized reviews are executed. The first one highlighted that one of the challenges in energy-related GHG emissions accounting was related to energy use representation. One possible solution approach identified was incorporating energy performance evaluation with indicators. The second identified that, under energy performance evaluation, adequate comprehension of EnPIs energy models and EnPIs reporting types is essential to increase awareness of EnPIs capacities and limitations in achieving an effective energy performance representation. Considering these fundamentals, this thesis proposal combines energy-related GHG emission accounting and energy performance evaluation with indicators to overcome identified barriers and improve energy-related GHG emission reporting. The proposed method aimed to improve those estimations by adopting activity data that adequately represent energy consumption and using suitable comparison baselines. An EnPI value in a given reporting type fulfills the activity data need, while an EnPI energy model is a suitable baseline for comparing activity data. A case study in the petroleum refining sector is developed to apply the proposed combination of methods. The proposed method produces more consistent results than other simplified approaches. Finally, from a standardization perspective, alignment opportunities are outlined in a broader combination of the two processes (energy performance evaluation with indicators with energy-related GHG emission accounting) in terms of guidance, including adequate activity data and a suitable baseline. Implementing these opportunities could follow different paths, from informative annexes in standards covering these topics to a guidance standard.



**Keywords**: GHG emission accounting, GHG emission reporting, energy performance evaluation, EnPI, energy models, standardization.

# RESUMO

GALLO, Alexandre de Barros. **Combinando contabilidade de emissões de gases de efeito estufa e indicadores de desempenho energético para aprimorar o reporte de emissões de carbono associadas a energia**. 2023. 256f. Tese de Doutorado – Programa de Pós-Graduação em Energia, Universidade de São Paulo. São Paulo. 2023.

As mudanças climáticas são um dos desafios de sustentabilidade mais significativos de nossos tempos. Melhorias no reporte de emissões de GEE podem aumentar a credibilidade nas reivindicações de redução de emissões de GEE, o que é fundamental para combater as mudanças climáticas e promover a neutralidade de carbono. O principal objetivo desta tese é melhorar o reporte de emissões de GEE relacionadas à energia, metodologicamente e por meio de normalização, combinando a contabilidade de emissões de GEE e avaliação de desempenho energético com indicadores, considerando seus pontos fortes e desafios subjacentes. Foram realizadas duas revisões sistematizadas. A primeira destacou que um dos desafios na contabilização das emissões de GEE relacionadas à energia estava relacionado à representação do uso de energia. Uma solução possível identificada seria incorporar a avaliação de desempenho energético com indicadores. A segunda revisão identificou que, na avaliação do desempenho energético, a compreensão adequada das modelagens energéticas dos IDE e dos tipos de reporte dos IDE é essencial para aumentar a consciência das capacidades e limitações dos IDE na obtenção de uma representação efetiva do desempenho energético. Considerando esses fundamentos, a proposta desta tese combina a contabilização das emissões de GEE relacionadas à energia e a avaliação do desempenho energético com indicadores para superar as barreiras identificadas e melhorar o reporte de emissões de GEE relacionados à energia. O método proposto visa melhorar essas estimativas adotando dados de atividade que representem adequadamente o consumo de energia e usando linhas de base de comparação adequadas. O valor do IDE em um determinado tipo de reporte atende à necessidade dos dados de atividade, enquanto uma modelagem energética do IDE é uma linha de base adequada para comparação desse dado de atividade. Um estudo de caso no setor de refino de petróleo é desenvolvido para aplicar a combinação de métodos proposta. O método proposto produz resultados mais consistentes do que outras abordagens simplificadas. Finalmente, do ponto de vista da normalização, as oportunidades de alinhamento são delineadas em uma combinação mais ampla dos dois processos (avaliação de desempenho energético com indicadores com contabilidade de emissões de GEE relacionadas à energia) em termos de orientação, incluindo também um dado de atividade e uma linha de base adequados. A implementação dessas oportunidades poder seguir diferentes caminhos, desde anexos informativos em normas que abordam esses temas até uma norma/guia de orientação.

**Palavras-chave**: Contabilidade de emissões de GEE, reporte de emissões de GEE, avaliação de desempenho energético, IDE, modelagem energética, normalização.

## FIGURE LIST

# TABLE LIST

## ACRONYMS AND ABBREVIATIONS LIST

| | |
|---|---|
| AC | Action cycle |
| AD | Activity data |
| AFOLU | Agriculture, forestry, and other land use |
| API | American Petroleum Institute |
| BEV | Battery electric vehicle |
| BP | Belonginess percentage |
| BTU | Bitumen treating unit |
| CCS | Carbon capture and storage |
| CD | Committee draft |
| CDM | Clean Development Mechanism |
| CDU | Crude distillation unit |
| CF | Carbon footprint |
| COP | Conference of the Parties |
| CRU | Catalytic reforming unit |
| CUSUM | Cumulative sum |
| DCU | Delayed coking unit |
| DEA | Decomposition analysis |
| DIS | Draft of international standard |
| EBM | Evidence-based medicine |
| EBP | Evidence-based practice |
| EC | Exploratory cycle |
| EEI | Energy efficiency index |
| EF | Emission factor |
| EII | Energy intensity index |

| | |
|---|---|
| EmI | Emission indicator |
| EnB | Energy baseline |
| EnMS | Energy Management System |
| EnPI | Energy performance indicator |
| EPIA | Energy performance improvement action |
| FDIS | Final draft of international standard |
| fs | Fuel share |
| GC | Global citations |
| GHG | Greenhouse gas(es) |
| HGU | Hydrogen generation unit |
| IEA | International Energy Agency |
| IoT | Internet of things |
| IPCC | Intergovernmental Panel on Climate Change |
| IPMVP | International performance measurement and verification protocol |
| ISO | International Organization for Standardization |
| ISO/TC | ISO Technical Committee |
| ISO/TC/SC | Subcommittee of an ISO/TC |
| ISO/TR | ISO Technical Report |
| LC | Local citations |
| LCA | Life cycle assessment |
| LMDI | Log Mean Divisia Index |
| LPG | Liquefied petroleum gas |
| LPGRU | LPG recovery unit |
| LR | Linear regression |
| MBN | Million British Thermal Unit per Thousand barrels per Energy Factor |
| MBTU | Million British Thermal Units |

| | |
|---|---|
| MCP | Multiple country production |
| MLR | Multiple linear regression |
| NLR | Non-linear regression |
| NRGF | Energy factor |
| NZE | Net zero |
| NZEB | Nearly zero energy building |
| PDCA | Plan-Do-Check-Act |
| PR | Page-rank |
| PWI | Preliminary work item |
| SCP | Single country production |
| SEC | Specific energy consumption |
| SEU | Significant energy use |
| SJR | SCImago Journal Rank |
| SNIP | Source Normalized Impact per Paper |
| TC | Total citations |
| TLS | Total link strength |
| TS | Time slice |
| UNEP | United Nations Environment Programme |
| UNFCCC | United Nations Framework Convention on Climate Change |
| VDU | Vacuum distillation unit |
| WD | Work draft |
| WoS | Web of Science |

## SUMMARY

# 1 INTRODUCTION

This work compiles findings from different articles developed by the author. Table 1.1 shows the status of those articles by the submission of this thesis's original version. The overall objective of this set of articles is to present, by different methodological approaches, how GHG emission accounting and energy performance evaluation with indicators can be combined to improve energy-related GHG emission reporting.

Table 1.1 – Status of the articles composing this thesis

| Chapter | Article | Journal | Status |
|---|---|---|---|
| 3 | Energy-related greenhouse gas emissions: a review of accounting methods | Journal of Cleaner Production | Submitted |
| 4 | Evaluation of energy performance: a review of indicator definitions and associated methods | Applied Energy | Submitted |
| 5 | Improving energy-related carbon emissions reporting by evaluating energy performance with indicators – A case study on petroleum refining sector | - | Under development |
| 6 | Aligning standardization movements in GHG and Energy management to improve energy-related carbon emissions reporting | - | Under development |

Source: Author's elaboration

The first article conducts a systematized review of scientific publications on energy-related GHG emissions accounting methods. The second article shows a systematized review of scientific publications related to indicator definitions and associated methods for evaluating energy performance. In both cases, the scientific articles have been investigated to analyze the current state of scientific research and trends, define the relevant conceptions, premises, and features, determine the challenges reported, and identify possible solutions to these issues.

Considering these methodology foundations regarding energy-related GHG emission accounting and energy performance evaluation with indicators from the first and second articles, the third proposes combining both tools, understanding their limitations and challenges, to overcome identified barriers and improve energy-related GHG emission reporting.

The last article undertakes a different methodological perspective to present the author's participation in national and international standardization activities related to energy performance evaluation with indicators. It proposes aligned GHG and Energy Management standardization movements to improve energy-related carbon emissions reporting.

The remaining sections of this introduction present the aim of this research, its objectives, and questions, as well as some thoughts regarding the originality of this work. Chapter 2 comprehensively discusses elements of research methodology and how they are applied in this thesis, as well as some details on research methods. Chapters 3, 4, 5 and 6 reproduce the article contents, with adjustments to better fit into the overall thesis structure. Chapter 7 presents overall conclusions, drawing some elements from each previous chapter. Finally, after the References section, APPENDIX A, APPENDIX B, and APPENDIX C concentrate on additional material pulled from Chapters 3, 4, and 5 making the thesis's main body more streamlined.

## 1.1 Research aim, objectives, and questions

Energy performance indicators usually assist in energy performance evaluation. Different types of energy performance indicators can be established, but the decision process for adopting the indicator needs to be clarified for organizations. Organizations perceive that the difficulty in choosing an adequate energy performance indicator can negatively impact improving energy performance. An organization's energy performance improvement can be translated as reducing its greenhouse gas (GHG) emissions, but this association is not clearly established. The challenges in associating energy consumption with GHG emissions reduce the transparency in the reported emissions announced by the organizations. Finally, credibility in GHG emission reduction claims by organizations is fundamental for combating climate change and the movement toward carbon neutrality. These concatenated and intricated thoughts motivated the development of this work. Detailed motivation and relevance of each element of this thesis are presented in the Introduction section of their respective chapters.

The aim of this research is "to improve energy-related GHG emission reporting, methodologically and through standardization, by combining GHG emission accounting and energy performance evaluation with indicators, considering their underlying strengths and challenges". This overall element can be dismembered into specific objectives such as:

- Identify the current state and trends, strengths, and challenges of GHG emission accounting.
- Identify the current state and trends, strengths, and challenges of energy performance evaluation with indicators.
- Elaborate a combined proposal, using strengths and challenges of both GHG emission accounting and energy performance evaluation with indicators, to improve energy-related GHG emission reporting.
- Transpose of the findings from this combined proposal into a standardization movement.

Consequently, these specific objectives can be translated into questions and secondary questions:

- "Focusing on energy-related emissions, what are the current state and trends on approaches adopted to greenhouse gas emissions accounting?" – Answered in Chapter 3.
    - Q1 – "In general, what are the current state and trends on approaches adopted to greenhouse gas emissions accounting?"
    - Q2 – "Considering these approaches, what are the ones adopted when evaluating energy-related emissions?"
    - Q3 – "Considering these approaches on energy-related emissions, what are the factors reflecting energy that are considered?"
- "What are the current state and trends on approaches adopted to energy performance improvement evaluation using indicators?" – Answered in Chapter 4.
    - Q1 – "In general, how are energy performance indicators applied?"
    - Q2 – "Considering these applications, what are adopted for energy performance improvement evaluation?"
    - Q3 – "Considering these indicators, how are they defined (reporting type and calculation method)? Are there elements of energy management or energy saving projects present?"

- "What are the challenges in GHG emission accounting that energy performance evaluation with indicators can overcome and improve energy-related GHG emission reporting?" – Answered in Chapter 5.
- "What are the current standardization movements in GHG management and Energy management that can be triggered to promote their integration and improve energy-related GHG emission reporting?" – Answered in Chapter 6.

## 1.2 Originality

Two main originality aspects are present in this work. The first is to effectively propose integrating two major methodological approaches usually observed as complementary but lacking literature reinforcing their synergies to overcome their challenges with their strengths.

The second is methodological since this thesis encompasses two research processes. Following Chapters 3, 4, and 5, the first research process is based on a pragmatic hypothetico-deductive stance, axiologically unbiased with a detached researcher, ontologically realistic, and epistemologically objective.

On the other hand, embracing the last five years of experiences in national and international standardization forums, Chapters 6 reproduce the second research process following a critical realistic abductive stance, axiologically biased with a participant researcher, ontologically realist (critic realism), and epistemologically constructionist.

These two research processes converge into the same proposal but with different approaches. Therefore, under the standardization perspective, the combination of these approaches could be called Evidence-based Standardization, paralleling Evidence-based Medicine and Evidence-based Practices, covered in the methodology section.

# 2 RESEARCH METHODOLOGY

This Chapter presents the research methodology employed during the development of this thesis. Subsection 2.1 outlines research methodology considerations, applying them to describe this thesis's overall approach and how the Chapter 3, Chapter 4, Chapter 5, and Chapter 6 research content are articulated together, as reported in Subsection 2.2.

Despite this work structure being a compilation of findings from different articles, those reported in Chapter 3 – ACCOUNTING ENERGY-RELATED GREENHOUSE GAS EMISSIONS – and Chapter 4 – EVALUATING ENERGY PERFORMANCE WITH INDICATORS – share the same methods. For brevity, their method sections have been condensed into Subsection 2.3, which describes the combined methods used for systematized literature review and bibliometric analysis.

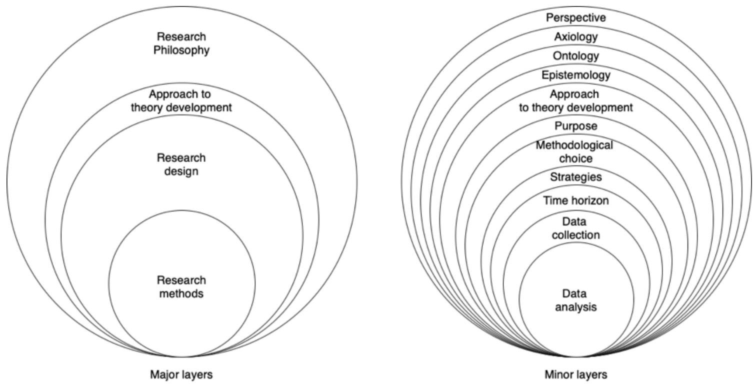
The research development reported in Chapter 5 – COMBINING GHG EMISSION ACCOUNTING AND ENERGY PERFORMANCE INDICATORS – is based on Chapter 3 and Chapter 4 findings, which are combined, discussed, and used in an application example. Finally, Chapter 6 – STANDARDIZATION ASPECTS RELATED TO GHG EMISSION ACCOUNTING AND ENERGY PERFORMANCE EVALUATION transposes the discussions and conclusions from Chapter 5 within a standardization process.

## 2.1 Research methodology considerations

This subsection discusses research methodology considerations. The terminologies methodology and method are sometimes used interchangeably, but to be more precise, there are some distinctions between them. More specifically, method refers to a technique or procedure used to collect and analyze data, whereas methodology is the theory that guides how research should be conducted. Using the term design rather than methodology, when appropriate, clarifies that methods refer to techniques or procedures, helping avoid misleading interpretations (SAUNDERS; LEWIS; THORNHILL, 2019).

This subsection discussion starts with an even broader aspect, research philosophy. The research aspects, from research philosophy to practical techniques and procedures, can be schematized in the diagram of Figure 2.1, using the concept of research 'onion' presented by (SAUNDERS; LEWIS; THORNHILL, 2019). At the end of this subsection, the relationships between research philosophy, research design, and research method are schematized using the conceptual map of Figure 2.10. Finally, a content summary of each research 'onion' layer is presented in Table 2.4.

Figure 2.1 – Research' onion' concept




Source: Author's elaboration based on (SAUNDERS; LEWIS; THORNHILL, 2019)

### 2.1.1 Research problem, questions, and hypotheses

Research is a popular term used in daily activities such as collecting facts or information without a defined objective and reassembling and reordering facts or information without interpretation. Even though research frequently comprises these gathering of information processes, research is, scientifically speaking, a systematic process done with a specific objective to answer a research question or solve a research problem. Consequently, before starting a research process, the researcher needs to define a research topic and express it in terms of a research question(s), related research aim, and set of research objectives (SAUNDERS; LEWIS; THORNHILL, 2019; SHEHZAD, 2011).

The central/general research question is the focal point of a research project, influencing the literature to be reviewed, the research design and methods, and the way the research is delivered. Additionally, given that a clear set of conclusions is a key indicator of a successful research process, developing a straightforward research question is the first step in this direction. The research question can be translated as a statement of purpose, also called research aim and central/general research objective, stating what is intended to be achieved through the research process. Moreover, the research question may derive more detailed questions, also known as secondary questions, that can also be used as a set of secondary research objectives. Finally, the researcher can state an expected or predicted answer to a research question as a hypothesis, which shall be assessed during the research process (SAUNDERS; LEWIS; THORNHILL, 2019; SHEHZAD, 2011).

### 2.1.2 Research philosophies

Research philosophy connects knowledge development and its nature, carrying significant assumptions from the researcher's viewpoint and serving as the foundation for research design and research methods. Research philosophy discussions often follow three primary paradigms: epistemology, ontology, and axiology (OKESINA, 2020; ŽUKAUSKAS; VVEINHARDT; ANDRIUKAITIENĖ, 2018).

Epistemology discusses the knowledge nature and what constitutes acceptable knowledge, considering the object and the subject. Epistemologically, meaning is either intrinsic to an object (objectivist), constructed between the object and the subject (constructivist), or exists within the subject (subjectivist). Ontology concerns the nature of reality, with social phenomena' natures as entities. Ontologically, reality can be unique, as in naïve realism, or multiple, as in relativism. Finally, axiology examines the nature and role of values and ethics, to which extent they impact the research and the role and relation between researcher and research. Therefore, axiologically, a perspective can be value-free and unbiased, value-laden and biased, or value-driven, combining the previous ones (OKESINA, 2020; ŽUKAUSKAS; VVEINHARDT; ANDRIUKAITIENĖ, 2018).

Research philosophy perspectives can be distinguished according to their underlying assumptions on the continuum of objectivism and subjectivism. Objectivism embraces natural science assumptions, characterized by a realist ontology, an epistemology centered on discovering truth through observable, measurable facts, and a value-free, detached axiology. Subjectivism includes artistic and humanistic principles, entailing a relativist ontology, an epistemology centered on opinions, narratives, interpretations, and perceptions, and a value-bound, reflexive axiology. There are several evolving perspectives of research philosophies, but four are frequently discussed: positivism, interpretivism, critical realism, and pragmatism (MCBRIDE; MISNIKOV; DRAHEIM, 2022; TURYAHIKAYO, 2021).

The positivistic research philosophy holds that only sensory-observed facts are reliable. Thus, researchers collect and analyze data using objective approaches, and research findings are quantified. Consequently, positivism relies on statistically studied quantifiable observations as human interpretation is not permitted because the researcher is not considered a part of the research (MCBRIDE; MISNIKOV; DRAHEIM, 2022; MOON; BLACKMAN, 2014; TURYAHIKAYO, 2021; ŽUKAUSKAS; VVEINHARDT; ANDRIUKAITIENĖ, 2018).

On the contrary, interpretivism requires researchers to comprehend the differences between humans in our role as social actors. People are social actors who interpret the world; hence things and people are distinguished. These interpretations shape the researcher's worldview and conduct. Interpretivists are often interdependent with their research, and findings interpretation can contribute to reliability issues. Despite this, it is frequently not the objective to generalize but rather to bring intriguing new insights into a specific environment (MCBRIDE; MISNIKOV; DRAHEIM, 2022; MOON; BLACKMAN, 2014; ŽUKAUSKAS; VVEINHARDT; ANDRIUKAITIENĖ, 2018).

Positivism and interpretivism are the two most well-known research philosophies, with each extreme mutually exclusive paradigms about knowledge nature and source. However, certain aspects can come under the heading of both philosophies. For example, whichever approach a researcher chooses, a clear set of findings needs to be produced, and its validity must be justified (MCBRIDE; MISNIKOV; DRAHEIM, 2022; MOON; BLACKMAN, 2014; ŽUKAUSKAS; VVEINHARDT; ANDRIUKAITIENĖ, 2018).

According to pragmatic research philosophy, the research question is the most crucial determinant of the research philosophy. Therefore, pragmatism is slightly different from other philosophies in that action must come before theory, knowledge, or understanding, as it is only possible to attain these via action. Consequently, pragmatism lies somewhere in between positivism and interpretivism, as critical realism (ELDER-VASS, 2022; KHIN; FUI, 2012; MCBRIDE; MISNIKOV; DRAHEIM, 2022; MOON; BLACKMAN, 2014).

Critical realism is a philosophical perspective in which manifestations of the real world, rather than the real world itself, are experienced, resulting in a layered reality. This stratified ontology includes the Empirical, events that are witnessed or experienced; the Actual, events and non-events generated by the Real that may or may not be observed; and the Real, causal structures and mechanisms with enduring features. In addition, it combines the positivist view that reality is objective with the interpretivist notion that knowledge of reality is socially constructed (ELDER-VASS, 2022; HEEKS; OSPINA; WALL, 2019; KHIN; FUI, 2012; LAWANI, 2021).

Therefore, while critical realism appropriates paradigms from positivists and interpretivist, pragmatism stays orthogonally at this spectrum, claiming from whatever is relevant to support action and produce useful knowledge. Despite that, some contend that critical realism and pragmatism are comparable, even recognizing their confluence as a distinct research perspective: pragmatist-critical realism, based on the socially constructed experience of the manifestations of an external, independent reality that seeks to provide pragmatic and liberating solutions to research topics (ELDER-VASS, 2022; HEEKS; OSPINA; WALL, 2019; KHIN; FUI, 2012; LIPSCOMB, 2011).

Research philosophy perspectives and associated ontological, epistemological, and axiological assumptions are summarized in Table 2.1.

Table 2.1 – Research philosophy perspectives and associated ontological, epistemological and axiological assumptions

| Perspective | Axiology | Ontology | Epistemology |
|---|---|---|---|
| Positivism | - Detached observer<br>- Value-free and unbiased | - Unique, real external, interdependent<br>- Naïve realism | - Objectivist<br>- True and accurate findings |
| Interpretivism | - Active interpreter<br>- Value-bound and biased | - Complex, rich, socially constructed<br>- Relativism | - Subjectivist<br>- Created findings, understanding different perspectives |
| Critical realism | - Active interpreter<br>- Value-driven | - Layered, external, independent<br>- Realism | - Subjectivist<br>- Value-mediated findings, as accurate as possible |
| Pragmatism | - Active interpreter<br>- Value-driven | - Complex, rich, practical consequence - Realism and/or Relativism | - Objectivist and/or Subjectivist<br>- Value-relational, findings as result of action |

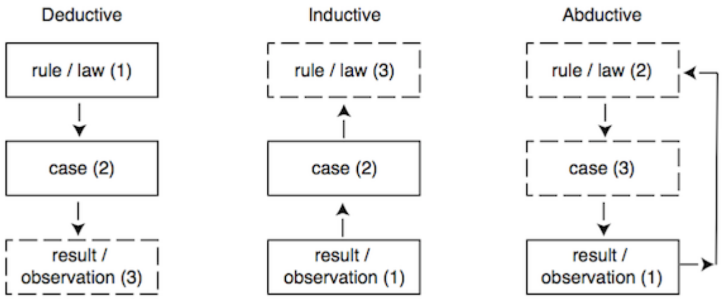
Source: Author's development based on (MCBRIDE; MISNIKOV; DRAHEIM, 2022; OKESINA, 2020; SAUNDERS; LEWIS; THORNHILL, 2019; WILSON, 2014; YUCEL, 2018; ŽUKAUSKAS; VVEINHARDT; ANDRIUKAITIENĖ, 2018)

### 2.1.3 Research approaches for theory development

Deduction, induction, and abduction are the primary research approaches to theory development. The deduction is an analytical theory-testing process, considering a theory already established, generating hypotheses, and designing a strategy to test the hypotheses' validity. In contrast, induction is a synthetic theory-generating process, beginning with prior evidence (such as observations of specific cases) and aiming to generalize the investigated issue. Finally, abductive research is a synthetic theory-elaborating process, exploring phenomena and generating new theories (or modifying existing ones), which are subsequently tested, often through new observations (HOUSER; KLOESEL, 1992; MARCH, 1976).

A first scheme to represent and compare deductive, inductive, and abductive processes, based on (FISCHER, 2001), is presented in Figure 2.2. It includes evaluating the sequence of elements, from those that are supposed to be true (solid boxes in Figure 2.2) to those that are inferred (dashed boxes in Figure 2.2) (KIM; LEE, 2019).

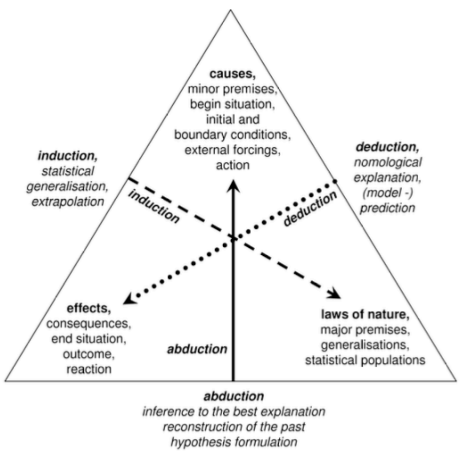
Figure 2.2 – Research approaches to theory development based on rules, cases and results/observations




Source: (FISCHER, 2001)

A second scheme, based on (KLEINHANS; BUSKES; DE REGT, 2010), represent the different relations of research approaches to laws, causes, and effects, where two of them (an edge of a triangle) are used to infer the third (opposite vertex of the referred edge), as schematically depicted in Figure 2.3.

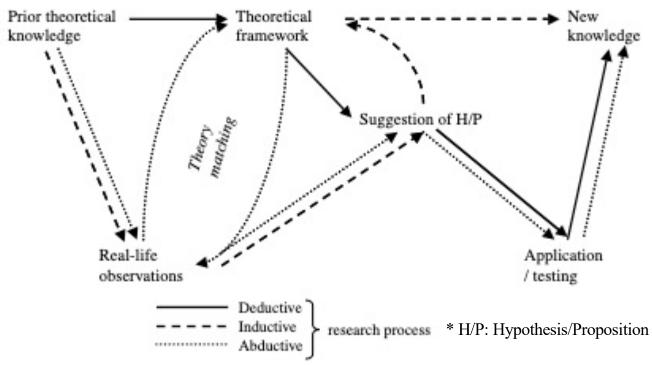
Figure 2.3 – Research approaches for theory development based on causes, effects, and laws




Source: (KLEINHANS; BUSKES; DE REGT, 2010)

Also, abduction is classified as selective/explanatory, where a plausible cause is inferred from known rules and effects, or creative/innovative, where only effects are known, and both rules and causes are inferred. This last concept might indicate a problem regarding the relation of two elements determining the third one, but it is compatible with the synthetic abduction process (KROLL; KOSKELA, 2016; LAMÉ; YANNOU; CLUZEL, 2018; MARCH, 1976). Using the research process illustrated in Figure 2.4, in innovative abduction, a theory is inferred from known observations and then evaluated in theory matching iterative process to arrive at the suggestion of a hypothesis or proposition (SPENS; KOVÁCS, 2006).

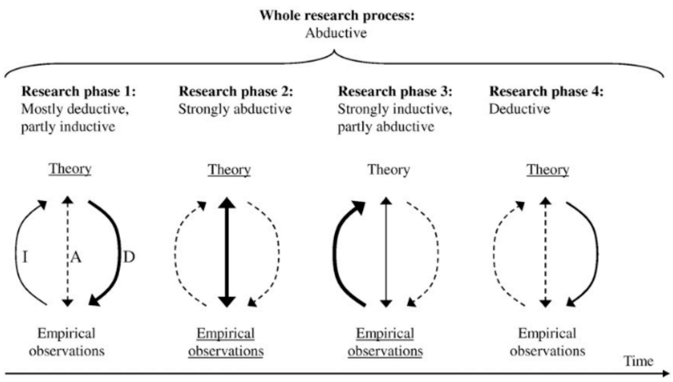
Figure 2.4 – Research process according to approaches to theory development




Source: (SPENS; KOVÁCS, 2006)

Moreover, Peirce concept of abduction can comprehend two overlapping meanings (HOUSER; KLOESEL, 1992), as discussed by (CHIASSON, 2005). The first meaning is straightforward, an inferring process distinct from deduction and induction, while the second is an umbrella concept covering the cycle of abduction-deduction-induction. Some authors use abduction when referring to both meanings, as illustrated in Figure 2.5, while others refer to the umbrella concept as retroduction, particularly critical realists (CHIASSON, 2005).

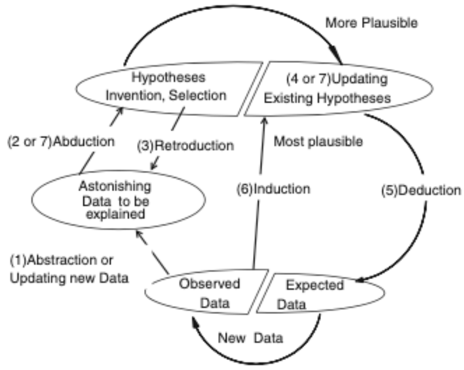
Figure 2.5 – Example of an abductive research process over time




Source: (JÄRVENSIVU; TÖRNROOS, 2010)

Conversely, as presented by (OH, 2012), another interpretation of Peirce's concept of abduction would lead to the following components: a hypothesis-projection (abduction) and a hypothesis-testing (retroduction) (RESCHER, 1978; RITZ, 2020; ZIMRING, 2019). These components are coupled, so observation leads to explanatory hypotheses, which are then tested in observation, as presented in Figure 2.6, somehow approaching the concept of "theory matching" included in Figure 2.4.

Figure 2.6 – Example of an abductive research process cycle




Source: (OH, 2014)

Research philosophy perspectives and associated research approaches to theory development are summarized in Table 2.2.

Table 2.2 – Research philosophy perspectives and associated research approach to theory development

| **Perspective** | **Approach to theory development** |
|---|---|
| Positivism | Deductive |
| Interpretivism | Inductive |
| Critical realism / Pragmatism | Deductive, Inductive, and/or Abductive |

Source: (OH, 2012; SAUNDERS; LEWIS; THORNHILL, 2019; SPENS; KOVÁCS, 2006; WILSON, 2014)

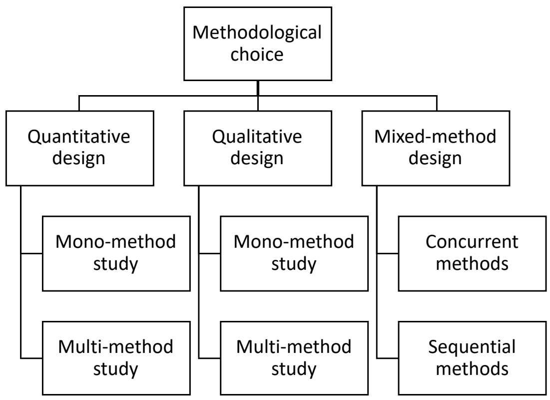
### 2.1.4 Research design and research methods

Despite the close relationship between research design and research methods, there is a distinction (ABUTABENJEH; JARADAT, 2018; SAUNDERS; LEWIS; THORNHILL, 2019). As summarized by (YIN, 2014), the first is logical, whereas the second is logistical, i.e., design is the plan, while the method is the way to plan execution. The research design process transforms the research question into a research project by incorporating its purpose, methodological choices, strategies, and time horizon coherently (SAUNDERS; LEWIS; THORNHILL, 2019).

According to the research purpose, a research design may fall into three categories: exploratory, descriptive, and explanatory (also known as causal or correlational). Exploratory research is a valuable means of finding new insights and assessing a study subject to clarify the understanding or the nature of the problem. Descriptive research aims to portray an accurate profile of a study object, being an extension of, or a forerunner to, another piece of research. For example, a research project may utilize description as a precursor to explanation (descripto-explanatory research). Finally, explanatory research emphasizes studying a situation or problem to explain the relationships between variables and establish causal relationships (PONTE et al., 2007).

The methodological choices involved in research comprise choosing from quantitative, qualitative, or mixed-method designs. The first two consider conducting the studies through either mono- or multi-method structures. In contrast, the later methodological choice combines quantitative and qualitative methods, as presented in Figure 2.7.

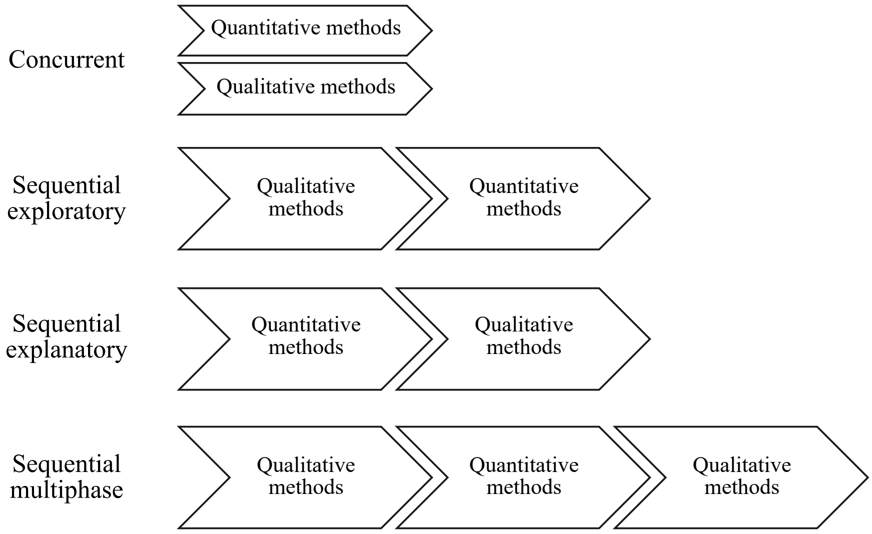
Figure 2.7 – Methodological choice options




Source: Author's elaboration based on (SAUNDERS; LEWIS; THORNHILL, 2019)

This combination in mixed-method designs can be structured in multiple ways, including concurrent, sequential exploratory, sequential explanatory, and sequential multiphase, as presented in Figure 2.8. In addition, mixed methods can also be fully or partially integrated based on the extent to which mixed methods are used throughout the research stages. Lastly, merging methods involves quantitizing qualitative or qualitizing quantitative data, which is much more common than the former. While combining methods, there is a risk that the relative value of each kind of data may be diminished. Hence care should be taken when merging them (PONTE et al., 2007).

Figure 2.8 – Mixed-methods combinations in research design




Source: (SAUNDERS; LEWIS; THORNHILL, 2019)

Possible research strategies include an experiment, survey, archival and documentary research, case study, ethnography, action research, grounded theory, and narrative inquiry. The first two are primarily associated with quantitative research, while the last four with qualitative. For example, the archival and documentary research and case study may entail quantitative, qualitative, or mixed-method design. Given the variety of qualitative research strategies, with their contrasting characteristics, the decision between qualitative research strategies is likely to generate the most difficulty. The most important key to selecting a research strategy (or strategies) is that a reasonable level of coherence throughout the research design is achieved, enabling answering the research question(s) and meeting the objective(s) (PONTE et al., 2007).

Finally, another research design element is its time horizon, which characterizes its relationship with time. For example, if the objective is to investigate a subject at a particular time, the design has a time horizon called cross-sectional. In contrast, the time horizon is called longitudinal if it should represent events over a period.

After designing, i.e., planning the research, it is necessary to outline a way to implement it by adopting methods for data collection and, subsequently, data analysis. The data collection comprises but is not limited to, interviews, questionnaires, observation, and secondary data. The data analysis includes, among others, descriptive statistics, inferential statistics, grounded theory, narrative analysis, discourse analysis, visual analysis, and content analysis (PONTE et al., 2007).

The relationship between the previously discussed research philosophy perspectives and research design elements (purposes, methodological choices, and strategies) is presented in Table 2.3. The time horizon classifications presented can be applied to either, being more related to the research problem.

Table 2.3 – Research philosophy perspectives and relation to purposes, methodological choices and strategies

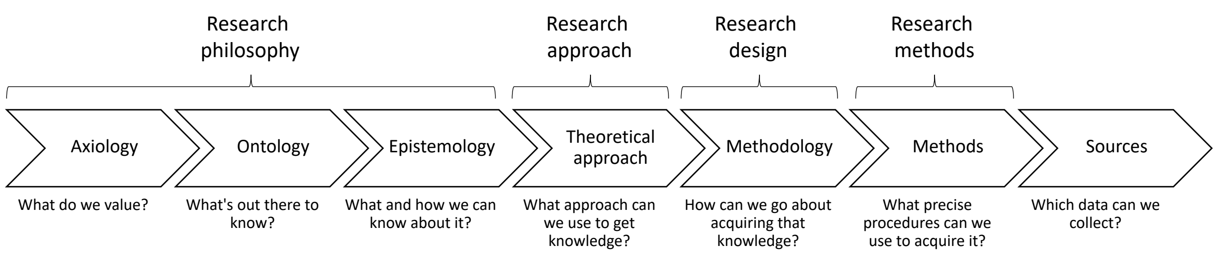
| **Perspective** | **Purpose** | **Methodological choice** | **Strategies** |
|---|---|---|---|
| Positivism | Descriptive<br>Explanatory | Quantitative | Experimental, Survey, Case study |
| Interpretivism | Descriptive<br>Exploratory | Qualitative | Case study, Action research, Grounded theory, Ethnography |
| Critical realism / Pragmatism | Descriptive<br>Explanatory<br>Exploratory | Quantitative<br>Qualitative<br>Mixed methods | Experimental, Survey, Case study, Action research, Grounded theory, Ethnography, Archival and documental research |

Source: Author's elaboration based on (JAKSIC; SILIC; SILIC, 2021; MAXWELL; MITTAPALLI, 2010; MCBRIDE; MISNIKOV; DRAHEIM, 2022; OKESINA, 2020; SAUNDERS; LEWIS; THORNHILL, 2019; WILSON, 2014)

### 2.1.5 Summary on research methodology

After presenting research methodology through paradigms on philosophy, approach, design, and methods, this subsection aims to summarize this information and create an insightful conceptual map to connect all these elements. First, it is possible to adapt Grix's paradigmatic building blocks (GRIX, 2002), similarly to work done by (BROWN; DUEÑAS, 2020), to cover all elements discussed previously, resulting in Figure 2.9.

Figure 2.9 – Research paradigm building blocks and their relation to the research process




Source: Author's elaboration based on (BROWN; DUEÑAS, 2020; GRIX, 2002)

Each paradigmatic building block from Figure 2.9 is a macro and micro layer of the research ‘onion’ concept presented in Figure 2.1 having their content summarized in Table 2.4.

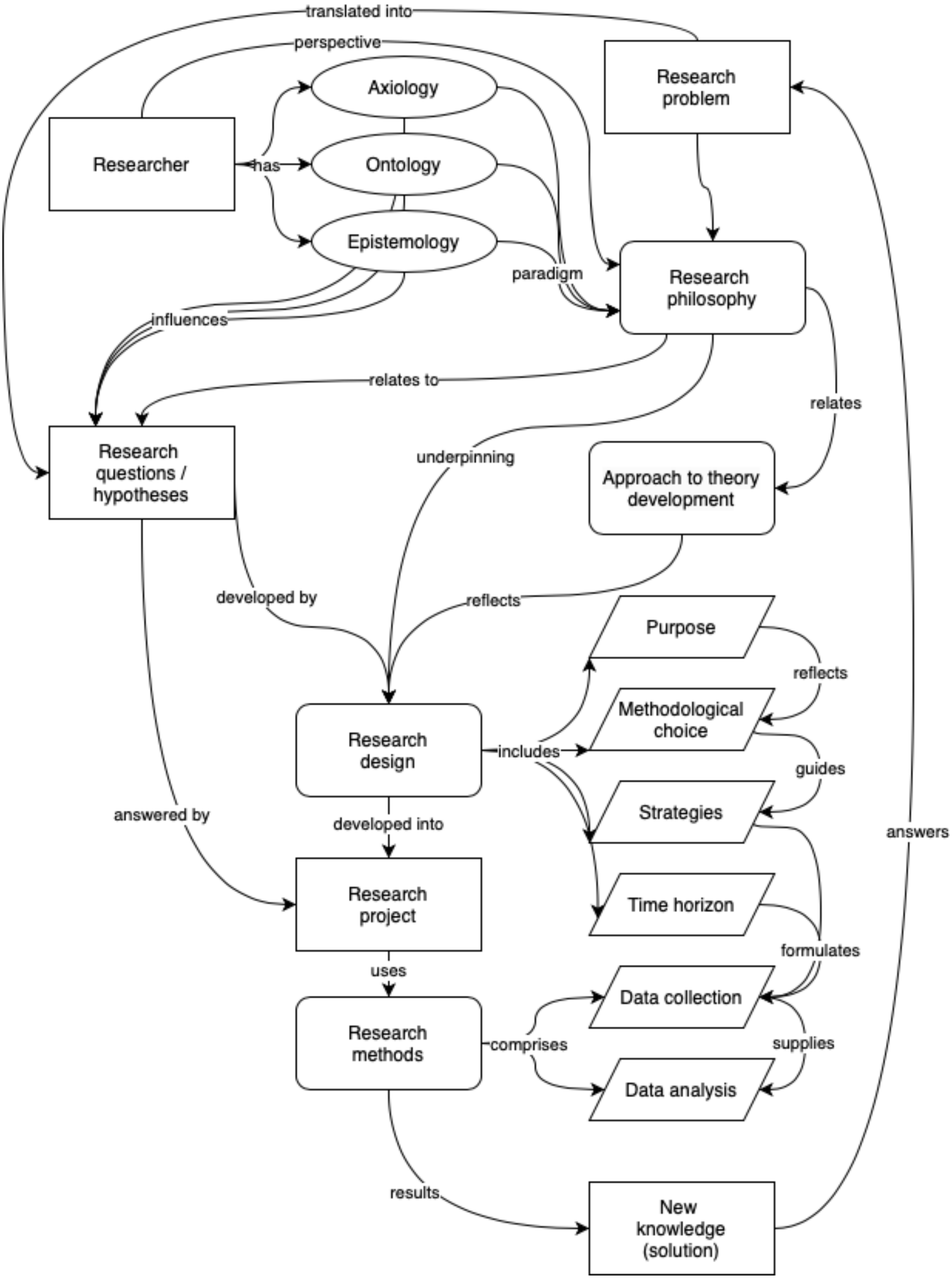
Table 2.4 – Content summary of each research’ onion’ layer

| **Research’ onion’ layers** | | **Contents** |
|---|---|---|
| **Macro** | **Micro** | |
| Philosophy | Perspective | Positivism, Interpretivism, Critical realism, and Pragmatism |
| | Axiology | Value-free, Value-bound, Value-neutral, Value-laden, and Value-driven; Biased and Unbiased |
| | Ontology | Realism and Relativism |
| | Epistemology | Objectivist, Constructionist, and Subjectivist |
| Approach to theory development | | Deductive, Inductive, and Abductive |
| Design | Purpose | Exploratory, Descriptive, and Explanatory |
| | Methodological choices | Qualitative and Quantitative: Mono- or Multi-method<br>Mixed method: Concurrent or sequential |
| | Strategies | Experiment, Survey, Case study, Action research, Grounded theory, Ethnography, and Archival and documental research |
| | Time horizon | Cross-sectional and longitudinal |
| Method | Data collection techniques and procedures | Interviews, Questionnaires, Observation, and Secondary data |
| | Data analysis techniques and procedures | Descriptive statistics, Inferential statistics, Grounded theory, Narrative analysis, Discourse analysis, Visual analysis, and Content analysis |

Source: Author’s elaboration based on (JAKSIC; SILIC; SILIC, 2021; MAXWELL; MITTAPALLI, 2010; MCBRIDE; MISNIKOV; DRAHEIM, 2022; OH, 2012; OKESINA, 2020; SAUNDERS; LEWIS; THORNHILL, 2019; SPENS; KOVÁCS, 2006; WILSON, 2014; YUCEL, 2018; ŽUKAUSKAS; VVEINHARDT; ANDRIUKAITIENĖ, 2018)

Finally, an expansion of each paradigmatic building block from Figure 2.9 and their content summarized in Table 2.4 is developed into an insightful conceptual map in Figure 2.10, which underlines the relationships of all these elements, following a first design developed by (PRADEEP, 2021).

Figure 2.10 – Summary of research methodology considerations as a conceptual map

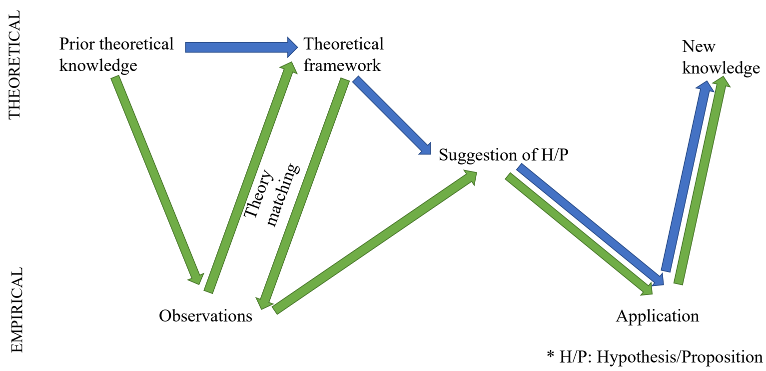



Source: Author’s elaboration based on (PRADEEP, 2021)

## 2.2 Research methodology applied to this thesis

This thesis research methodology is composed of two research processes. The first research process is based on a pragmatic hypothetico-deductive stance, axiologically unbiased with a detached researcher, ontologically realistic, and epistemologically objective. The resulting approach of this first process is deductive, as depicted in blue in Figure 2.11. The second research process follows a critical realistic stance, axiologically biased with a participant researcher, ontologically realist (critic realism), and epistemologically constructionist. The resulting approach of this second process is abductive, as depicted in green in Figure 2.11. Based on these paradigms, both research processes were designed.

Figure 2.11 – Overall research processes in this thesis



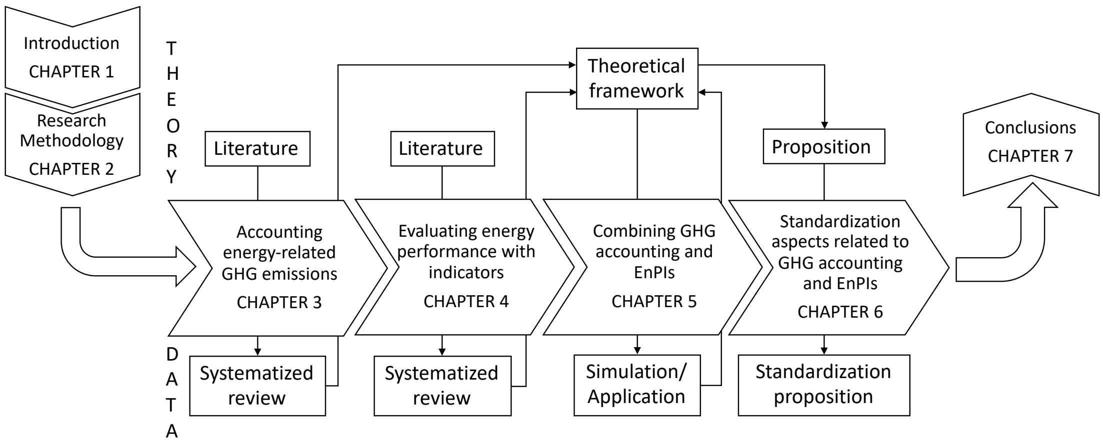

Source: Author's elaboration

The first research design follows a descripto-explanatory perspective, aiming to describe two subjects (Accounting of energy-related GHG emissions and Evaluating energy performance with indicators) and explain their combination's causes and consequences. Consequently, a quantitative multi-method archival and documental research strategy was considered for the descriptive segment, using secondary data from the literature, combining statistical analysis, visual analysis, and content analysis as research methods. Details on these methods are presented in Subsection 2.3. A quantitative mono-method simulation/application strategy was adopted for the explanatory segment, using secondary data from a survey and statistical analysis as research methods. In both segments, the research is longitudinal, each with its timespan.

The second research design follows an exploratory-descriptive perspective, aiming to explore, as a complete participant, a specific environment (Standardization forum related to energy performance evaluation with indicators) and to describe, based on the exploratory experience, how two subjects (Accounting of energy-related GHG emissions and Evaluating energy performance with indicators) can be combined. Consequently, a qualitative mono-method action research strategy was considered, using primary data from observation, combining elements of content and narrative analysis as research methods. The exploratory segment is developed throughout the action research in a longitudinal time horizon. After completing the exploratory cycles, the descriptive segment is a cross-sectional action that describes and suggests a final standardization proposition.

Finally, this thesis's overall structure is presented in Figure 2.12, exhibiting where the development of each research process is reported as well as how the relation of theoretical (theory) and empirical (data) perspectives play a role while building the proposed new knowledge, drawing some connections from the diagram in Figure 2.11.

Figure 2.12 – Overall structure of this thesis




Source: Author’s elaboration

## 2.3 Systematized literature review and bibliometric analysis

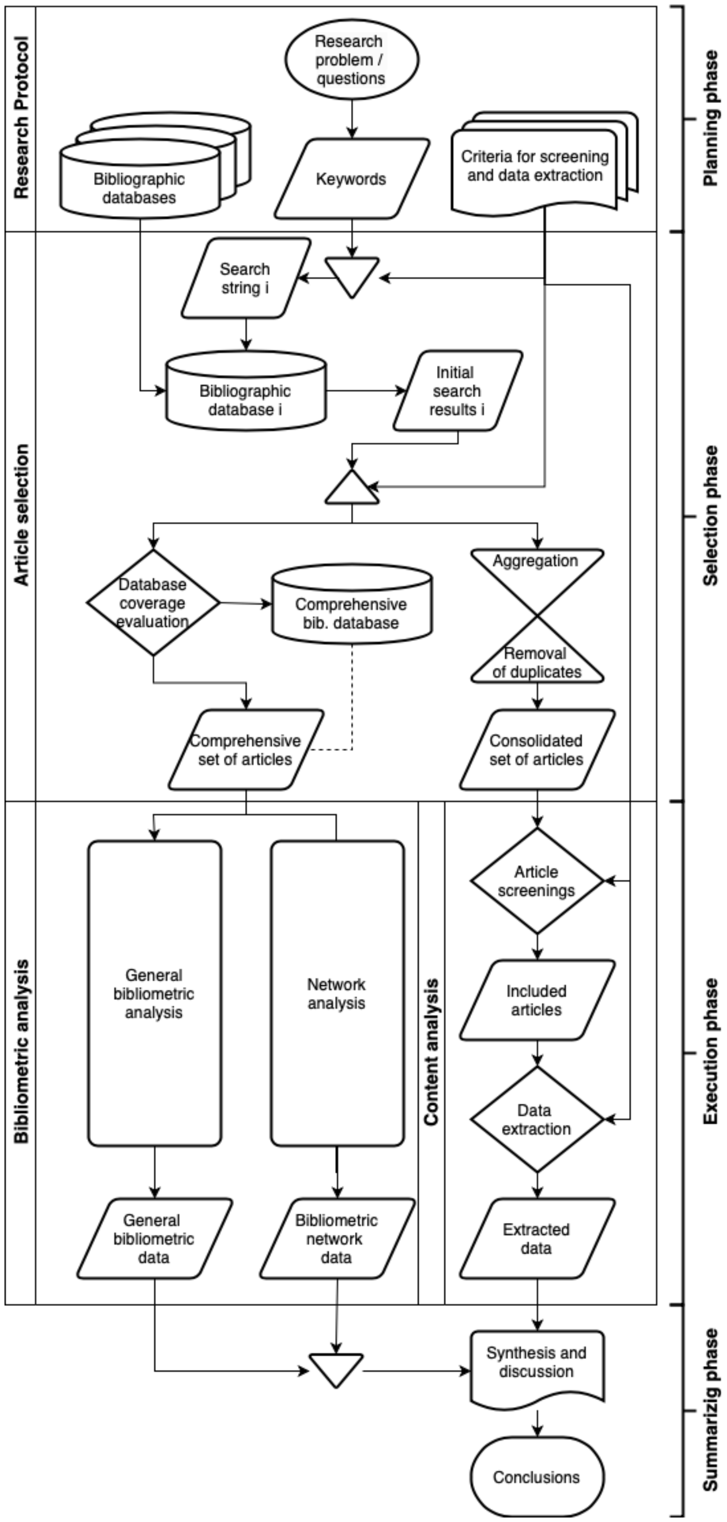
According to (FOSTER; JEWELL, 2017), systematic review processes arose in medical and social sciences in the 1970s. These systematic review processes were then incorporated, in the 1990s, by the notion of Evidence-based Medicine (EBM), “the integration of best research evidence with clinical expertise and patient values” (SUR; DAHM, 2011). Even though systematic reviews are most linked with health sciences disciplines, systematic review methods have been used in various fields outside of medicine. In the early 2000s, management and engineering authors started to advocate using similar research methodologies, and the EBM concept was expanded into EBP (Evidence-based Practice) (PULLIN; STEWART, 2006; TRANFIELD; DENYER; SMART, 2003). Based on EBM, one could state that EBP aims to develop a given topic and associated decision-making based on current best research evidence integrated with practical experience and human values (DYBA; KITCHENHAM; JORGENSEN, 2005; KITCHENHAM; DYBA; JORGENSEN, 2004). Therefore, the systematic review process has a significant role in collecting the so-called current best evidence (BORREGO; FOSTER; FROYD, 2014; HENRY; STIEGLITZ, 2020; JAMES; RANDALL; HADDAWAY, 2016; KITCHENHAM; BRERETON, 2013).

Literature review typologies can be categorized into different main types, and for this work, two are more relevant: a systematic review and a systematized review. The first is known for systematically searching for, evaluating, and synthesizing research evidence, frequently adhering to guidelines on the conduct of a review. The second attempts to incorporate elements of the systematic review process without claiming that the result is a systematic review. In non-health science subjects, the distinctions between these two categories are less frequently highlighted, and "systematic review" may stand out as an umbrella term for reviews that adhere to the features of the systematic review procedure (FOSTER; JEWELL, 2017; GRANT; BOOTH, 2009; SUTTON et al., 2019).

Bibliometric analysis, a term introduced by (PRITCHARD, 1969) to describe procedures that intend to quantify the process of written communication, is one of the most common approaches utilized in systematic and systematized reviews. Bibliometric analysis is a technique that uses a set of quantitative methods to measure, track, and evaluate the metadata of scholarly publications, providing an overview of any research subject. It identifies the authors' publications, the most prestigious journals, the methods employed, and the conclusions reached. The bibliometric analysis includes processing a significant quantity of bibliographic data and is typically assisted by software applications (ELIE; GRANIER; RIGOT, 2021; PRITCHARD, 1969; ROEMER; BORCHARDT, 2015; TANDON et al., 2021).

An overview of the methods of this work regarding the systematized literature review and bibliometric analysis can be seen in Figure 2.13. The main phases involve the development of a research protocol and the process of article selection, followed by bibliometric and content analysis. These steps, together with the discussion and conclusion sections, can be depicted within a systematized review structure, as also shown n Figure 2.13, which includes a planning phase, a selection phase, an execution phase, and a summarizing phase. The following subsections explain each step's procedures, including specific methods and tools applied.

Figure 2.13 – Methods overview for systematized review and bibliometric analysis




Source: Author’s elaboration.

### 2.3.1 Research protocol

The research protocol is the primary outcome of a planning phase in a systematized review process, containing information about implementing all other systematic review phases, namely selection, execution, and summarizing. Therefore, the first step is to define the research problem and related research questions. This is one of the most critical aspects of the systematic review, as the researcher, given the answers to the research questions, will be able to define how and where to act concerning the problem. Then, it is possible to identify appropriate keywords related to the research problem, which will guide the search for related publications and might undergo refinement until the structuring of an adequate string that will result in relevant publications (DOMINKOVIĆ et al., 2022; FABBRI et al., 2016; HERNANDES et al., 2012; REJEB et al., 2022).

The second step is identifying article database sources to be defined and initially selected. There are various bibliographic databases (e.g., Web of Science, Scopus, Dimensions, Google Scholar, Microsoft Academic, PubMed, EMbase, SpringerLink, etc.). Still, not all of them include information that makes bibliometric analysis straightforward. Finding the appropriate database depend on several factors, such as access, scientific coverage, availability of exporting data, and types of exported data (FABBRI et al., 2016; HERNANDES et al., 2012; MARTÍN-MARTÍN et al., 2021; MORAL-MUÑOZ et al., 2020; QIN et al., 2022; SINGH et al., 2021; SRIDHAR et al., 2022). Thus, the present work focuses initially on the most adopted bibliographic databases used in bibliometrics analysis: Web of Science (WoS), Scopus, and Dimensions. More discussion on databases and their appropriateness occur during the selection phase implementation, described in subsection 2.3.2.

The third step is establishing criteria for checks and screenings to which the initial search results will be subjected. For example, when querying a database, the search string might already include general inclusion and exclusion criteria such as publication type, i.e., article, conference paper, book chapter; publication year; publication language. Additional general inclusion and exclusion criteria might be applied later, concerning the available information after database export, for example, checking if author, abstract, and keyword information is present. After being checked, two screenings are applied subsequently (FABBRI et al., 2016; HERNANDES et al., 2012; QIN et al., 2022; REZA et al., 2021; SRIDHAR et al., 2022; WALI et al., 2022).

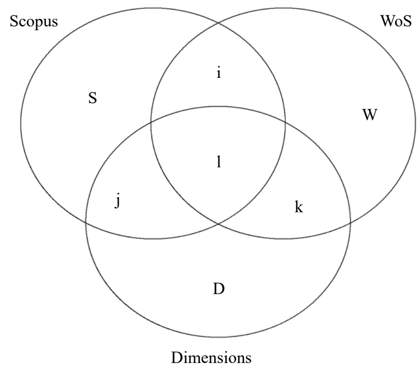
The first screening evaluates whether a given publication will be included in the list of those studied more in-depth, requiring specific inclusion and exclusion criteria. The second classifies the first screened articles according to quality criteria, judging which articles are of insufficient quality to be included in the review synthesis. This screening may assist the data extraction process, helping specify the information extracted from the selected articles. After all the articles that should be included in the review have been identified, the specified information needs to be systematically retrieved from each article (FABBRI et al., 2016; HERNANDES et al., 2012; QIN et al., 2022; SRIDHAR et al., 2022; WALI et al., 2022). The initial search and checks occur during the selection phase’s implementation, as described in subsection 2.3.2. The two screenings and data extraction occurs during the execution phase, described in subsection 2.3.4.

### 2.3.2 Article selection

This phase involves searching and preprocessing the results to be submitted to bibliometric and content analyses. First, within the initially selected databases, the literature is queried using the search strings, which are defined based on keywords and criteria from the research protocol and might be refined to better search results. The result of the initial search process passes through a first check using general inclusion and exclusion criteria from the research protocol, resulting in a preprocessed batch of selected articles for each database. Aggregating bibliometric information exported from multiple sources can be challenging as the availability and format of information that can be exported are limiting factors (ARIA; CUCCURULLO, 2017; MORAL-MUÑOZ et al., 2020). Therefore, these initial search results are analyzed to evaluate these databases’ coverage.

Database coverage is a subject investigated in the literature comparing metrics such as journal coverage (SINGH et al., 2021) and article citation citations (MARTÍN-MARTÍN et al., 2021). First, the initial results obtained are evaluated to assess their overlaps as schematized in Figure 2.14. Then, using an appropriate bibliometric tool, these results are combined pair-wisely, and finally, all of them together, always eliminating duplicates.

Figure 2.14 – Overlapping search results of three bibliographic databases




Source: Author’s elaboration.

Therefore, it is possible to determine each of the variables in Figure 2.14 by solving the following system of linear equations:

$$
\begin{aligned}
&S+i+j+l = \text{Scopus results}\\
&W+i+k+l = \text{WoS results}\\
&D+j+k+l = \text{Dimensions results}\\
&S+W+i+j+k+l = \text{Scopus and WoS combined results}\\
&S+D+i+j+k+l = \text{Scopus and Dimensions combined results}\\
&D+W+i+j+k+l = \text{Dimensions and WoS combined results}\\
&S+D+W+i+j+k+l = \text{Scopus, WoS, and Dimensions combined results}
\end{aligned}
\tag{2.1}
$$

This work will consider using the Pareto Principle (80/20 rule) as a criterion to choose the most comprehensive database by comparing these batches of selected articles. The selected articles from the most comprehensive database will be considered for bibliometric analysis with data visualization. Finally, selected articles are consolidated by combining all selected articles and removing duplicates, which will then be used in content analysis.

### 2.3.3 Bibliometric analysis

The bibliometric analysis with data visualization includes general bibliometric data analysis and network analysis. These two analyses are developed after the appropriate bibliometric data is retrieved from databases in the previous step. Different tools also support the development of these analyses by organizing and extracting analytical data, processing, and clustering data, and elaborating and plotting graphs and networks (Ding & Yang, 2022; Moral-Muñoz et al., 2020; Osinska & Klimas, 2021). The following subsections will present the concepts adopted in this work for general bibliometric data analysis, network analysis, and the tools for these analyses.

#### 2.3.3.1 General bibliometric data analysis

General bibliometric data analysis gives an overview of scientific production over time, relevance, citation, and impact relative to the authors and the sources in the batch of selected articles. It also analyses documents and references, citations and keywords occurrences, and temporal dynamics (ARIA; CUCCURULLO, 2017; ARIA; MISURACA; SPANO, 2020; BELFIORE; CUCCURULLO; ARIA, 2022; GUEDES; BORSCHIVER, 2005; HARZING, 2010; ROEMER; BORCHARDT, 2015; ROJAS-SÁNCHEZ; PALOS-SÁNCHEZ; FOLGADO-FERNÁNDEZ, 2022).

Three fundamental bibliometric laws related to the source, author productivity, and word frequency help develop general bibliometric data analysis. First, Bradford's Law allows estimating the degree of relevance of sources in a study area based on the number of articles from this area published in each source. This law states that successive zones of periodicals with the same number of articles on the subject produce the simple geometric series $1:n:n^2$ (BRADFORD, 1934; BROOKES, 1969; CHEN; CHONG; TONG, 1994; GUEDES; BORSCHIVER, 2005).

Lotka's Law allows for evaluating the relative relevance of the authors considering the number of articles from a study area published by each author. According to Lotka's Law, the relationship between the number of authors and the number of articles they produce in any scientific field follows approximately the Inverse Square Law ($1/n^2$). However, statistical observations about the phenomenon of exponential growth of literature showed that the number of authors decreases faster than the Inverse Square Law, approaching the Inverse Cube Law ($1/n^3$) (GUEDES; BORSCHIVER, 2005; LOTKA, 1926; PAO, 1978; PRICE, 1965; VOOS, 1974).

Finally, Zipf's Laws allow estimating the word occurrence frequency in a scientific text and the region of concentration of keywords. Based on a word occurrence descending list, where the position on the list is the word rank (r), Zipf's Law states that the product of the word rank by the word frequency (f) is approximately constant. Zipf's Law was further developed, stating that high-rank words, i.e., low-occurrence words, have the same frequency. This development is referred to as Zipf-Booth Law or Zipf's Second Law, and consequently the previous one also as Zipf's First Law (BOOTH, 1967; CHEN; LEIMKUHLER, 1990; ZIPF, 1942, 1949). Mathematically, Zipf's Laws are represented as follows:

$$f_w . r_w = \text{constant} \tag{2.2}$$

$$\frac{I_1}{I_n} = \frac{n(n+1)}{c} = \frac{n(n+1)}{2} \tag{2.3}$$

where $r_w$ is the rank of a word w; $f_w$ is the frequency of the word w; $I_1$ is the number of words with frequency 1; $I_n$ is the number of words with frequency n; and c is a constant that is equal to 2 for the English language.

Goffman enhances Zipf's Laws analysis by highlighting that the first law is valid for the high-frequency zone while the second describes the low-frequency zone. Therefore, Goffman proposes a transition point from which lower ranks (higher frequency) words would have higher semantic content, i.e., keywords (GOFFMAN, 1966; GOFFMAN; NEWILL, 1964; GUEDES; BORSCHIVER, 2005; PAO, 1978). The Goffman Transition Point occurs when the words of frequency n tend to one in Equation (2.3), which allows calculating the value of n, as expressed below:

$$n = \frac{-1 + \sqrt{1+4cI_1}}{2} = \frac{-1 + \sqrt{1+8I_1}}{2} \tag{2.4}$$

where $I_1$ is the number of words with frequency one and c is a constant that is equal to 2 for the English language.

In addition to identifying a semantic core of keywords, some visualization approaches help evidence this core and establish a relation to other keywords in relative importance. From the overall ensemble of keywords, keyword treemap and keyword cloud can be adopted as two different ways to visualize them. The keyword treemap displays keywords in a rectangle partitioned proportionally to the keyword occurrence. Each partitioned rectangle usually displays the keyword, its occurrence in absolute, and the percentage of total occurrences. In the keyword cloud, keywords are displayed in a geometric form, usually an ellipse, and the size of the words is proportional to their occurrences. It is a common practice to use functions, such as square root or log, to smooth the difference in size, notwithstanding keeping proportionality (ARIA; CUCCURULLO, 2017; MCDONALD, 2009).

Finally, a third visualization method is considered, using occurrence frequency and time as variables while plotting a trend topic graph. Time is plotted on the horizontal axis, while the keywords are displayed vertically. A bubble is placed on a reference year for each keyword, and its size reflects the keyword occurrence while the reference year is the keyword occurrence distribution median. The horizontal lines for each keyword represent the limits between the first and third quartile of the keyword occurrence distribution (ARIA; CUCCURULLO, 2017).

When analyzing sources, authors, or documents, scientific production's impact is commonly assessed by measuring absolute citation numbers or using indexes or metrics. The most common indexes are the h-index and g-index, which will be detailed below, and although defined focusing on authors, they can also be applied to sources (ARIA; CUCCURULLO, 2017; HARZING; ALAKANGAS; ADAMS, 2014; ROEMER; BORCHARDT, 2015).

The h-index of an author is, as defined by J. Hirsch in 2005, the number that satisfies the two following criteria: h of the author's N articles have at least h citations, and the remaining (N - h) articles have no more than h citations. Thus, the h-index incorporates a measure of quantity (number of articles) and an estimate of quality/impact (citations to these articles). Furthermore, the h-index not only requires that the author publishes many articles but also that they must be cited to count. Hence, the h-index favors authors that publish frequently and impactfully (HARZING, 2010; HARZING; ALAKANGAS; ADAMS, 2014; HIRSCH, 2005; JALAL, 2019; YU; JIN; QIU, 2021).

Measured based on the distribution of citations received from an author's publications, the g-index is the biggest number such that the top g articles collectively accumulated at least $g^2$ citations. As a result of this concept, the g-index evaluates overall performance. Comparatively, the h-index is the number of publications that meet a specific threshold, which rises as h increases; the g-index permits citations from more-cited articles to be leveraged to boost less-cited ones to fulfill this barrier. Therefore, the g-index is always at least the h-index and typically greater. However, unlike the h-index, the g-index saturates whenever the average number of citations for all published articles surpasses the total number of published articles. Therefore, the g-index is inadequate for this circumstance due to how it is defined (EGGHE, 2006; HARZING, 2010; JALAL, 2019; YU; JIN; QIU, 2021).

The h-index and the g-index are restricted by the number of articles an author has published. Therefore, these indexes, particularly the g-index, will always favor academics who publish more articles. These indices are consequently unsuitable for evaluating the effect of authors who have published one or two ground-breaking contributions but no other highly cited articles. Therefore, measuring absolute citation numbers can be relevant to evaluate such cases (EGGHE, 2006; HARZING, 2010; JALAL, 2019; YU; JIN; QIU, 2021).

Measuring absolute citation numbers can be tackled by considering global or local citations. The global approach assesses the number of citations an article has received from the entire publications database. Therefore, it considers the influence of this article on the whole database, which may be substantial for many articles whose citations may come from disciplines other than the one under consideration. In contrast, the local approach determines the number of citations an article has received from the documents included in the batch of selected articles under consideration by analyzing their entire reference lists (ARIA; CUCCURULLO, 2017; ROEMER; BORCHARDT, 2015; YU; JIN; QIU, 2021).

Finally, another impact metric commonly evaluated is PageRank, which measures popularity and prestige. Although initially developed to assess website interconnectedness and prioritize them in search engines, it can be expanded to identify the citation link between articles. Given its definition, PageRank takes the shape of a probability distribution over articles. Therefore, summing PageRank estimates for all articles will equal one. Using Equation (2.5) and an iterative method, PageRank corresponds to the primary eigenvector of the articles' normalized citation matrix (TANDON et al., 2021; WALTMAN; YAN; VAN ECK, 2011). For example, the PageRank of article A (denoted PR(A)) in a network of N articles is calculated as expressed in the equation below:

$$\mathrm{PR(A)} = \frac{(1-d)}{N} + d\left(\frac{PR(T_1)}{C(T_1)} + \ldots + \frac{PR(T_n)}{C(T_n)}\right) \tag{2.5}$$

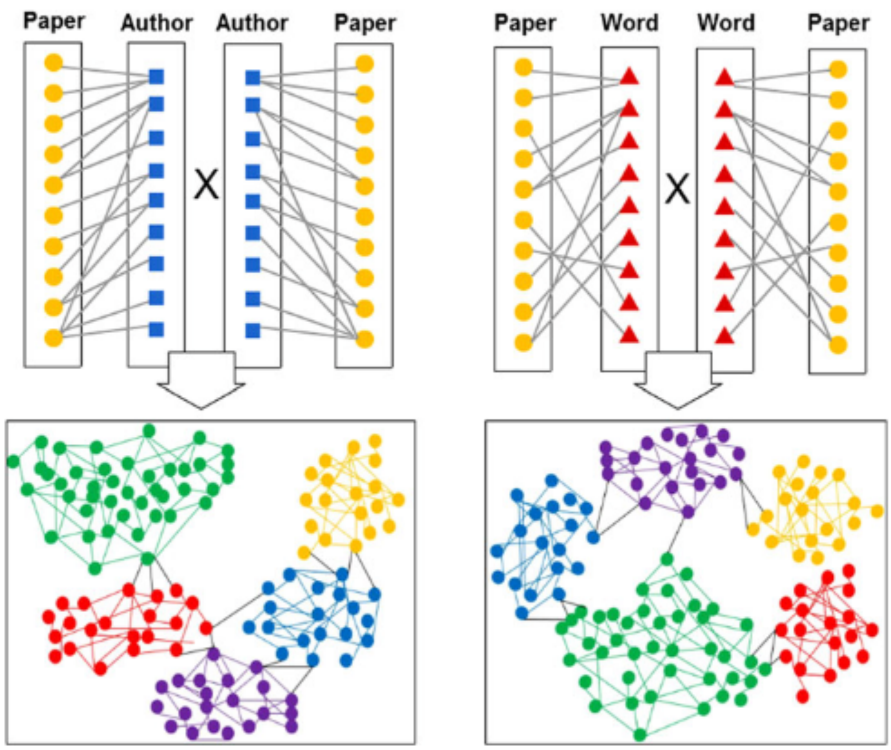
where $T_i$ is an article citing article A; $C(T_i)$ is the number of citations of article $T_i$; and d is a damping factor[1].

[1] The damping factor (d) ranges from 0 and 1, indicating the proportion of random walks that continue to propagate through the citations. It can also be determined by estimating the leakage probability (1-d), which is the inverse of the number of links one would follow before abandoning the search and beginning a new one. In (BRIN; PAGE, 1998) original Google PageRank algorithm, the parameter d was set to 0.85, while the case of article citations has significantly shorter paths with an average length of 2 (CHEN et al., 2007), making d = 0.5 more appropriate.

#### 2.3.3.2 Network analysis

Finding representations of intellectual links throughout the constantly evolving body of scientific knowledge is the goal of science mapping. Network analysis is one of the approaches used to depict the overall state of scientific knowledge (BÖRNER; CHEN; BOYACK, 2003; MORRIS; DER VEER MARTENS, 2008; SMALL, 1997). Building networks is accompanied by data clustering when the nodes of a network are divided into clusters in which the connection (density of edges) is greater between the nodes of the same cluster compared to those of different clusters (CLAUSET; NEWMAN; MOORE, 2004; LEYDESDORFF, 2011; RADICCHI et al., 2004; XU et al., 2018). A schematic representation of the network analysis process is depicted in Figure 2.15.

Figure 2.15 – Network analysis schematic construction process




Source: (YAN; DING; JACOB, 2012)

Data clustering has been used to classify a set of publications, allowing for topological analysis and identifying topics, interrelations, and collaboration patterns. Data clustering has received increasing attention from researchers, turning it into a critical research field in network analysis (BLONDEL et al., 2008; LANCICHINETTI; FORTUNATO, 2009; RADICCHI et al., 2004; XU et al., 2018). Existing clustering techniques are present today in software tools or programming libraries without the need to preprocess data, which allows a broader adoption of these science mapping tools. Nevertheless, a basic understanding of clustering techniques remains essential to perform meaningful analyses and avoid misinterpretations of the results (VAN ECK; WALTMAN, 2017).

According to (FORTUNATO, 2010; YAN; DING; JACOB, 2012), data clustering methods can be divided into traditional and modularity-based methods. Traditional approaches include graph partitioning, hierarchical clustering, partitional clustering, and spectral clustering. Methods based on modularity include clustering algorithms that measure the strength of communities using modules. For example, k-means is a typical traditional method for partitional data clustering that employs a two-phase iterative algorithm to minimize the sum of point-to-centroid Euclidean distances over all k clusters, represented by the cost function shown below:

$$\sum_{i=1}^{k} \sum_{X_j \in S_i} \|x_i - c_i\|^2 \qquad (2.6)$$

where $S_i$ is the subset of points of the i-th cluster; and $c_i$ is its centroid[2].

The drawbacks of traditional clustering algorithms are considerable. For instance, more information is required to comprehend the hierarchies' true structure because hierarchical clustering isolates single peripheral vertices from the communities. Moreover, the number of clusters must be determined prior to implementation in graph partitioning and partitional clustering. In addition, the treatment of overlapping nodes in particular networks might be arbitrary (FORTUNATO, 2010; YAN; DING; JACOB, 2012).

Since the early 2000s, as reported by (YAN; DING; JACOB, 2012), modularity-based approaches have been developed progressively. (GIRVAN; NEWMAN, 2002) created an approach that employs edge betweenness to determine the community limits, which algorithm consists of four iterative steps. This computationally intensive approach has been optimized to be more efficient (CLAUSET; NEWMAN; MOORE, 2004). Modularity, a metric established by (NEWMAN; GIRVAN, 2004), was used into a subsequent algorithm to evaluate the

[2] Each centroid is the mean of the points in that cluster, and the method used to choose the initial cluster centroid positions is randomly selecting k observations from X (the data matrix).

community structures in unweighted networks. (CLAUSET; NEWMAN; MOORE, 2004) then describe an algorithm for weighted networks in which each cell has a value representing the weight between two nodes (BLONDEL et al., 2008; XU et al., 2018). The quality function to be maximized in this latest algorithm is defined as follows:

$$Q=\frac{1}{2m}\sum_{ij}\left[A_{ij}-\frac{k_i k_j}{2m}\right]\delta(c_i,c_j) \tag{2.7}$$

where $A_{ij}$ represents the weight of the edge between nodes i and j; $k_i$ is the degree of a vertex i in a weighted network, equato to the sum of the weights of the edges attached to node i ($k_i = \sum_j A_{ij}$); $c_i$ is the community to which node i is assigned; δ(u,v) equals 1 if u = v, and equals 0 otherwise; and m denotes the total number of links in the network, represented by the sum of weights of all edges as every edge is calculated twice when adding up all the $A_{ij}$ (m $=\frac{1}{2}\sum_{ij} A_{ij}$).

An integrated mapping and clustering technique was developed as a variation of Equation (2.7) used in VOSviewer (WALTMAN; VAN ECK, 2013; WALTMAN; VAN ECK; NOYONS, 2010). The new modeling involves minimizing the following function:

$$V(x_1,\ldots,x_n)=\sum_{i<j} s_{ij}d_{ij}^2-\sum_{i<j} s_{ij}d_{ij} \tag{2.8}$$

where $s_{ij} = (2mA_{ij})/(k_i k_j)$ and $d_{ij}$ is defined differently for mapping and clustering.

For mapping, $d_{ij}$ represents the distance, in a p-dimensional map, between two nodes. In contrast, for clustering, $d_{ij}$ is the inverse of the resolution parameter (except when i=j, where it equals zero). They are mathematically expressed as follows:

$$d_{ij}=\|x_i-x_j\|=\sqrt{\sum_{k=1}^{p}(x_{ik}-x_{jk})^2} \tag{2.9}$$

$$d_{ij}=\begin{cases}0, & \text{if } x_i=x_j\\ \frac{1}{\gamma}, & \text{if } x_i\neq x_j\end{cases} \tag{2.10}$$

where $\gamma$ is called the resolution parameter.

Finally, the authors demonstrated that minimizing V is equivalent to maximizing $\hat{V}$ from Equation (2.11). Consequently, it is possible to observe that Q for a weighted network from Equation (2.7) is a particular case of $\hat{V}$ from Equation (2.11) when the resolution parameter $\gamma$

and the weights $w_{ij}$ are equal to 1 (WALTMAN; VAN ECK, 2013; WALTMAN; VAN ECK; NOYONS, 2010).

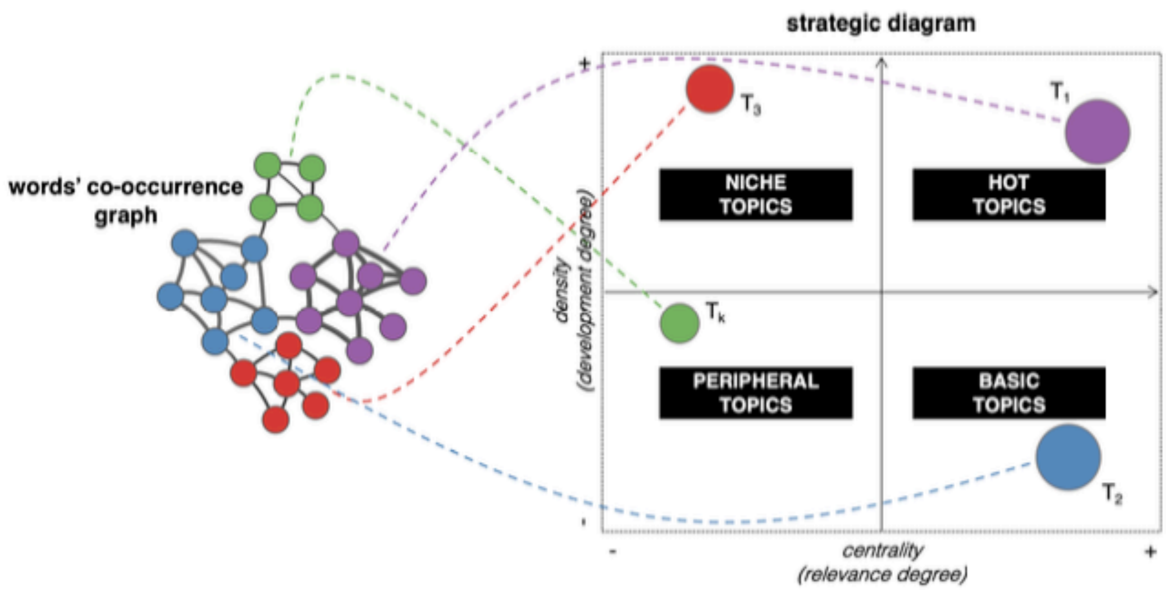
$$\widehat{V}(x_1,\ldots,x_n)=\frac{1}{2m}\sum_{i<j}\delta(x_i,x_j)w_{ij}\left[A_{ij}-\gamma\frac{k_ik_j}{2m}\right] \tag{2.11}$$

where $w_{ij}$ are weights ($w_{ij} = 2m/k_ik_j$).

Presented in the following subsection, this work's adopted tools perform data clustering using modularity-based methods while executing network analysis. Network analysis can be used to explore various knowledge structures, such as the conceptual structure showing key ideas and trends, the intellectual structure illustrating how an author's work affects a community, and the social structure portraying the relationships between countries, institutions, and authors (ANTE; STEINMETZ; FIEDLER, 2021; ARIA; CUCCURULLO, 2017; LOZANO et al., 2019; PRICE, 1965; VAN ECK; WALTMAN, 2014; YAN; DING; JACOB, 2012).

The conceptual structure can be evaluated using a co-occurrence network comprising a cluster of keywords considered themes. Then, each theme can be further analyzed considering Callon's centrality and density, producing a strategic or thematic map (ARIA et al., 2022; YU; JIN; QIU, 2021). This map is a two-axis plot, with the x-axis for centrality and the y-axis for density, as demonstrated in Figure 2.16.

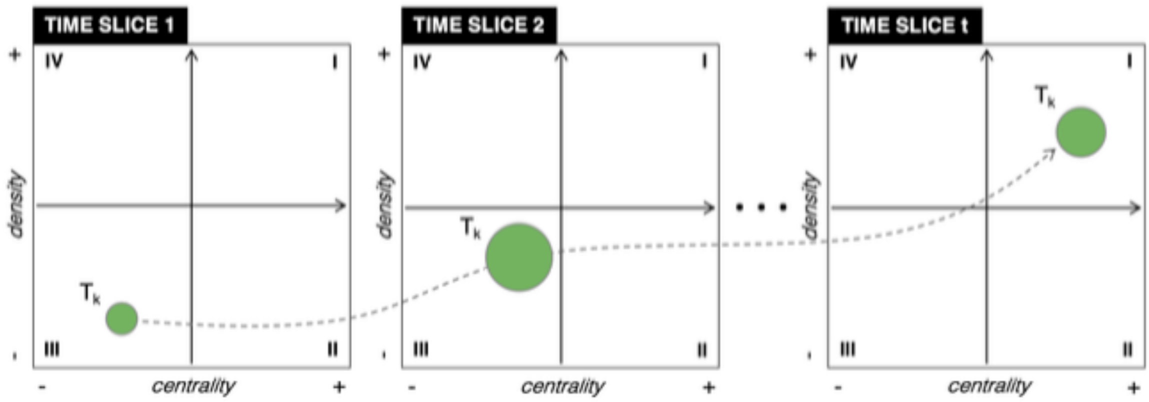
Figure 2.16 - Thematic map construction based on a words' co-occurrence network




Source: (ARIA et al., 2022)

Motor themes (or hot topics) in the upper-right quadrant are well-developed and important for structuring a study area. Themes in this quadrant are externally tied to elements relevant to other conceptually related themes. Specialized and peripheral themes (or niche topics) in the upper-left quadrant have solid internal connections but weak external connections, making them of only moderate value for the study area. The marginal and underdeveloped themes (peripheral topics) in the lower-left quadrant primarily depict emerging or vanishing ideas. Basic and transversal themes (or basic topics) in the lower-right quadrant are relevant for research but require further elaboration. By dividing the analysis timeframe, using a thematic map each time, the slice allows evaluating of a thematic evolution over time, as in Figure 2.17, and highlighting themes merging or splitting trends (ARIA et al., 2022; COBO et al., 2011).

Figure 2.17 - Thematic evolution across time slices of a thematic map.




Source: (ARIA et al., 2022)

Secondly, the intellectual structure is illustrated in networks representing the relationship between nodes that symbolize references. Network edges might be interpreted differently depending on the considered relationship type, such as direct citation, co-citation, i.e., relations between articles cited by the same article, and bibliographic coupling relations, i.e., relations between articles that cite the same articles (ARIA; CUCCURULLO, 2017).

The most prevalent citation analysis in the bibliometric analysis is the co-citation between authors or articles, but recent developments have promoted direct citation analysis. Some challenges should be considered when choosing one of these relationships approaches. First, bibliographic coupling and co-citation are indirect relations and are therefore anticipated to provide less precise information about the relationship between articles than direct citation. Since there is significantly more bibliographic coupling (or co-citation) between articles than direct citations, using a bibliographic coupling (or co-citation), relationship can easily result in computational challenges when building the networks. Finally, within a period of analysis, some publications may lack direct citation links with other publications, and these articles cannot be classified into a cluster using direct citation relations. This issue is particularly severe when the analysis duration is restricted (KLAVANS; BOYACK, 2017; WALTMAN; VAN ECK, 2012).

Finally, the social structure illustrates the relationships between countries, institutions, and authors in a particular field of scientific research. Co-authorship networks are the most prevalent kind of social structure, allowing uncovering, for example, groups of regular authors, influential authors, and relevant institutions in a particular study field (ARIA; CUCCURULLO, 2017; PETERS; VAN RAAN, 1991).

### 2.3.4 Content analysis

The content analysis involves initially screening for in-deep analysis, quality appraisal, and data extraction. The quality appraisal involves a second screening where the selected articles are evaluated according to the defined quality inclusion and exclusion criteria after consolidation. After this screening, a data extraction process is conducted to retrieve from the approved articles the applicable information defined previously. Finally, extracted data is synthesized and discussed, which can also be performed in the discussion and conclusions sections, involving also extracted data from bibliometric analysis.

Some authors consider that bibliometric analysis itself, particularly network analysis, is a content analysis method that combines bibliometric data from the articles employing quantitative and qualitative techniques (BORTOLUZZI; CORREIA DE SOUZA; FURLAN, 2021; REJEB et al., 2022). Other authors consider that the bibliometric analysis is a part of the execution phase as it processes data and generates new content to be further analyzed in comparison with other data retrieved from article contents (MUNZLINGER; NARCIZO; DE QUEIROZ, 2012; OKOLI; SCHABRAM, 2010). This work is consistent with the second school of thought, as it employs both bibliometric analysis and data extraction from article contents, which are combined.

### 2.3.5 Tools for analysis

The research protocol must be recorded and referred to throughout the systematized review process. This record might be done using word processing software or spreadsheet software. Other specialized tools can help register the research protocol and, unlike reference-management tools such as Mendeley and Zotero, support the systematized research process (or systematic research, depending on the case). RevMan, SLR Tool, and StArt are three examples of these specialized tools (FABBRI et al., 2016; FERNÁNDEZ-SÁEZ; BOCCO; ROMERO, 2010; HERNANDES et al., 2012; HINDERKS et al., 2020; MONTEBELO et al., 2007). This work adopted StArt to register the research protocol as it has features that facilitate the content analysis.

StArt (State of the Art through Systematic Review) was developed in the 2010s by a Brazilian research group adopting (KITCHENHAM; BRERETON, 2013) approach to systematic reviews in software engineering. It provides support to the systematic literature review process activities, except for the search of primary studies in electronic databases, which must be done manually with results imported into StArt (FABBRI et al., 2016, 2012; HERNANDES et al., 2012; MONTEBELO et al., 2007).

The article selection involves first querying databases with the defined search strings using each database's web-based applications. The results, including the most comprehensive bibliometric information, are then exported using one of the available formats in each database. The export format must be compatible with the following tools that will be applied. For example, StArt works with BibTeX, while Biliometrix/Biblioshiny recommends plaintext for WoS and CSV for Scopus and Dimensions (ARIA; CUCCURULLO, 2017; FABBRI et al., 2016). Finally, analyzing the comprehensiveness of the initially selected databases involves comparing these exported files. This work adopted processing the data in an R environment using the Bibliometrix library, which has a specific function to merge databases and exclude duplicates while using the Venn Diagram package to illustrate the findings.

Bibliometrix is an open-source R package for performing comprehensive analyses following the stages based on scientific mapping analysis workflow. Biblioshiny is a web-based user interface to operate the Bibliometrix R-package. By adopting Biblioshiny, it is possible not only to explore the analytics capabilities of Bibliometrix but also and take advantage of Bibliometrix's feature to produce graphs and networks. Biblioshiny operates through three-level metrics (source, author, and document) and three knowledge structures (conceptual, intellectual, and social) (ARIA; CUCCURULLO, 2017; COBO et al., 2011).

General bibliometric data analysis and network analysis can be performed using different tools. For general bibliometric data analysis, programming libraries are one of the most flexible alternatives, as the code can be used to process and analyze, incorporating other software. For network analysis, the most common are Bibexcel (accompanied by external software like Pajet for visualization), Biblioshiny, CiteSpace, CitNetExplorer, and VOSviewer (MORAL-MUÑOZ et al., 2020; OSINSKA; KLIMAS, 2021; TANDON et al., 2021). This work adopted the Bibliometrix library to extract analytic data and VOSviewer to develop a network analysis complemented by Biblioshiny, particularly word mapping, thematic mapping, and thematic evolution.

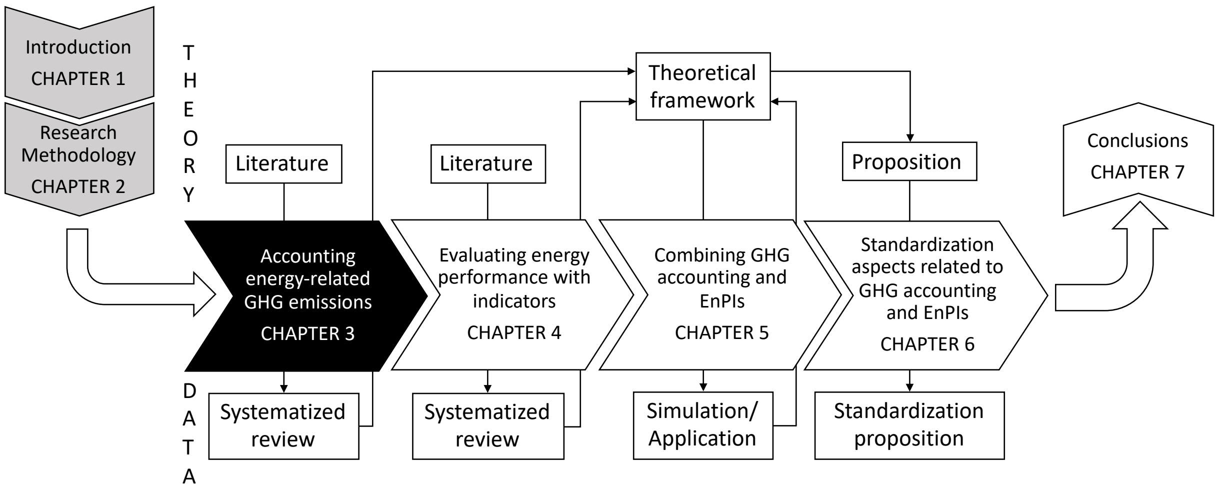
VOSviewer is a software tool designed to construct and visualize bibliometric networks with sources, authors, or individual articles as actors based on co-citation, bibliographic coupling, or co-authorship relations. It offers the possibility of building co-occurrence networks using a text-mining functionality and networks (co-authorship, co-occurrence, and citation-based) from bibliographic data. VOSviewer can work with various bibliographic databases, such as WoS, Scopus, Dimensions, PubMed, and RIS format (MORAL-MUÑOZ et al., 2020; VAN ECK; WALTMAN, 2010).

Finally, the content analysis comprises quality appraisal and data extraction from the consolidated set of articles. This work adopted StArt for research protocol record because it features software support for reading information from the articles. It is directly associated with quality criteria and filling data extraction forms. Although StArt also has a specific field for registering discussion and conclusions, other elements from content analysis, this work adopted recording this directly in a word processing software since extracted data need to be analyzed together with bibliometric analysis results.

# 3 ACCOUNTING ENERGY-RELATED GREENHOUSE GAS EMISSIONS

This Chapter presents the article submitted to the Journal of Cleaner Production titled "Energy-related greenhouse gas emissions: a review of accounting methods". The contents are from the original manuscript, but adjustments were made to adapt the article to this thesis format. Therefore, the published version may contain a different structure and changes suggested by the journal's editor and reviewers. This chapter's contribution in the context of this thesis is highlighted in Figure 3.1.

Figure 3.1 – Overall structure of this thesis highlighting Chapter 3 contribution




Source: Author's elaboration

## 3.1 Introduction

Climate change is one of the most significant sustainability challenges of our times, and its main causes are associated with human economic and social activities. These anthropogenic activities involve increasing energy use, primarily from fossil fuels, resulting in a rise in the atmospheric concentration of greenhouse gases (GHG). Since the Industrial Revolution, CO2 concentration has augmented steadily and significantly, from 280 ppm to 418 ppm. In its Sixth Assessment Report, the Intergovernmental Panel on Climate Change (IPCC) estimates that the global mean temperature will climb between 1.6 and 3.9ºC by 2100, depending on the climate change mitigation actions are in place (CCGG GROUP, 2022; CHOUDHARY; SRIVASTAVA; DE, 2018; IPCC, 2022).

Given the Paris Agreement and the goal of keeping global temperature rise below 1.5ºC by the end of the century, the median emissions gap in 2030 varies from 20 $GtCO2_{eq}$ with full implementation of conditional NDCs, to 23 $GtCO2_{eq}$ considering full implementation of unconditional NDCs, or 25 $GtCO2_{eq}$ keeping current policies. This signals the need for significant additional efforts in reducing GHG emissions to reach the 1.5ºC pathway, considering that GHG emissions in these scenarios by 2030 are estimated at 52, 55, and 58 $GtCO2_{eq,}$ respectively (DHAKAL et al., 2022; UNEP, 2022).

Energy use is the most contributing anthropogenic factor to GHG emissions, accounting for three-quarters of total anthropogenic emissions. In 2019, considering the five global economic sectors, energy supply was the most significant, with 34% of total emissions (20 $GtCO2_{eq}$), followed by industry with 24% (14 $GtCO2_{eq}$), AFOLU (Agriculture, forestry, and other land use) with 22% (13 $GtCO2_{eq}$), transport with 15% (8.9 $GtCO2_{eq}$), and buildings with 6% (3.3 $GtCO2_{eq}$). If GHG emissions are allocated in their final use sectors, industry share increases to 34% (20 $GtCO2_{eq}$), and buildings share to 16% (9.7 $GtCO2_{eq}$). Therefore, activity in each economic sector may have direct and indirect GHG emissions associated with energy use (DHAKAL et al., 2022; UNEP, 2022; WRI, 2022).

International commerce and global value chains introduce another complexity layer besides the energy-related GHG emission allocation. For example, not only are GHG emissions embedded in imported goods, but additional GHG emissions are expected from transportation for longer distances. Consequently, the increasing complexity of supply chains presents major hurdles for carbon accounting. Furthermore, given that energy systems and product design and production have multiple direct and indirect sources of carbon emissions, it became challenging for businesses to account for the GHG emissions of their products and services. Therefore, as with other key management decisions, a robust data system is critical for achieving meaningful carbon reductions in businesses and residences. As a result, effective carbon accounting can become an increasingly important instrument in the fight against climate change, measuring the magnitude of GHG emissions related to activities and evaluating climate change mitigation strategies' effectiveness (SCHALTEGGER; CSUTORA, 2012; WEGENER; LABELLE; JERMAN, 2019).

Indeed, there is a growing interest in research on carbon accounting, with GHG emissions reporting being a particular focus. One point of debate is that reported GHG emissions' meaningfulness depends on their capacity to reflect reality while keeping independence from interested parties. Another point of discussion is the influence of the current range of allowed methodologies for estimating GHG emissions, which has already raised concerns about the adequacy of reported GHG emissions. For example, numerous GHG accounting methods have been established, including inventories (at national, local, and organizational levels), project-level methods, product-level life cycle assessments, and policy assessments. Considering this variety of methodologies, which method is optimal for a given objective is not always straightforward. As a result, these concerns may undermine GHG emissions reporting's capacity to offer meaningful and comparable data for assessing an organization's environmental performance (BRANDER, 2016, 2017; BRANDER; GILLENWATER; ASCUI, 2018; UDDIN; HOLTEDAHL, 2013).

Considering the relevance of accounting methods in reporting greenhouse gas emissions and the role played by energy-related emissions, this work aims to conduct a systematized review of scientific publications on energy-related GHG emissions accounting methods. First, the scientific articles have been investigated to analyze the current state of scientific research and trends. Then, a discussion of the findings highlights relevant conceptions, premises, and features and reports challenges and possible solutions to these issues.

After this introduction, Section 3.2 presents the methodology used for the systematized review, including the adopted research protocol and article selection. Section 3.3 presents the findings of bibliometric and content analysis. A critical analysis discussion is presented in Section 3.4, wherein the challenges are also described. Finally, conclusions and implications are highlighted in Section 3.5.

## 3.2 Methods

The combination of methods applied in this work follows the overview presented in Figure 2.13. For the sake of brevity, the theory and general elements of systematized review and bibliometric analysis were presented in Section 2.3.

### 3.2.1 Adopted research protocol

According to the proposed methods, adopting a research protocol involves mainly three steps. The first step starts with outlining the research problem and associated questions to define keywords that will compose search strings. As pointed out, this review aimed to collect and analyze the literature on greenhouse gas emissions accounting, mainly focusing on publications dealing with energy-related ones. Based on this objective, the following research question was formulated: "Focusing on energy-related emissions, what are the current state and trends on approaches adopted to greenhouse gas emissions accounting?". This general question was then divided into three stepwise questions:

- Q1 – "In general, what are the current state and trends on approaches adopted to greenhouse gas emissions accounting?"
- Q2 – "Considering these approaches, what are the ones adopted when evaluating energy-related emissions?"
- Q3 – "Considering these approaches on energy-related emissions, what are the factors reflecting energy that are considered?"

Considering these secondary questions, Q1 was used to develop the search string, Q2 was used to screen the initial results, and Q3 was used to retrieve information from the articles in data extraction. After following these steps, the research protocol is completed. Considering Q1, three keywords should compose the search string: greenhouse gas, emission, and accounting. These base keywords are then expanded, considering possible alternatives, as presented in Table 3.1, which includes synonyms, acronyms, and abbreviations.

Table 3.1 – Base keywords and alternatives for greenhouse gas emission accounting

| **Base keyword** | **greenhouse gas** | **emission** | **accounting** |
|---|---|---|---|
| Considered alternatives | ghg<br>carbon<br>carbon dioxide<br>CO2<br>CO2eq | - | calculation<br>estimation<br>assessment<br>quantification<br>measurement<br>evaluation<br>analysis |

Source: Author's elaboration.

The second step, an initial selection of bibliographic databases, was previously accomplished in presented in Section 2.3. Within these databases, the query was performed by searching only in title, abstract, and keywords, when available, using search strings developed specifically for each database. Before defining these search strings, the third step for research protocol adoption was accomplished.

In this third step, all criteria needed for the subsequent review phases are defined. These criteria are summarized in Table 3.2. It comprises general inclusion and exclusion criteria adopted in the search string and in checking consistency of results from the databases. Following that, based on Q2 was developed in-deep analysis inclusion and exclusion criteria while quality criteria and related data extraction information fields were developed from Q3. Some preliminary information was retrieved from the brief review used to present this work subject in the introduction section, particularly for data extraction information fields. After defining these criteria, the research protocol is adopted, and the review is moved to the next phase.

Table 3.2 – Criteria for the systematized review of energy-related greenhouse gas emission accounting methods

| Category | Criteria (I: Inclusion / E: Exclusion) |
|---|---|
| General inclusion and exclusion criteria adopted in the search string | (I) Article types: article, conference paper, review<br>(I) Article language: English<br>(E) Article type: book, book chapter, others<br>(E) Article language: other than English |
| General inclusion and exclusion criteria to check consistency | (I) Article basic bibliometric data fully available<br>(I) Publishing year in a range from 2000 to 2022<br>(E) Article basic bibliometric data not fully available<br>(E) Publishing year prior to 2000 |
| In-deep analysis inclusion and exclusion criteria | (I) Article fully available<br>(I) Article deal with energy-related emissions<br>(I) Article deal with accounting discussions<br>(E) Article not fully available<br>(E) Article deal only with non-energy-related emissions |
| Quality criteria | - Energy-related GHG emissions are calculated/estimated/assessed?<br>- Different accounting methods are used/discussed? |
| Data extraction information fields | - GHG accounting method mentioned [Multiples choices: IPCC, UNFCCC CDM, GHG Protocol, ISO 14064 series, other (should be specified)]. |

| Category | Criteria (I: Inclusion / E: Exclusion) |
|---|---|
| | - Energy-related factor [Multiple choices: Simple metric, Ratio, Statistical method (Linear Regression), Statistical method (Multiple Linear Regression), Engineering modeling, other (should be specified)]. |

Source: Author's elaboration.

### 3.2.2 Article selection outcomes

Following the proposed methods, article selection involved composing search strings used in querying selected bibliographic databases, namely Web of Science (WoS), Scopus, and Dimensions. These strings were developed to contemplate keyword combinations and general including and excluding criteria. Search strings also considered that searching was only done in title, abstract, and keywords, when available.

The keyword combination was a sequence of loose phrases under double quotation marks combined with Boolean operators (AND, OR). Each loose phrase combines Table 3.1 base keywords and considered alternatives. Particularly regarding the keyword "accounting" and its alternatives, a modification was made to include variants using wildcards (*). Therefore, keyword combinations include 48 loose phrases and, aiming to simplify the representation, Table 3.3 include the search strings without explicitly mentioning the keyword combination. The three bibliographic databases were queried using the respective search strings, and raw results were obtained. Using general inclusion and exclusion criteria to check consistency, as presented in Table 3.2, checked results were attained. The number of raw and checked results is shown in Table 3.3 by database.

Table 3.3 – Database search strings and initial results

| Database | Search string | Raw results | Checked results |
|---|---|---|---|
| Scopus | TITLE-ABS-KEY ( keyword combinations[2] ) AND ( LIMIT-TO ( DOCTYPE , "ar" ) OR LIMIT-TO ( DOCTYPE , "re" ) OR LIMIT-TO ( DOCTYPE , "cp" ) ) AND ( LIMIT-TO ( LANGUAGE , "English" ) ) | 2021 | 1955 |

| Database | Search string | Raw results | Checked results |
|---|---|---|---|
| Web of Science (WoS) | ( keyword combinations[2] ) (Topic) and English (Languages) and Editorial Material or Data Paper or Correction or News Item (Exclude – Document Types) | 846 | 819 |
| Dimensions[1] | ( keyword combinations[2] ) | 353 | 319 |

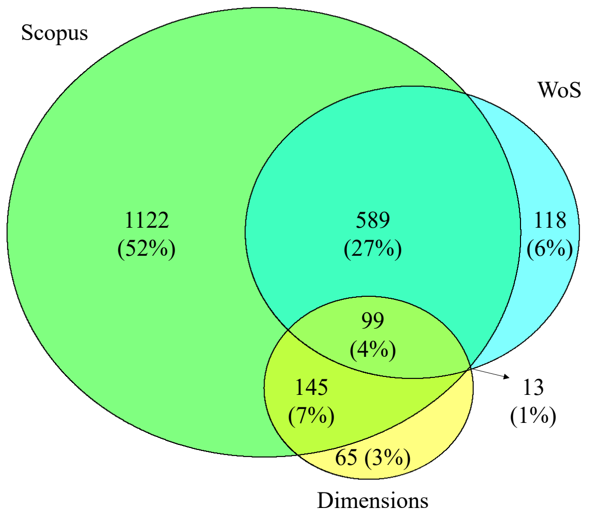
[1] Search string includes only keyword combination. Title and abstract were selected as "Search in" option. Article types "Article, Proceeding or Preprint" were selected as a filter.

[2] Keyword combinations: loose phrases, combined with Boolean operator (AND, OR), structured as "A emission B" where A can be greenhouse gas, ghg, carbon, carbon dioxide, CO2 or CO2eq; and B can be account*, calculat*, estimat*, assess*, quantificat*, measur*, evaluat*, analysis.

Source: Author's elaboration.

After this initial search, database coverage is assessed by evaluating how these checked results overlap. Using the function "mergeDbSources" from Bibliometrix R-package was possible to determine all values needed to solve the system of linear equations from Equation (2.1). After solving this system of linear equations, results regarding the overlapping of Scopus, WoS, and Dimensions databases are shown in Figure 3.2.

Figure 3.2 – Overlapping search results from Scopus, WoS, and Dimensions




Source: Author's elaboration using data processed in Bibliometrix (ARIA; CUCCURULLO, 2017)

In total, there are 2193 non-duplicated articles found together in all three databases. Scopus database shows the more comprehensive coverage, covering almost 80% of the articles found in total (1955 of 2148), overlapping more than 80% of WoS results and 75% of Dimensions results. WoS results embrace almost 40% of the total (819 of 2148), overlapping 35% of Scopus results and 35% of Dimensions results. Dimensions have narrower results (equivalent to 15% of the total). When considering unique articles, Dimensions results correspond to 3% of the total, and WoS unique articles also represent a small share, 6%. In contrast, Scopus unique articles are by far the largest share, corresponding to more than 50% of total results.

Scopus is the most comprehensive database, representing over 90% of total results, vastly exceeding the Pareto Principle. Therefore, Scopus was considered the most comprehensive database used in bibliometric analysis and data visualization. The total combined results, including 2148 articles, were then examined in content analysis, allowing retrieving any valid information from articles found only in WoS and Dimensions.

## 3.3 Findings

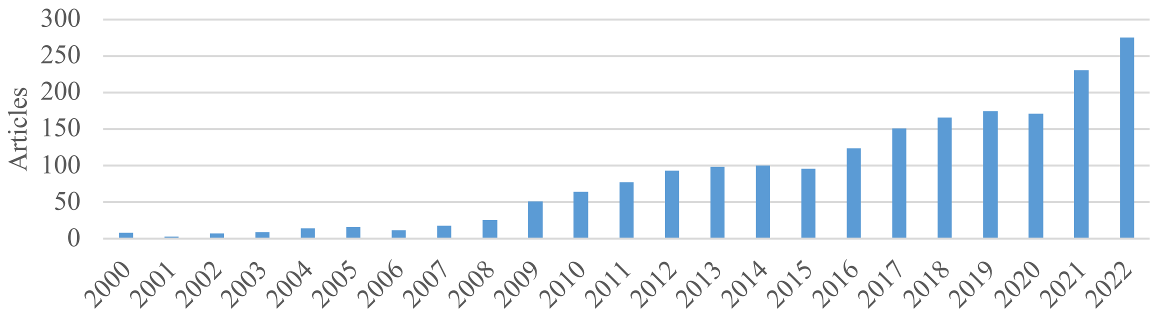
In this section are presented the findings from this systematized review execution phase. Firstly, general bibliometric data analysis is presented in subsection 3.3.1, analyzing Scopus checked results from the previous section using Bibliometrix/Biblioshiny tool. Then, network analysis is developed in subsection 3.3.2, analyzing Scopus checked results using VOSviewer and Bibliometrix/Biblioshiny tools. Finally, content analysis is performed in subsection 3.3.3, analyzing full combined results using the StArt tool.

### 3.3.1 General bibliometric data analysis

As an overview of the findings, the bibliometric analysis covered 1955 articles from 2000 to 2022. These articles were originally published in a total of 831 sources, authored by 5964 authors, 137 (2.3%) of which are authors of 146 (7.5%) single-authored articles. These last numbers show a highly collaborative environment, with an average of 4.2 authors per article and more than 20% of international collaboration. Finally, as a general indication of article contents, there are 4780 authors' keywords, which may include duplicates considering misspellings, acronyms, abbreviations, and singular-plural variations.

The annual scientific production in Figure 3.3 shows how the total of 1955 articles considered is distributed temporally within the timespan from 2000 to 2022. Analyzing this graph, four different waves are noticeable, with the first starting in 2001, another in 2007, a third in 2015, and finally, the last in 2020. Incidentally, a series of events might have contributed to these waves. For example, IPCC Third, Fourth, and Fifth Assessment Reports were published respectively in 2001, 2007, and 2014. Subsequently, Paris Agreement was adopted at COP 21 in 2015. Then, COVID-19 Pandemic broke out in late 2019, and associated lockdowns raised discussion regarding GHG emissions impacts. Finally, IPCC Sixth Assessment Report was published in 2022.

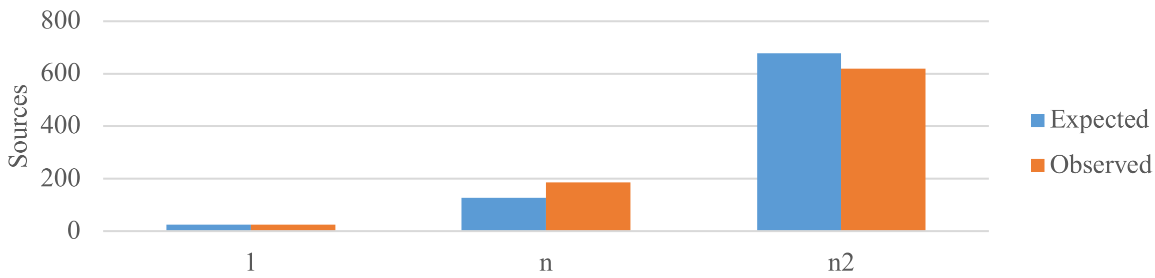
Figure 3.3 – Annual scientific production




Source: Author's elaboration using data processed in Bibliometrix (ARIA; CUCCURULLO, 2017)

After this overview, the first bibliometric data investigated are the articles' sources. Identifying core sources is done by considering Bradford's Law, which can be applied by dividing the total articles into three groups with approximately equal numbers of documents. The results in terms of a number of sources, both expected and observed, according to Bradford's Law, are presented in Figure 3.4. The first zone and smaller group of sources, so-called core sources, comprise 24 academic journals. The following two zones have 187 and 620 academic journals, respectively.

Figure 3.4 – Bradford's Law expected and observed values




Source: Author's elaboration using data processed in Bibliometrix (ARIA; CUCCURULLO, 2017)

Considering the top 10 core sources, the number of articles (N) from each academic journal in the bibliometric analysis is shown in Table 3.4. The most relevant core source is the Journal of Cleaner Production, which stands out with more than double the frequency of the second one. Starting from the third core source, there is a steady decline in frequency, which became smoother from the tenth source onwards. Another way to assess the relevance of the sources, as proposed in the Methods section, is to calculate total citations (TC) and impact indexes such as h-index and g-index. These parameters for the same top 10 core sources are presented are also presented in Table 3.4

Table 3.4 – Top 10 core sources and their total citation, h-index, and g-index

| Source (Academic journals) | N | TC | h-index | g-index | CiteScore | SNIP | SJR |
|---|---|---|---|---|---|---|---|
| Journal of Cleaner Production | 136 | 3630 | 1 | 36 | 15.8 | 2.444 | 1.921 |
| Sustainability (Switzerland) | 65 | 595 | 17 | 13 | 5 | 1.31 | 0.664 |
| Iop Conference Series: Earth and Environmental Science | 42 | 57 | 112 | 4 | 0.6 | 0.409 | 0.202 |
| Energy Policy | 37 | 1304 | 4 | 21 | 12.4 | 2.034 | 2.126 |
| Energies | 34 | 270 | 35 | 10 | 5 | 1.104 | 0.653 |
| Environmental Science and Pollution Research | 32 | 340 | 29 | 12 | 6.6 | 1.154 | 0.831 |
| Science of the Total Environment | 30 | 1177 | 6 | 16 | 14.1 | 2.175 | 1.806 |
| Energy | 29 | 1797 | 2 | 19 | 13.4 | 2.038 | 2.041 |
| Applied Energy | 28 | 1572 | 3 | 19 | 20.4 | 2.652 | 3.062 |
| Renewable and Sustainable Energy Reviews | 25 | 808 | 11 | 16 | 28.5 | 4.535 | 3.678 |

Source: Author's elaboration using data processed in Bibliometrix (ARIA; CUCCURULLO, 2017)

As expected, assessing source relevance from multiple measures may result in different results. Aiming to evaluate these results comparatively, the top 10 core sources are ranked in each measure (number of articles, total citations, h-index, and g-index). The comparative results are presented in Table 3.5.

Table 3.5 – Top 10 core sources and their ranking according to total citations, h-index, and g-index

| Source (Academic journals) | N rank | TC rank | h rank | g rank | CiteScore rank | SNIP rank | SJR rank |
|---|---|---|---|---|---|---|---|
| Journal of Cleaner Production | 1 | 1 | 1 | 1 | 22 | 47 | 65 |
| Sustainability (Switzerland) | 2 | 17 | 8 | 7 | 225 | 216 | 257 |
| Iop Conference Series: Earth and Environmental Science | 3 | 112 | 47 | 39 | 435 | 417 | 420 |
| Energy Policy | 4 | 4 | 2 | 2 | 47 | 81 | 52 |
| Energies | 5 | 35 | 14 | 12 | 226 | 265 | 260 |
| Environmental Science and Pollution Research | 6 | 29 | 10 | 9 | 171 | 248 | 208 |
| Science of the Total Environment | 7 | 6 | 5 | 3 | 37 | 60 | 75 |
| Energy | 8 | 2 | 3 | 4 | 44 | 80 | 55 |
| Applied Energy | 9 | 3 | 4 | 5 | 10 | 41 | 20 |
| Renewable and Sustainable Energy Reviews | 10 | 11 | 6 | 6 | 5 | 10 | 14 |

Source: Author's elaboration using data processed in Bibliometrix (ARIA; CUCCURULLO, 2017)

Considering the first four rankings, these comparative results show that six have a consistent ranking from these ten sources, i.e., staying within the top 10 or top 11 regardless of the measure considered. Analyzing the ranking of the considered measures, when aggregating their ranks in the first four measures, the following six academic journals have the lowest sums: Journal of Cleaner Production, Energy Policy, Science of the Total Environment, Energy, Applied Energy, and Renewable and Sustainable Energy Reviews. On the other hand, in terms of journal impact factors, three of the previously mentioned journals have different positions: Renewable and Sustainable Energy Reviews, Applied Energy, and Journal of Cleaner Production.

After analyzing the sources, the second bibliometric data investigated are the articles' authors. As mentioned earlier, there are 5964 authors in a total of 1955 articles. Many authors have published only one article within the researched subject and constraints, 5008 authors or 84%. The distribution of a number of authors according to the number of articles published is done by considering Lotka's Law, which is represented in Figure 3.5.

Figure 3.5 – Lotka's Law assessment with bibliometric data and regression line


Source: Author's elaboration using data processed in Bibliometrix (ARIA; CUCCURULLO, 2017)

The dotted line in Figure 3.5 is a regression line with a power function ($y = a.x^p$) having an exponent (p) of approximately negative 2.5. This adheres with Lotka's Law and the empirical observations stating that this correlation is proportional to either the Inverse Square Law ($1/x^2$) or the Inverse Cube Law ($1/x^3$). Considering the most productive authors, as in Table 3.6, the top 12 have published 298 articles, or 15% of all articles, while representing only 0.2% of all authors. Another way to assess the relevance of the authors, as proposed in the Methods section, is to calculate total citations (TC) as well as impact indexes as h-index and g-index. These parameters for the same top 12 most productive authors are also presented in Table 3.6.

Table 3.6 – Top 12 most productive authors and their total citation, h-index, and g-index

| Authors | N. articles | TC | h-index | g-index |
|---|---|---|---|---|
| Zhang Y | 35 | 501 | 46 | 11 |
| Wang Y | 32 | 317 | 93 | 10 |
| Liu Y | 30 | 610 | 37 | 11 |
| Li Y | 28 | 1346 | 5 | 9 |
| Zhang X | 27 | 357 | 81 | 9 |
| Wang J | 25 | 629 | 36 | 13 |
| Li J | 23 | 570 | 38 | 10 |
| Zhang J | 21 | 338 | 83 | 9 |
| Wang H | 20 | 225 | 178 | 8 |
| Liu Z | 19 | 1833 | 1 | 10 |
| Li X | 19 | 253 | 7 | 15 |
| Ritter K | 19 | 8 | 2 | 2 |

Source: Author's elaboration using data processed in Bibliometrix (ARIA; CUCCURULLO, 2017)

Similarly, as observed with sources, assessing authors' relevance from multiple measures may result in different results. Aiming to evaluate these results comparatively, the top 12 most productive authors are ranked in each measure (number of articles, total citations, h-index and g-index). The comparative results are presented in Table 3.7.

Table 3.7 – Top 12 most productive authors and their ranking according to total citations, h-index, and g-index

| Authors | N. art. rank | TC rank | h rank | g rank |
|---|---|---|---|---|
| Zhang Y | 1 | 46 | 11 | 4 |
| Wang Y | 2 | 93 | 10 | 7 |
| Liu Y | 3 | 37 | 11 | 3 |
| Li Y | 4 | 5 | 9 | 8 |
| Zhang X | 5 | 81 | 9 | 9 |
| Wang J | 6 | 36 | 13 | 1 |
| Li J | 7 | 38 | 10 | 6 |
| Zhang J | 8 | 83 | 9 | 10 |
| Wang H | 9 | 178 | 8 | 15 |
| Liu Z | 10 | 1 | 10 | 5 |
| Li X | 11 | 140 | 20 | 15 |
| Ritter K | 12 | 3028 | 611 | 631 |

Source: Author's elaboration using data processed in Bibliometrix (ARIA; CUCCURULLO, 2017)

These comparative results show that only two have a consistent ranking from these ten authors, i.e., staying within the top 12 regardless of the measure considered. Analyzing the ranking of the considered measures, these same two authors (Li Y and Liu Z) have the lowest sum when aggregating their ranks in all measures. Furthermore, several authors with high total citations, over 1000, have low publication levels, which reduces their h-index and g-index, as illustrated by the top 10 most cited authors in Table 3.8. Finally, it is worth mentioning that when processing bibliometric data with Bibliometrix, some homonymous authors might have been aggregated.

Table 3.8 – Top 10 most cited authors

| Authors | TC | Number of articles |
|---|---|---|
| Liu Z | 1833 | 19 |
| Guan D | 1670 | 4 |
| Hubacek K | 1546 | 3 |
| Liu J | 1372 | 15 |
| Li Y | 1346 | 28 |
| Davis SJ | 1155 | 3 |
| Peters GP | 1142 | 2 |
| Feng K | 1140 | 2 |
| Zhao Y | 1109 | 13 |
| Ciais P | 1096 | 8 |

Source: Author's elaboration using data processed in Bibliometrix (ARIA; CUCCURULLO, 2017)

Another approach to evaluating author-related bibliometric data involves investigating their affiliations and respective countries. Considering that one author might have more than one affiliation, the total number of mentioned affiliations might exceed the number of authors. Table 3.9 presents the top 10 most mentioned affiliations. Within the top 10 most mentioned, eight are Chinese institutions, one from the USA and one from the United Kingdom.

Table 3.9 – Top 10 most mentioned affiliations

| Affiliation | Country | Mentions |
|---|---|---|
| Tsinghua University | China | 126 |
| Beijing University | China | 30 |
| Tongji University | China | 70 |
| North China Electric Power University | China | 54 |
| Beijing Normal University | China | 56 |
| University of California | USA | 40 |
| China University of Mining and Technology | China | 37 |
| Southeast University | China | 36 |
| University of Leeds | United Kingdom | 35 |
| Wuhan University of Technology | China | 34 |

Source: Author's elaboration using data processed in Bibliometrix (ARIA; CUCCURULLO, 2017)

Another way to see the crossing between data from affiliations and countries is to expand the analysis from the top 10 to the top 50 most mentioned affiliations and their respective countries, as depicted in Table 3.10. Again, the results show that China stays on top while slightly reducing its share from 80% to around 70%, and a more diversified scenario arises from top 30 onwards.

Table 3.10 – Countries with most mentioned affiliations from Top 10 to Top 50

| Country | Most mentioned affiliations | | | | |
|---|---|---|---|---|---|
| | Top 10 | Top 20 | Top 30 | Top 40 | Top 50 |
| China | 8 | 15 | 21 | 28 | 33 |
| USA | 1 | 3 | 4 | 4 | 6 |
| United Kingdom | 1 | 2 | 2 | 2 | 3 |
| Brazil | 0 | 0 | 1 | 1 | 1 |
| Canada | 0 | 0 | 1 | 1 | 1 |

| Country | Most mentioned affiliations | | | | |
|---|---|---|---|---|---|
| | Top 10 | Top 20 | Top 30 | Top 40 | Top 50 |
| Sweden | 0 | 0 | 1 | 1 | 1 |
| Malaysia | 0 | 0 | 0 | 1 | 1 |
| Netherlands | 0 | 0 | 0 | 1 | 1 |
| Japan | 0 | 0 | 0 | 1 | 1 |
| Iran | 0 | 0 | 0 | 0 | 1 |
| Mexico | 0 | 0 | 0 | 0 | 1 |

Source: Author's elaboration using data processed in Bibliometrix (ARIA; CUCCURULLO, 2017)

This discussion leads to a second approach to assess country relevance. In this case, the articles are distributed according to the corresponding author's country, being also divided between single country production (SCP) and multiple country production (MCP), and total citations (TC) of these articles. Analyzing the corresponding authors, their respective countries sum 82 in total. Therefore, the top 16 (roughly 20% of corresponding countries) are responsible for approximately 80% of the articles adhering to the Pareto Principle. The top 16 corresponding countries and their metrics are presented in Table 3.11.

Table 3.11 – Top 16 corresponding countries and metrics of number of articles, TC, SCP, and MCP

| Country | N | TC | TC/Article | SCP | MCP | MCP/Articles |
|---|---|---|---|---|---|---|
| China | 641 | 9221 | 14.4 | 516 | 125 | 0.195 |
| USA | 268 | 10292 | 38.4 | 208 | 60 | 0.224 |
| United Kingdom | 101 | 3104 | 30.7 | 69 | 32 | 0.317 |
| Canada | 75 | 2223 | 29.6 | 57 | 18 | 0.240 |
| Australia | 68 | 1827 | 26.9 | 38 | 30 | 0.441 |
| Italy | 47 | 840 | 17.9 | 34 | 13 | 0.277 |
| India | 44 | 487 | 11.1 | 38 | 6 | 0.136 |
| Japan | 43 | 728 | 16.9 | 33 | 10 | 0.233 |
| Brazil | 42 | 459 | 10.9 | 30 | 12 | 0.286 |
| Netherlands | 34 | 1536 | 45.2 | 16 | 18 | 0.529 |
| South Korea | 34 | 204 | 6.0 | 29 | 5 | 0.147 |
| Germany | 25 | 566 | 22.6 | 14 | 11 | 0.440 |
| Malaysia | 25 | 277 | 11.1 | 20 | 5 | 0.200 |
| France | 24 | 277 | 11.5 | 12 | 12 | 0.500 |
| Spain | 23 | 677 | 29.4 | 14 | 9 | 0.391 |
| Iran | 20 | 506 | 25.3 | 18 | 2 | 0.100 |

Source: Author's elaboration using data processed in Bibliometrix (ARIA; CUCCURULLO, 2017)

Similarly, as observed with sources and authors, assessing countries' relevance from multiple measures may result in different results. Therefore, aiming to evaluate these results comparatively, the top 16 corresponding countries and their metrics are presented in Table 3.12.

Table 3.12 – Top 16 corresponding countries and metrics of number of articles, TC, SCP, and MCP

| Country | N rank | TC rank | TC/Art. rank | SCP rank | MCP rank | MCP/Art. rank |
|---|---|---|---|---|---|---|
| China | 1 | 2 | 33 | 1 | 1 | 53 |
| USA | 2 | 1 | 5 | 2 | 2 | 49 |
| United Kingdom | 3 | 3 | 8 | 3 | 3 | 37 |
| Canada | 4 | 4 | 9 | 4 | 5 | 47 |

| Country | N rank | TC rank | TC/Art. rank | SCP rank | MCP rank | MCP/Art. rank |
|---|---|---|---|---|---|---|
| Australia | 5 | 5 | 15 | 5 | 4 | 26 |
| Italy | 6 | 7 | 25 | 7 | 7 | 42 |
| India | 7 | 16 | 44 | 6 | 17 | 57 |
| Japan | 8 | 8 | 28 | 8 | 11 | 48 |
| Brazil | 9 | 17 | 45 | 9 | 8 | 39 |
| Netherlands | 10 | 6 | 4 | 13 | 6 | 17 |
| South Korea | 11 | 27 | 51 | 10 | 20 | 55 |
| Germany | 12 | 12 | 20 | 19 | 10 | 27 |
| Malaysia | 13 | 21 | 43 | 11 | 21 | 52 |
| France | 14 | 22 | 41 | 24 | 9 | 18 |
| Spain | 15 | 9 | 10 | 17 | 12 | 29 |
| Iran | 16 | 14 | 16 | 12 | 33 | 60 |

Source: Author's elaboration using data processed in Bibliometrix (ARIA; CUCCURULLO, 2017)

These comparative results show that some behaviors can be identified within these sixteen countries. Except for the MCP/Articles ranking, six countries have a consistent ranking, i.e., staying within the top 16 regardless of the measure considered, namely the USA, United Kingdom, Canada, Australia, and the Netherlands. Analyzing the ranking of the considered measures, these same six authors have the lowest sum when aggregating their ranks in all measures. China has a very high position ranking, except in the TC/Articles ranking, due to its high productivity and difficulties keeping up high citation levels. Generally, countries' international collaboration strongly affects the MCP/Articles ranking. Considering all articles in this review, there is an average of approximately 26% multiple country productions. Analyzing MCP/Articles in Table 3.11, half of the top 16 corresponding countries have above-average international collaboration. However, several countries with relatively few published articles have done so through international cooperation, thus, having a high MCP/Articles rank.

After exploring bibliometric data regarding sources, authors, affiliations, and countries, a subsequent analysis comprises articles' local citations (LC) and global citations (GC). While LC reflects how often documents within the review cite another document contained in the review, GC considers citations by articles from the entire bibliographic database. Consequently, the ratio of these numbers (LC/GC) measures the article's impact outside the reviewed research field. Considering the most locally cited documents, these citation measures are presented in Table 3.13.

Table 3.13 – Top 10 locally cited documents and metrics of LC, GC and LC/GC ratio

| Document | LC | GC | LC/GC ratio |
|---|---|---|---|
| Reduced carbon emission estimates from fossil fuel combustion and cement production in China (LIU et al., 2015) | 33 | 907 | 3.6% |
| A review on Life Cycle Assessment, Life Cycle Energy Assessment and Life Cycle Carbon Emissions Assessment on buildings (CHAU; LEUNG; NG, 2015b) | 22 | 449 | 4.9% |

| Document | LC | GC | LC/GC ratio |
|---|---|---|---|
| The gigatonne gap in China's carbon dioxide inventories (GUAN et al., 2012) | 17 | 406 | 4.2% |
| New provincial CO2 emission inventories in China based on apparent energy consumption data and updated emission factors (SHAN et al., 2016) | 12 | 271 | 4.4% |
| Open-Source LCA Tool for Estimating Greenhouse Gas Emissions from Crude Oil Production Using Field Characteristics (EL-HOUJEIRI; BRANDT; DUFFY, 2013) | 12 | 65 | 18.5% |
| Consumption-based carbon emissions and International trade in G7 countries: The role of Environmental innovation and Renewable energy (KHAN et al., 2020b) | 10 | 275 | 3.6% |
| A top-bottom method for city-scale energy-related CO2 emissions estimation: A case study of 41 Chinese cities (JING et al., 2018) | 9 | 52 | 17.3% |
| Life cycle GHG emission analysis of power generation systems: Japanese case (HONDO, 2005) | 8 | 421 | 1.9% |
| A synthesis of carbon in international trade (PETERS; DAVIS; ANDREW, 2012) | 8 | 235 | 3.4% |
| Carbon footprints of cities and other human settlements in the UK (MINX et al., 2013) | 8 | 233 | 3.4% |

Source: Author's elaboration using data processed in Bibliometrix (ARIA; CUCCURULLO, 2017)

Considering all local and global citations, the overall LC/GC ratio is approximately 2%, and 17% (327 out of 1955) of the articles have an above-average LC/GC ratio. Analyzing these LC/GC ratio results in Table 3.13, the top 10 locally cited documents have an average ratio of 6.5%, three times the overall ratio. However, within this top 10, two articles have a significantly higher LC/GC ratio (EL-HOUJEIRI; BRANDT; DUFFY, 2013; JING et al., 2018), while the remaining eight have a ratio closer to the overall one. Comparatively, this means that these two articles have more relevance within this review subject, while the other eight arouse more interest in other subjects outside this research scope.

Finally, one last bibliometric data that can be explored are the authors' keywords. As mentioned earlier, there are a total of 4780 keywords. The total occurrences of these keywords amount to 7851, meaning an average of approximately four keywords per article. If duplicates are removed considering misspellings, acronyms, abbreviations, and singular-plural variations, this number is reduced to 4450. Synonyms and expressions with relatively close meanings were not merged to keep the authors' original intent as much as possible. The top 10 most frequent keywords are presented in Table 3.14

Table 3.14 – Top 10 most frequent keywords

| Keywords | Occurrences |
|---|---|
| GHG emissions | 237 |
| Life cycle assessment (LCA) | 221 |
| Carbon emissions | 217 |
| $CO_2$ emissions | 147 |
| Greenhouse gases | 135 |
| Climate change | 80 |
| Carbon footprint (CF) | 78 |
| Carbon dioxide ($CO_2$) | 71 |
| Emissions | 46 |

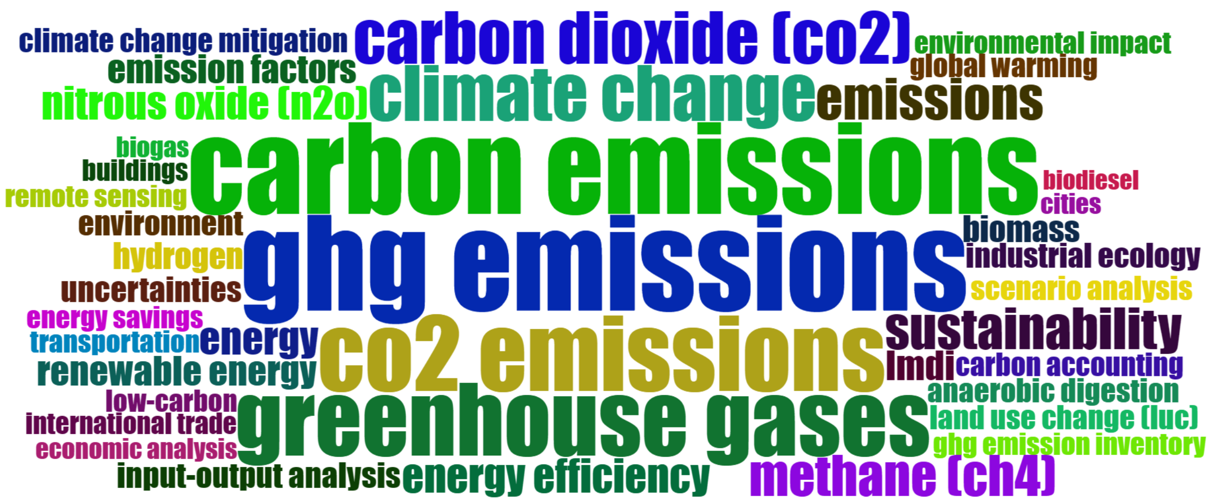
| Keywords | Occurrences |
|---|---|
| Sustainability | 44 |

Source: Author's elaboration using data processed in Bibliometrix (ARIA; CUCCURULLO, 2017)

Considering the last Bibliometric Law presented in the Method section, Booth-Zipf's Law, the Goffman Transition Point helps to define a semantic core group of keywords. In the present case, there is a total of 3680 keywords with occurrences equal to one. Therefore, according to Equation (2.4), the Goffman Transition Point occurs at approximately 85 occurrences. Using this information and the ranking from Table 3.14, the top 5 keywords are the constituents of this semantic core.

Starting from the overall ensemble of keywords, some techniques were adopted as different ways to visualize them. The keyword cloud is depicted in Figure 3.6, showing how the top 5 keywords, the semantic core defined using the Goffman Transition Point, stands out in its center while several other complementary keywords surround them.

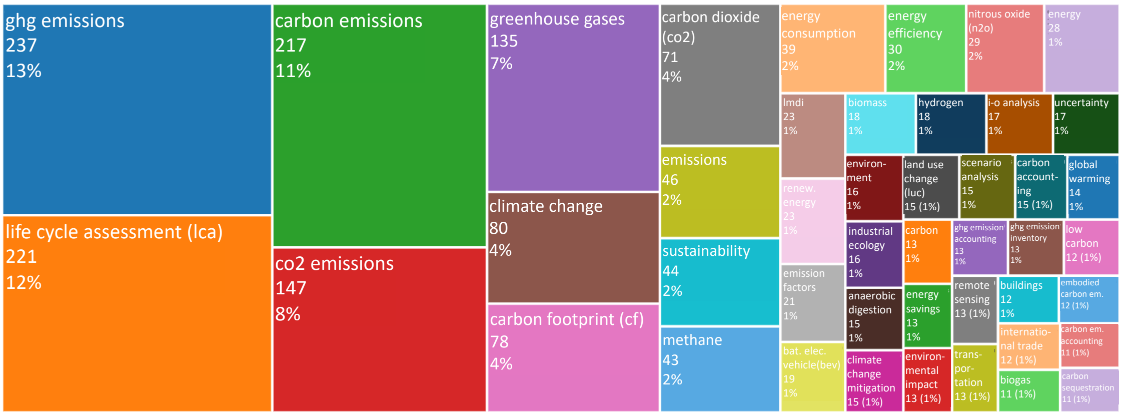
Figure 3.6 – Keyword cloud




Source: Author's elaboration using Biblioshiny (ARIA; CUCCURULLO, 2017)

The keyword treemap, shown in Figure 3.7, also helps localize and estimate some of these complementary subjects. For example, energy performance related keywords (such as energy consumption, energy efficiency, energy savings) sum 84 occurrences (4%); non-CO2 GHGs related keywords (methane, nitrous oxide) total 72 occurrences (4%); and renewable energy-related keywords (renewable energy, biomass, biogas, hydrogen) compute 70 occurrences (4%).

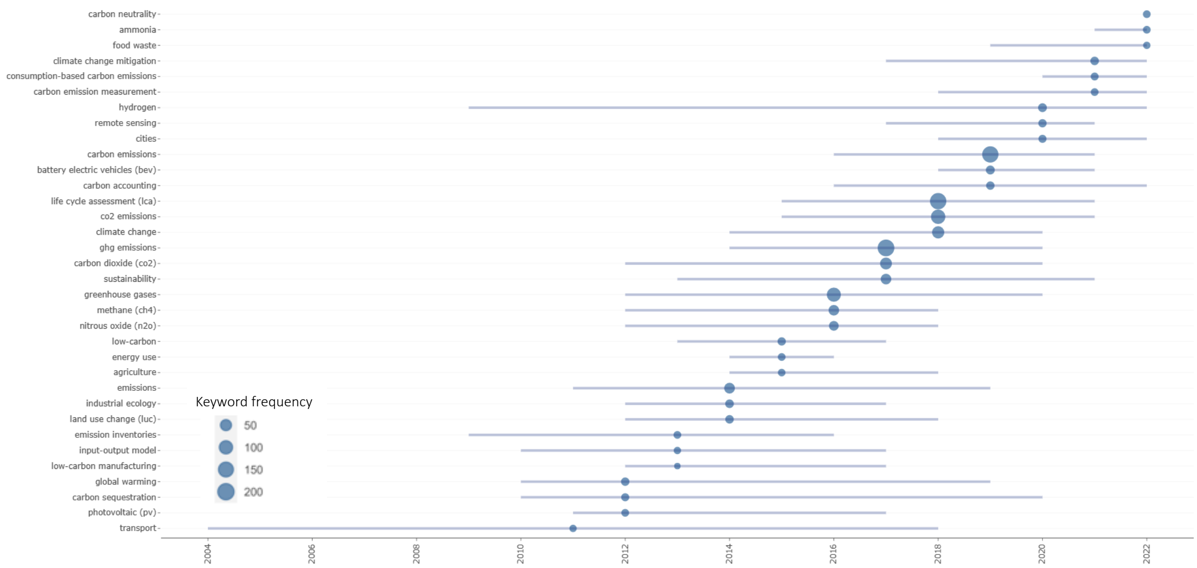
Figure 3.7 – Keyword treemap




Source: Author's elaboration using Biblioshiny (ARIA; CUCCURULLO, 2017)

Finally, the third visualization method considered, a trend topic graph, is displayed in Figure 3.8. In this method, it is possible to visualize that some topics, such as transportation and hydrogen, are temporally transversal, while the majority have a narrower timespan. For example, discussions related to GHG emission accounting gained more relevance around 2018. Climate change associated keywords move from global warming in 2012 to climate change in 2016, climate change mitigation in 2021, and carbon neutrality in 2022. Some trend topics relate to renewable energy and related technologies, from photovoltaic solar energy in 2012 to battery electric vehicles (BEV) in 2019 and hydrogen in 2020. Finally, carbon capture and storage (CCS) related keywords are trend topics, from carbon sequestration in 2012 to ammonia in 2022 (mainly associated with low-carbon production with CCS).

Figure 3.8 – Keyword trend topics




Source: Author's elaboration using data processed in Bibliometrix (ARIA; CUCCURULLO, 2017)

### 3.3.2 Network analysis

Considering the characteristics of different network analyses exposed in the methods section, combinations of possible networks were selected. First, citation and co-authorship networks were favored to analyze the relationship between article authors and between their respective countries. Next, bibliographic coupling, citation, and co-citation networks were adopted to investigate article sources. Finally, bibliographic coupling and citation networks were considered to evaluate the articles' relation. In all these cases, the objective is to use network analysis to put into perspective the previous bibliometric data covered in general analysis.

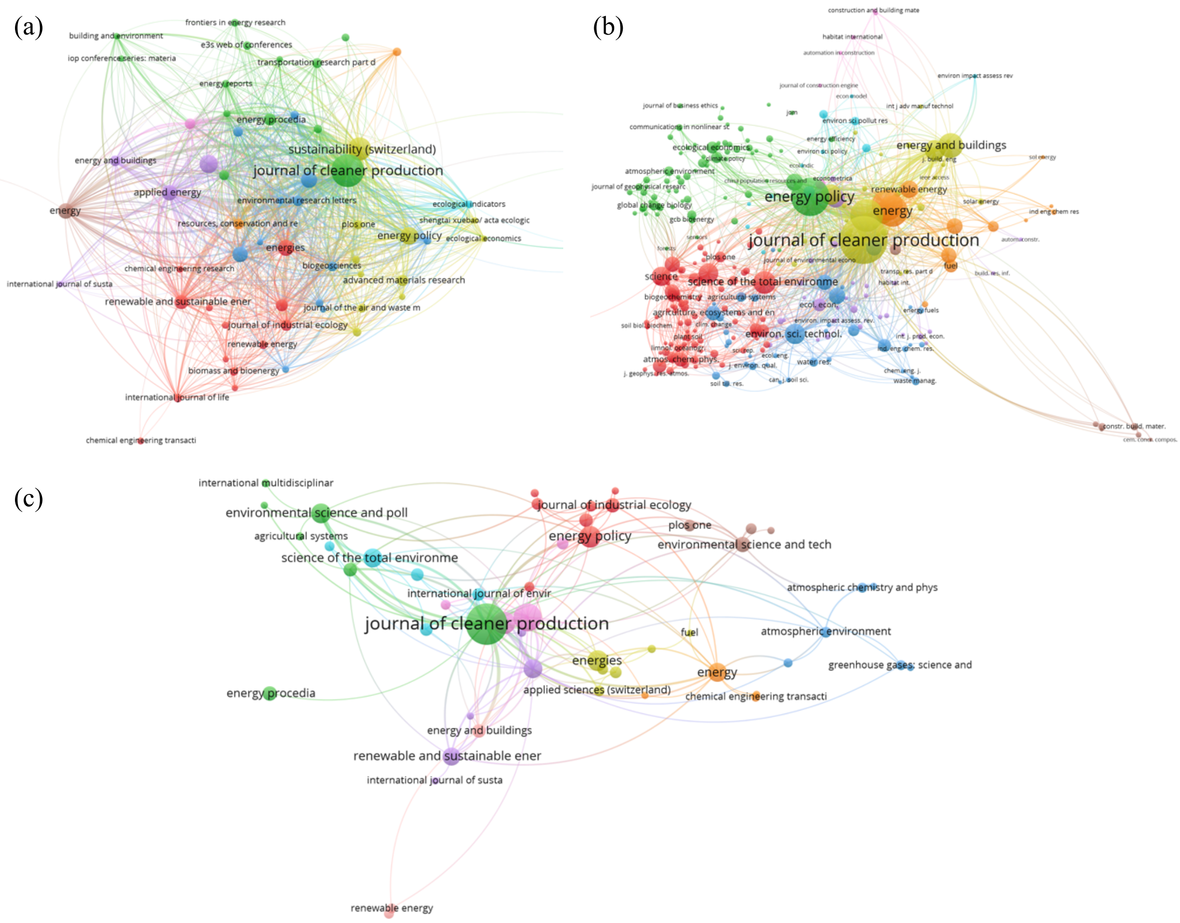
In terms of network structure, the following standards were considered. First, the vertex represents the network analysis unit, and its size reflects the number of associated articles. Second, the link between vertexes depends upon the network type, and the link width is proportional to its strength, i.e., how many times the same link connects the same two vertexes. Consequently, total link strength (TLS) is at least equal to the number of links. For example, in bibliographic coupling with sources as analysis units, the vertexes are sources (academic journals), and their size is the number of articles belonging to them. Third, a link represents that articles from two vertexes have cited references in common, and, finally, the strength of this link is proportional to the number of cited references in common that these articles have.

Each of these networks had its clusters investigated according to TLS (Total Link Strength) or the number of citations and the number of links. Complementary results for the top 3 vertexes with the highest TLS (or the number of citations) for the five most relevant clusters in these networks are presented in Table A.1, Table A.2, and Table A.3. The following paragraphs describe overall findings.

Bibliographic coupling, co-citation, and citation networks with article sources as analysis units are displayed in Figure 3.9. As expected from the top 10 core sources in Table 3.4, the Journal of Cleaner Production is a central source in all three networks, but this source scores high also in terms of TLS. Although an intermediate-size vertex, Applied Energy achieves the third position in TLS, resulting from its connections to several other clusters. The co-citation network reveals the relative importance of different sources: Environmental Science Technology, the primary vertex of the blue cluster; Science of the Total Environment, the central vertex of the red cluster; Energy and Buildings, a relevant vertex of the yellow cluster;

and Energy, a relevant vertex of the orange cluster. Finally, the Journal of Cleaner Production and Sustainability (Switzerland) is in the center of the citation network. Still, the Journal of Cleaner Production, Applied Energy, and Energy Policy have the highest TLS (in descending order, respectively).

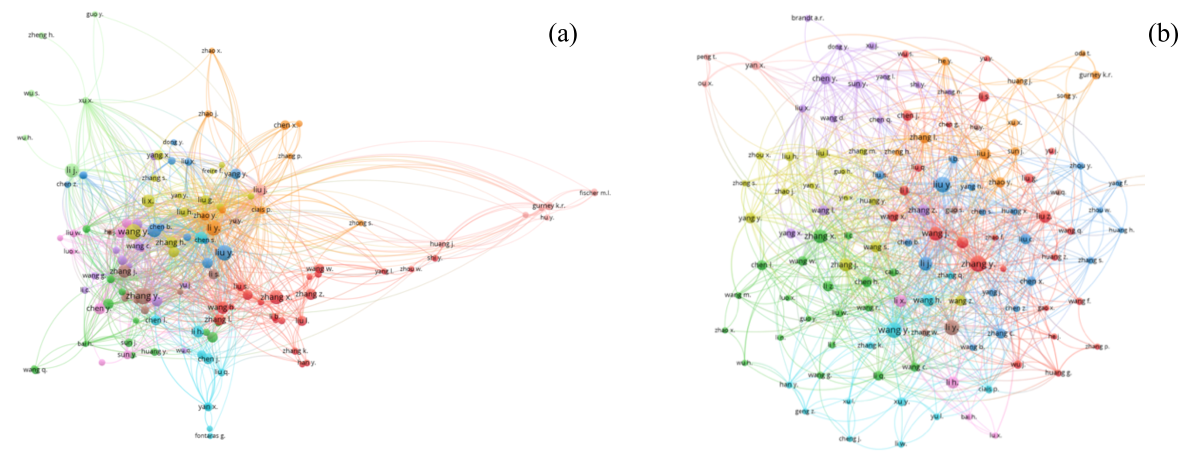
Figure 3.9 – Bibliographic coupling (a), Co-citation (b) and Citation (c) networks – Analysis unit: sources




Source: Author's elaboration using VOSviewer (VAN ECK; WALTMAN, 2010)

Citation and co-authorship networks with article authors as analysis unit are displayed in Figure 3.10. Observing the top 12 most productive authors presented in Table 3.6, these networks reveal that the top 3 most productive authors are also the most collaborative, as evidenced by Zhang Y., Wang Y., and Liu Y. being the three largest vertexes and having high TLS. The citation network also shows that Liu Y., despite being the third most productive author, figures as relevant as the first and the second, having the second highest TLS. One contributing factor is that the most locally cited article is authored by Liu Y., as reported in Table 3.13. Additionally, an intermediate vertex in the citation network has the third highest TLS, Cai B. An analysis of the top 50 most locally cited articles contribute to explaining this observation. Three articles are authored by Cai B., two by Khan Z., and the others by 45 different authors.

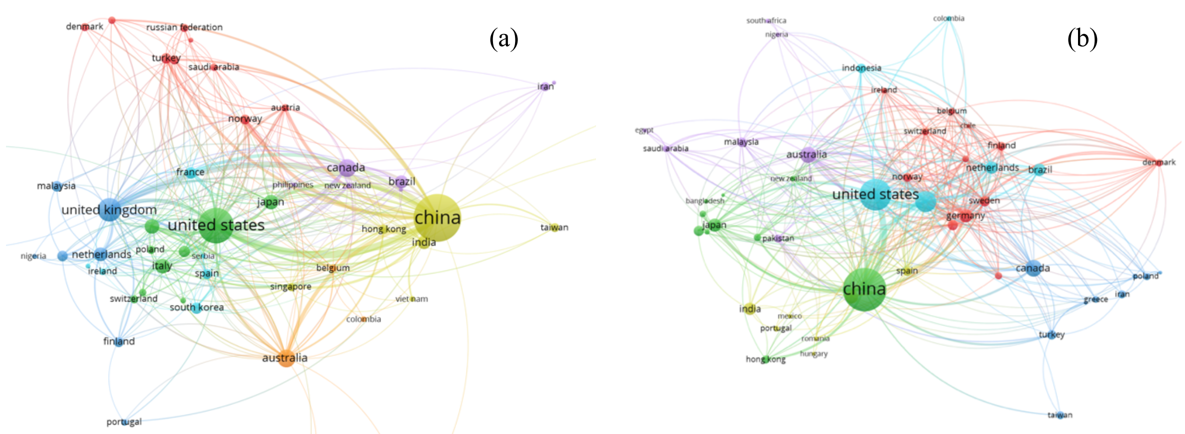
Figure 3.10 – Citation (a) and Co-authorship (b) networks – Analysis unit: authors




Source: Author's elaboration using VOSviewer (VAN ECK; WALTMAN, 2010)

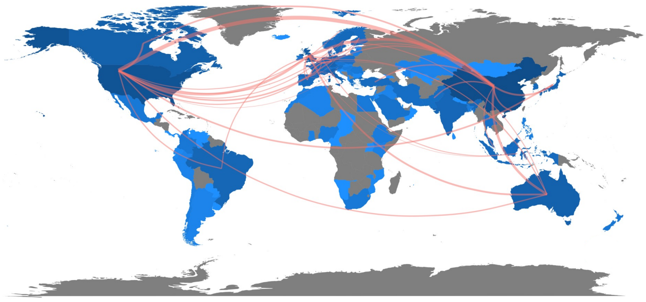
Citation and co-authorship networks with article authors' countries as analysis units are displayed in Figure 3.11. A co-authorship network geographical representation is shown in Figure 3.12. The top 3 countries with the most cited affiliations, in Table 3.10, and the top 3 corresponding countries, in Table 3.11, are consequently the three largest vertexes from citation and co-authorship networks: China, the USA, and the United Kingdom. However, some patterns are different when comparing citation networks to co-authorship networks. For example, the red cluster in the citation network connects the USA with several European countries. In contrast, these European countries are mainly interconnected in co-authorship, and the USA's co-authorship connections are more internationally diverse. Additionally, in terms of TLS, the same countries in the same order of relevance are observed.

Figure 3.11 – Citation (a) and Co-authorship (b) networks – Analysis unit: countries




Source: Author's elaboration using VOSviewer (VAN ECK; WALTMAN, 2010)

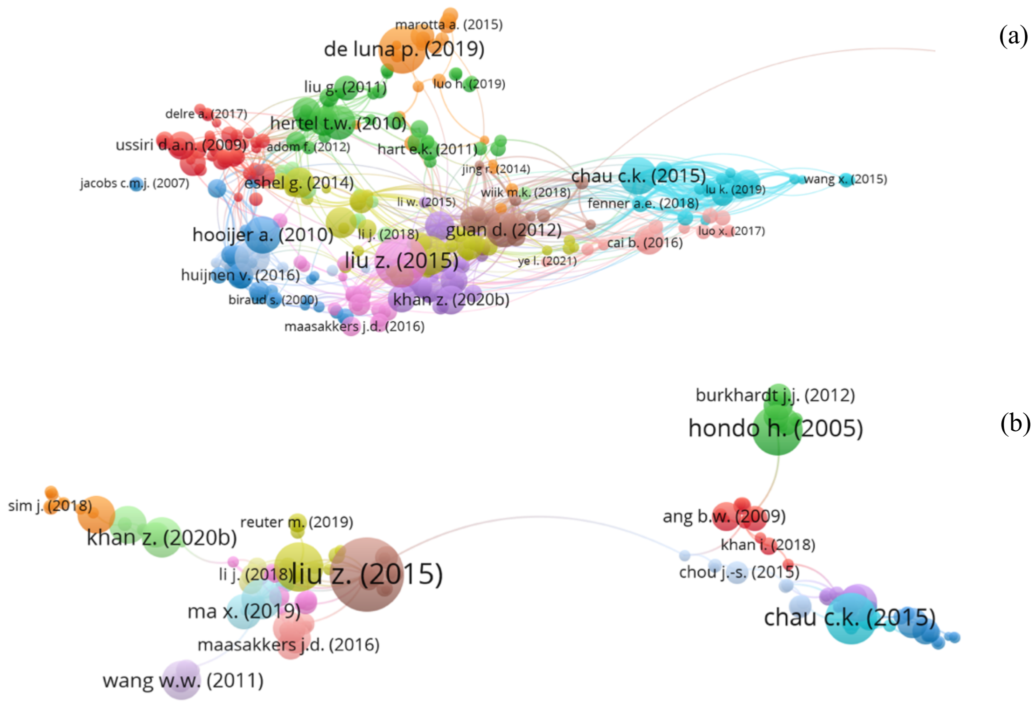
Figure 3.12 – Collaboration map – Analysis unit: countries



Source: Author's elaboration using Biblioshiny (ARIA; CUCCURULLO, 2017)

Bibliographic coupling and citation networks with articles as analysis units are displayed in Figure 3.13. Looking at both these networks, several most locally cited documents from Table 3.13 can be found as the main vertex of their clusters, particularly the top 3 (LIU et al., 2015), (CHAU; LEUNG; NG, 2015b) and (GUAN et al., 2012). Other documents that stand out in the bibliographic coupling network are (DE LUNA et al., 2019), the second most globally cited article, and (PETERS; DAVIS; ANDREW, 2012) and (BAI et al., 2016), articles with high TLS. In addition to these articles, the citation network also highlights the position of (HONDO, 2005) and (KHAN et al., 2020b), the sixth and eighth most locally cited documents with relevant TLS.

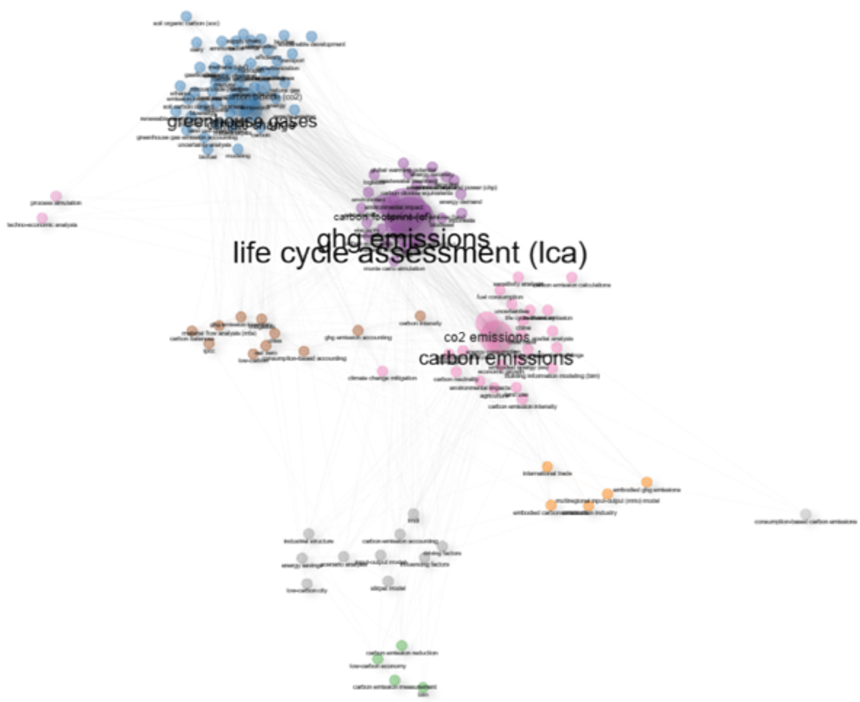
Figure 3.13 – Bibliographic coupling (a) and Citation (b) networks – Analysis unit: articles




Source: Author's elaboration using VOSviewer (VAN ECK; WALTMAN, 2010)

The last bibliometric data, keywords, is approached using a different method. Initially, a co-occurrence network is presented to perform a perspective evaluation. Then, this evaluation is translated into a thematic map. Subsequently, a thematic evolution is performed, using five time slices to represent the systematized review period from 2000-2022. The co-occurrence network with authors' keywords as analysis unit and the corresponding thematic map are displayed in Figure 3.14 and Figure 3.15, respectively. These findings are particularly relevant to highlight how the literature is organized in thematic clusters and how these clusters relate to each other in terms of relevance and development. There are three main clusters (blue, purple, and pink) in the basic themes' quadrant, followed by two intermediate clusters, one in the quadrant of motor themes (brown) and one in emerging/declining themes (grey). Finally, there are two clusters in the niche themes' quadrant (green and light grey) and two transitioning clusters, from emerging/declining to niche themes (light pink) and from niche to motor themes (orange). The clusters from Figure 3.15 were investigated by analyzing their associated keywords and articles. Complementary results regarding top keywords and top 3 articles related to each cluster are presented in Table A.4 and Table A.5, respectively. The following paragraph describes the overall findings.

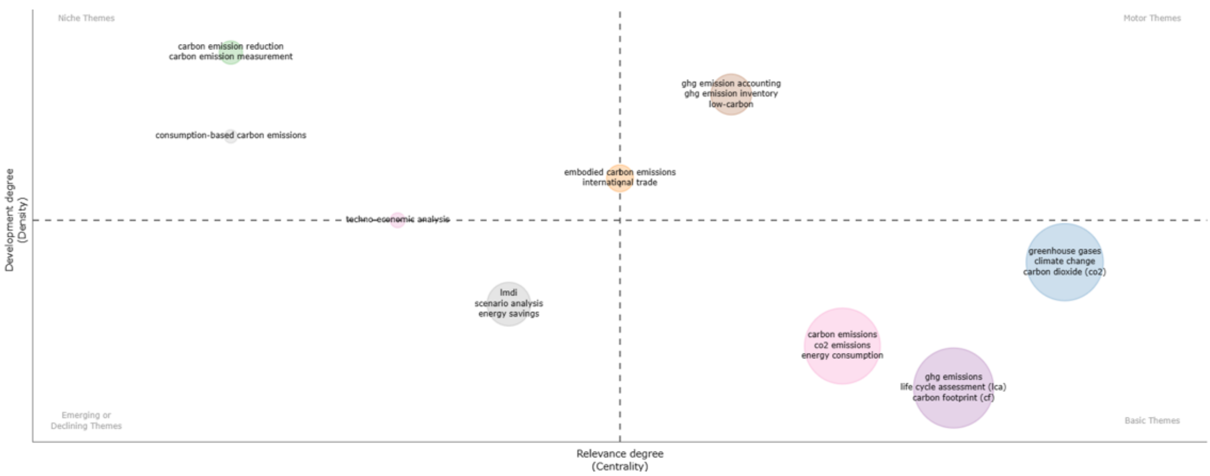
Figure 3.14 – Co-occurrence network – Analysis unit: authors' keywords




Source: Author's elaboration using Biblioshiny (ARIA; CUCCURULLO, 2017)

The three basic theme clusters regroup several publications on GHG emissions, differing by either approaches and sectors covered. Cluster #1 (purple) presents approaches with life cycle assessment (LCA) and carbon footprint (CF) mainly applied to transportation and agricultural sectors; Cluster #2 (blue) covers mainly the agrarian sector, with a variety of approaches, including LCA, inventorying and estimations. Cluster #3 (pink) deals with GHG emissions in the energy sector, with significant use of LCA and other approaches such as the input-output model. Cluster #4 (brown) is a motor theme cluster addressing a different question than the previous clusters, GHG emission accounting/inventorying in cities, and implications in low-carbon economy and policies. Cluster #5 (gray) is an emerging theme cluster in which articles focus on investigating GHG emissions by decomposition methods, particularly LMDI (Log Mean Divisia Index). Cluster #6 (orange) is an emerging theme cluster moving to the motor theme quadrant, discussing the carbon footprint of products and how they are impacted by trade and vice-versa. In this cluster, one of the approaches seen is consumption-based emissions, which is the focus of Cluster #9 (light grey), a niche theme. Cluster #7 (green) is a niche theme cluster with several approaches, mainly focused on industry and building sectors, to quantify carbon emission reductions. Finally, Cluster #8 (light pink) is an emerging theme cluster moving to a niche theme quadrant, addressing the techno-economic analysis of energy supply processes.

Figure 3.15 – Overall thematic map – Analysis unit: authors' keywords

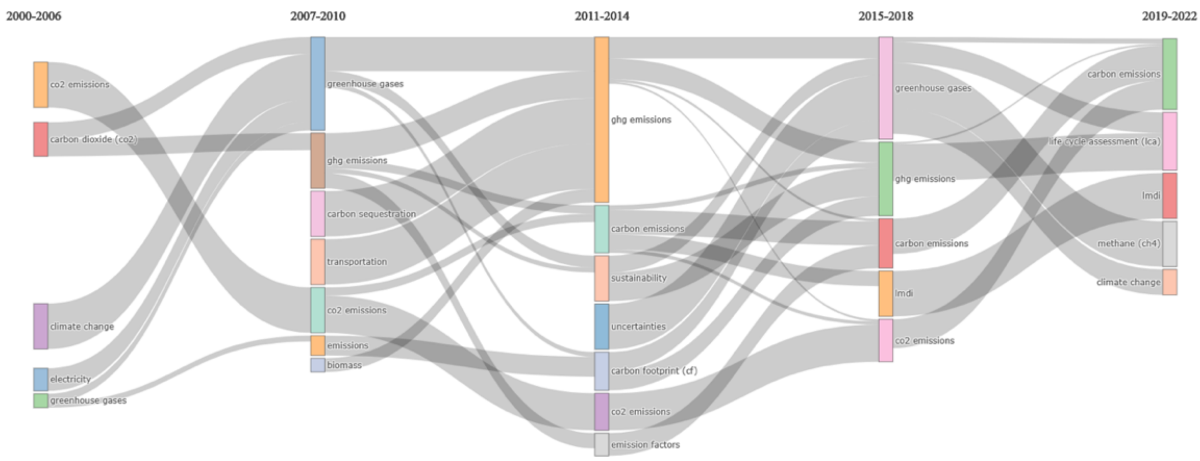



Source: Author's elaboration using Biblioshiny (ARIA; CUCCURULLO, 2017)

Thematic evolution with the author's keywords as an analysis unit is displayed in Figure 3.16. The thematic evolution shows technological and sectoral discussions within the first two time slices, such as biomass, electricity, carbon sequestration, and transportation. The successive three time slices move towards method discussion, from emission factor and carbon footprint to LCA and LMDI. While general GHG emissions concerns are transversal to the thematic evolution, in the last time slice, a non-$CO_2$ greenhouse gas gained notoriety, methane ($CH_4$).

For each time slice (TS) in thematic evolution, a thematic map was developed and shown subsequently in Figure 3.17 (TS1: 2000-2006), Figure 3.18 (TS2: 2007-2010), Figure 3.19 (TS3: 2011-2014), Figure 3.20 (TS4: 2015-2018), and Figure 3.21 (TS5: 2019-2022). The clusters from each time slice were investigated by analyzing their associated keywords and articles. The top keywords related to each cluster are presented, respectively, in Table A.6, Table A.8, Table A.10, Table A.12, and Table A.14. Top 3 articles for each cluster are exhibited, respectively, in Table A.7, Table A.9, Table A.11, Table A.13, and Table A.15. The following paragraphs describe overall findings.

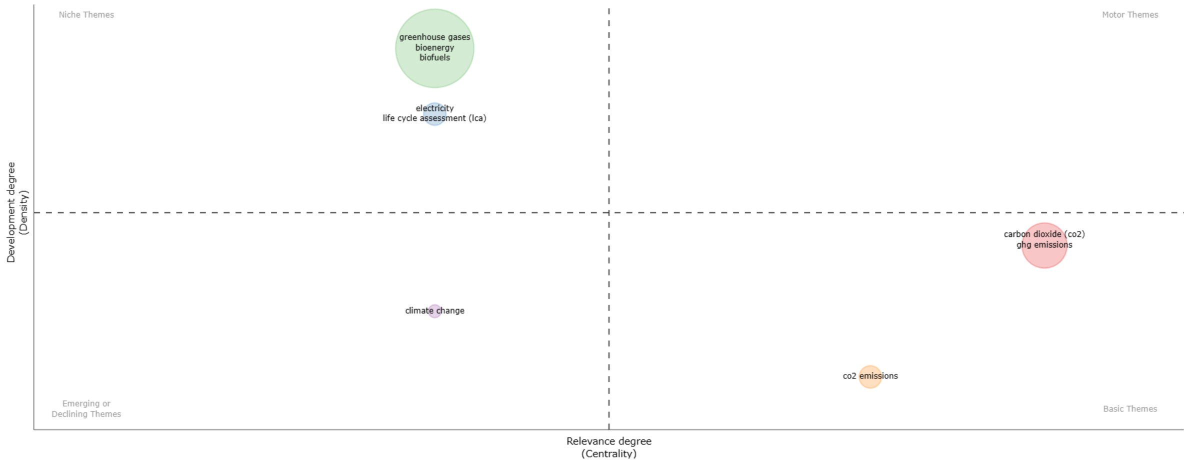
Figure 3.16 – Thematic evolution 2000 – 2022 – Analysis unit: authors' keywords




Source: Author's elaboration using Biblioshiny (ARIA; CUCCURULLO, 2017)

In TS1 (2000-2006) thematic map, from Figure 3.17, Cluster #1 (green) and Cluster #4 (blue) are niche theme clusters related to biomass and electricity, respectively. Both clusters cover bioenergy and renewable energy sources' relationship to GHG emissions. Cluster #2 (red) is a basic theme cluster that addresses GHG emissions in agriculture and land-use change (LUC). Cluster #3 (orange), a basic theme cluster, discusses emissions in defined regions and decomposition method challenges. Finally, Cluster #5 (purple) presents and discusses policy impacts from the climate change perspective. Cluster #1 (green) and Cluster #4 (blue) move to the motor themes quadrant in TS2 before fading out.

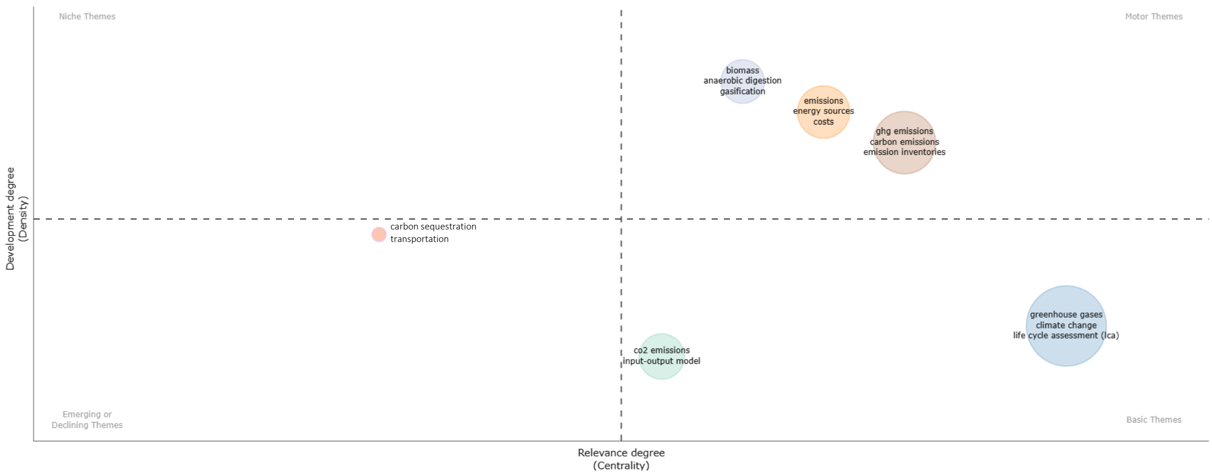
Figure 3.17 – Thematic map – 1st time slice (TS1: 2000 – 2006) – Analysis unit: authors' keywords




Source: Author's elaboration using Biblioshiny (ARIA; CUCCURULLO, 2017)

In TS2 (2007-2010) thematic map, from Figure 3.18, Cluster #1 (blue) is a basic theme cluster that covers several economic sectors but with the widespread use of LCA. This is an evolution movement since LCA started in a niche theme cluster in TS1. Cluster #4 (mint), also a basic theme cluster, encompasses urban environment and transportation scopes where GHG emissions are estimated using input-output models. The following three clusters are in the motor theme quadrant. Cluster #2 (brown) comprises discussions of GHG emissions inventories under the perspective of local governments or related to bioenergy and waste. Cluster #3 (orange) covers GHG emission estimation in energy production from different sources, except biomass, which is covered by Cluster #5 (lavender). Finally, Cluster #6 (rose/orange) is an emerging theme cluster containing transportation and carbon sequestration. This last cluster fades out from TS3 onwards compared to more cited themes.

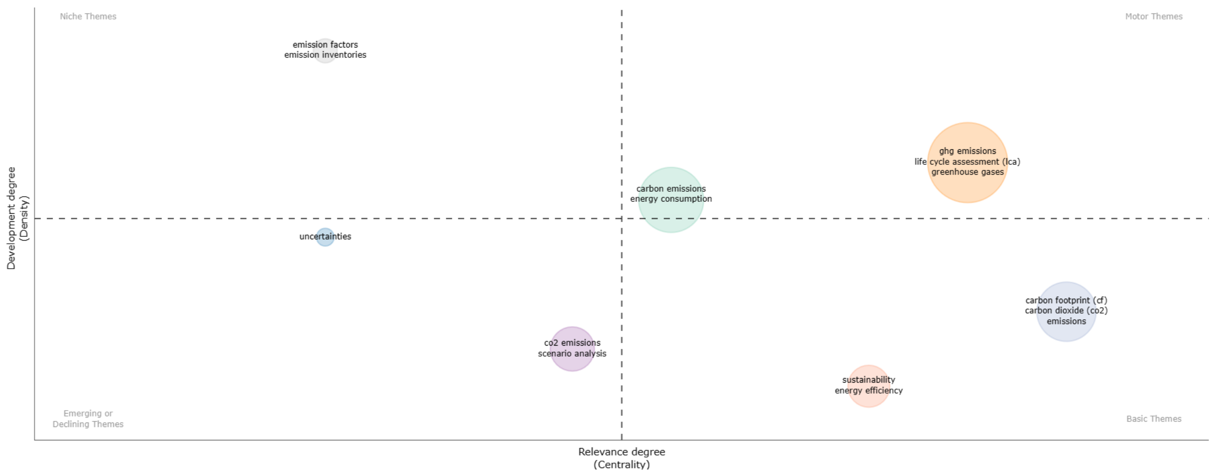
Figure 3.18 – Thematic map – 2nd time slice (TS2: 2007 – 2010) – Analysis unit: authors' keywords




Source: Author's elaboration using Biblioshiny (ARIA; CUCCURULLO, 2017)

In TS3 (2011-2014) thematic map, from Figure 3.19, Cluster #1 (orange) is the major cluster in the motor theme quadrant, discussing two major issues. The first is related to quantification by using LCA, which is a further evolution movement, not only in quadrant (basic to motor) but also in keyword ranking (3rd to 2nd). The latter issue concerns the impact of climate change mitigation strategies. Cluster #2 (mint) is also a motor theme cluster, which comprises discussions of energy-related emissions, mainly in the transportation and building sectors. Cluster #3 (lavender) and Cluster #5 (rose) are basic theme clusters focused on carbon footprint discussions and GHG emissions under sustainability and energy efficiency perspectives, respectively. Cluster #4 (purple) covers GHG emission evaluations in transportation, energy, and buildings, being scenario analysis the most common approach. Finally, both Cluster #6 (light grey) and Cluster #7 (blue) are interrelated, discussing modeling challenges. The first, in the niche theme quadrant, contains discussions regarding emission factors in GHG emission inventorying. In the emergent theme quadrant, the latter compasses uncertainty in estimation methods and GHG emission inventorying.

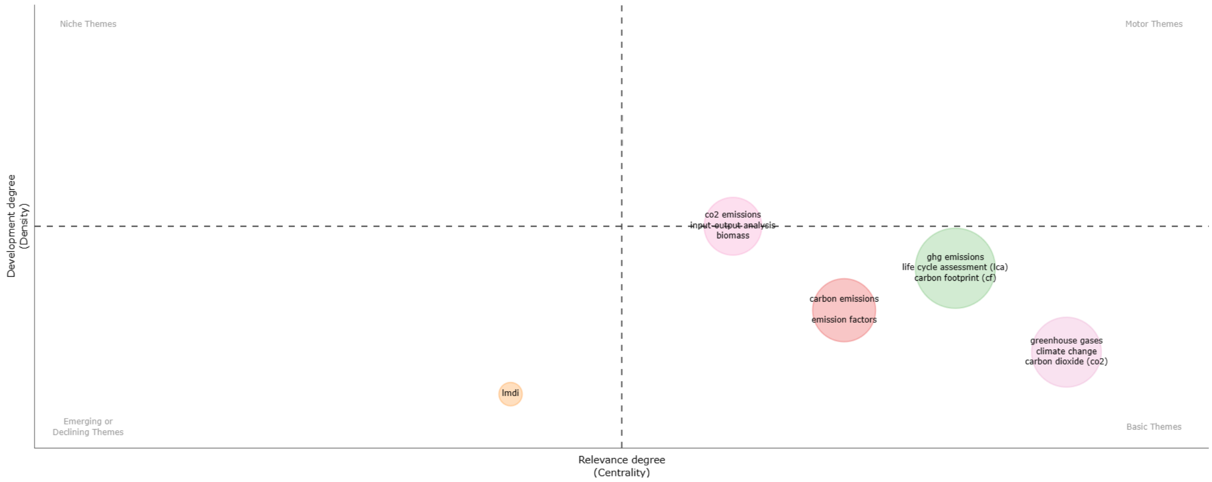
Figure 3.19 – Thematic map – 3rd time slice (TS3: 2011 – 2014) – Analysis unit: authors' keywords




Source: Author's elaboration using Biblioshiny (ARIA; CUCCURULLO, 2017)

In TS4 (2015-2018) thematic map from Figure 3.20, the three largest clusters are in the basic theme quadrant. Cluster #1 (green) is the major cluster, comprising discussions of LCA and carbon footprint in several sectors, from energy to agriculture. This shows a further evolution movement of LCA-related clusters, gradually returning to a basic theme cluster, after being in the motor theme quadrant. Cluster #2 (light pink) has a distinct coverage compared with previous clusters, as it discusses with more frequency non-$CO_2$ GHG such as methane ($CH_4$) and nitrous oxide ($N_2O$), mainly under the perspective of biomass and bioenergy. Cluster #3 (red) covers different carbon emission assessments, being buildings as one of the most relevant sectors, and discusses emission factors in LUC and other soil-related contexts. Cluster #4 (pink) lies in an intermediate region between motor and basic theme quadrants, presenting mainly buildings and biomass studies of related GHG emissions, with the input-output model as a frequent approach. Finally, Cluster #5 (orange) is located in the emerging theme quadrant, examining GHG emissions by decomposition methods, particularly LMDI.

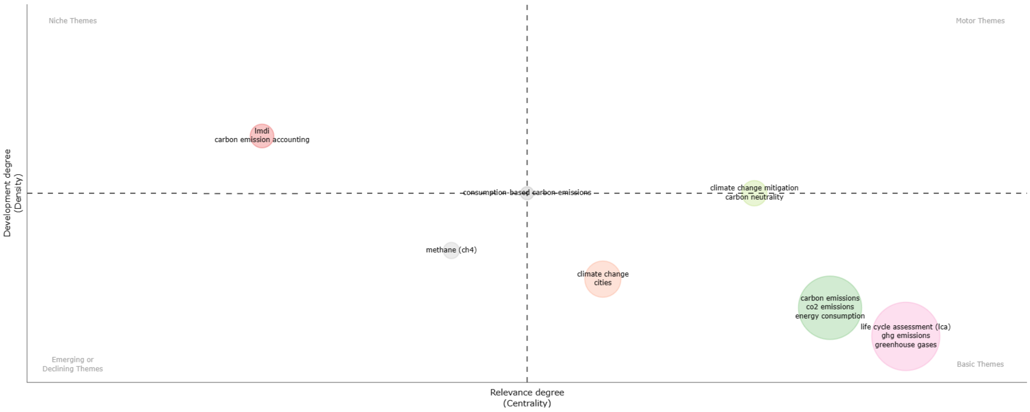
Figure 3.20 – Thematic map – 4th time slice (TS4: 2015 – 2018) – Analysis unit: authors' keywords




Source: Author's elaboration using Biblioshiny (ARIA; CUCCURULLO, 2017)

Finally, TS5 (2019-2022) thematic map, from Figure 3.21, has two main clusters in the basic theme quadrant. Cluster #1 (pink) is the first main cluster, an LCA-related cluster covering the energy and transportation sectors. This consolidates LCA as a highly relevant basic theme, being the 1st keyword in its cluster. On the other spectrum of relevance, another evolution of LMDI, initially an emerging theme in TS4, became a niche theme in Cluster #5 (red). Cluster #2 (green) is the second main cluster, discussing energy consumption-related emissions in different scenarios, such as specific energy-intensive processes, renewable energy and storage, and local/regional assessments. Cluster #3 is the last basic theme cluster, comprising assessments of city-level emissions, policies' impact, and bioenergy adoption. As a spin-off and evolution from the previous time slice, Cluster #6 (light grey) is an emerging theme cluster discussing GHG emissions from the perspective of methane ($CH_4$) emissions. On the other hand, a different spin-off results in Cluster 4# (lemon), which concentrates the discussion of climate change mitigation in a more recent trend topic, climate neutrality. Finally, Cluster 7# (grey) encompasses concepts of embodied carbon emissions and carbon footprint, including discussions on logistics and trade and approaches such as consumption-based emissions.

Figure 3.21 – Thematic map – 5th time slice (TS5: 2019 – 2022) – Analysis unit: authors' keywords

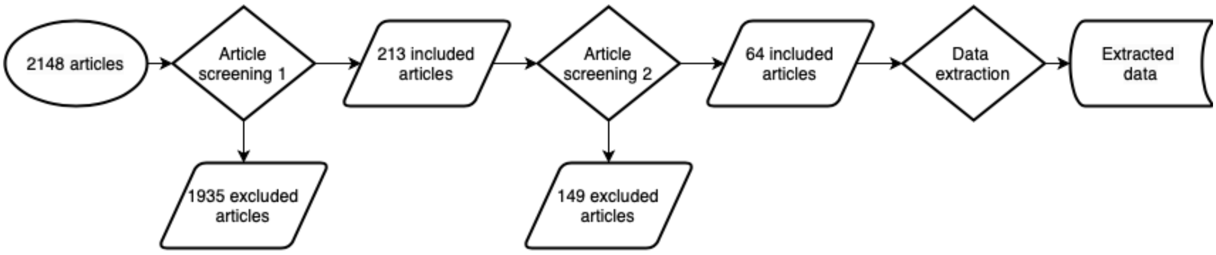



Source: Author's elaboration using Biblioshiny (ARIA; CUCCURULLO, 2017)

### 3.3.3 Content analysis

Complementing the literature's wide-ranging overview from the previous analysis, content analysis aimed to extract information from selected articles in-deep analysis. In article numbers, the content analysis processed 2148 articles in two screenings before data extraction, as illustrated in Figure 3.22.

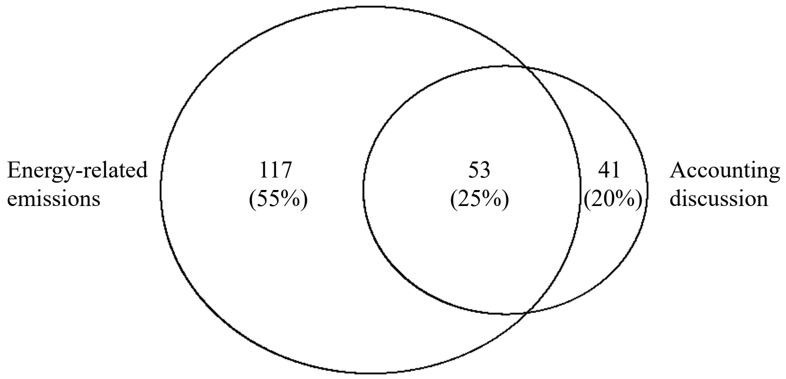
Figure 3.22 – Content analysis process flow




Source: Author's elaboration

Considering the first screening, two main approaches were investigated by analyzing the title and abstract. A total of 213 articles passed this screening, with their main subject covering energy-related emissions, GHG emission accounting discussion, or both approaches. Figure 3.23 presents how the articles that passed the first screening are distributed among these approaches. Although it is observed that application is more common as a subject than methodological discussions, this difference is not even more significant because the application considered here is only focused on energy-related emissions.

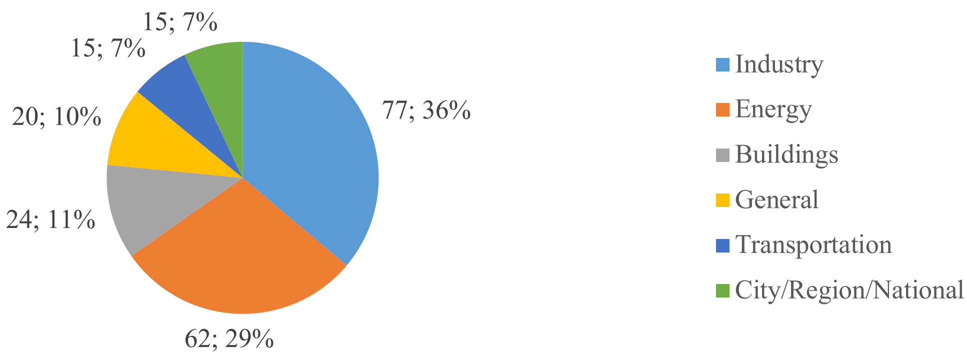
Figure 3.23 – Articles' main approach distribution after the first screening




Source: Author's elaboration

A first overview of these articles is drawn by collecting their object of analysis, mainly economic sectors such as Industry, Energy, Buildings, and Transportation. Additionally, a "City/Region/National" category was considered to classify those articles that discuss accounting over a geographical area rather than an economic sector. Finally, there may not be an object, thus, the article is classified into a "General" category, which mainly encompasses articles that discuss methodological concepts. Figure 3.24 presents how the articles that passed the first screening are distributed among these categories. As expected, the industrial and energy sectors are the most investigated. More detail is presented in Figure 3.25.

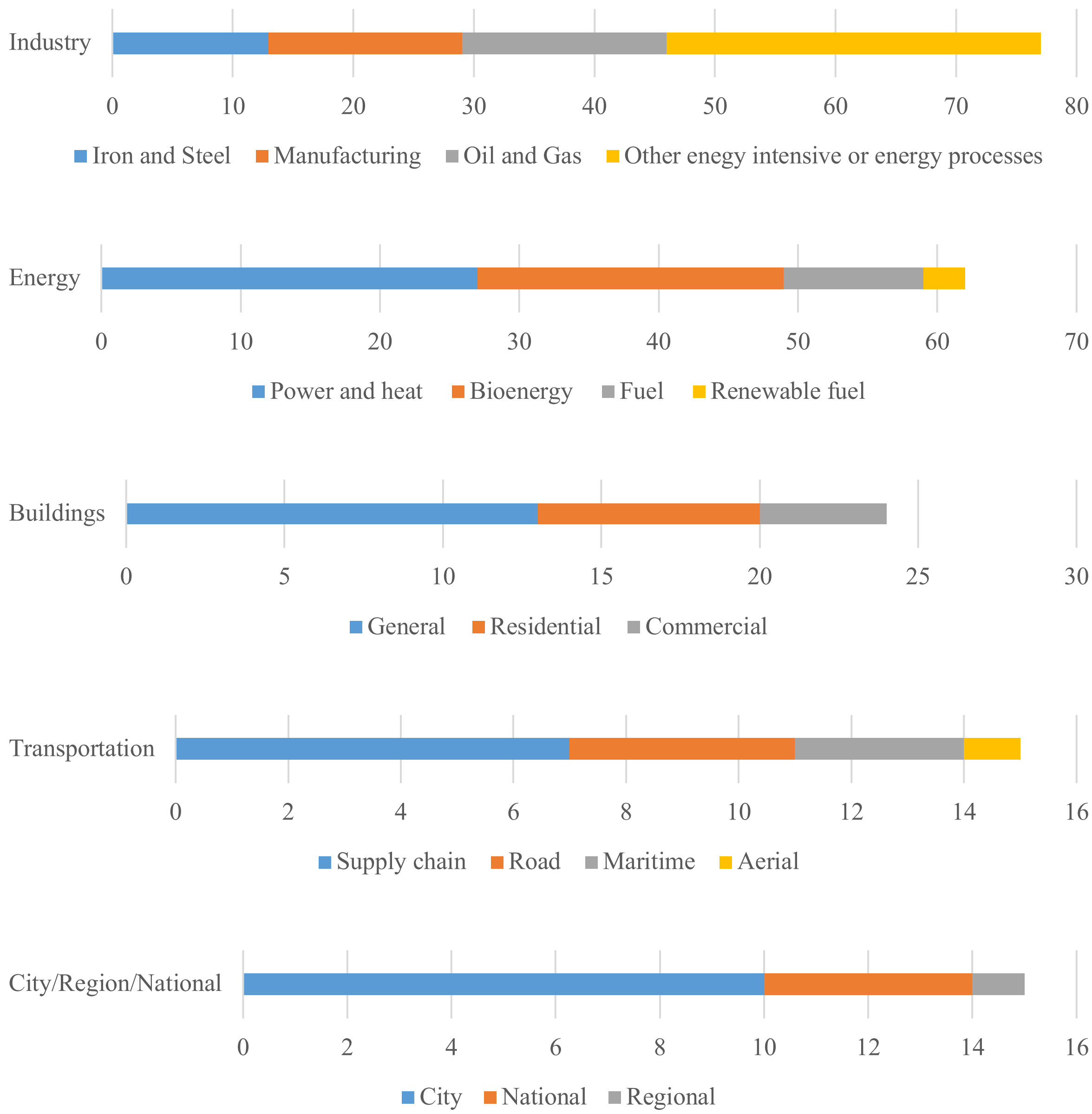
Figure 3.24 – Articles' sectoral distribution after the first screening




Source: Author's elaboration

Among the industrial sector, energy-intensive industries stand out, such as Oil and Gas, and Iron and Steel. Manufacturing industries are also a relevant result of mainly voluntary movements to reduce the carbon footprint of products and current carbon neutrality discussions. Power and heat generation dominate the scenario alongside bioenergy in the energy sector. The first has repercussions on other evaluations, particularly considering Scope 2 emissions, and the latter is often discussed under the perspective of life cycle assessment (LCA). Contrary to the previous sectors, the buildings sector has several publications giving general guidance, which may be applied to residential, commercial or other building types. A particular perspective covers the transportation sector, the effect of supply chain on carbon emissions, with frequent discussions related to embodied carbon emissions. Finally, the city-level was the most recurrent, habitually combined with policy discussions among the geographical coverages.

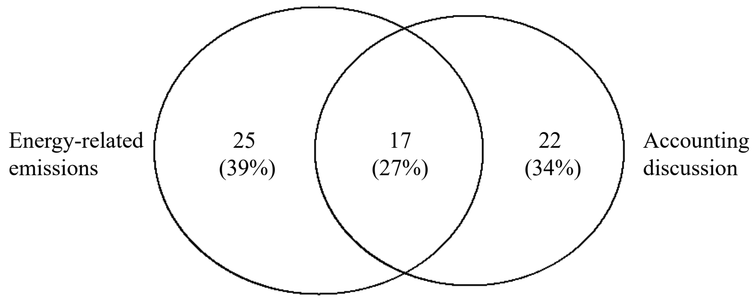
Figure 3.25 – Detailed sectoral distribution after the first screening




Source: Author’s elaboration

Considering the second screening, a brief full-length analysis was conducted to evaluate if the subjects of interest were just applied or described or if there was a more in-depth discussion. For the approach of energy-related GHG emissions, it was considered if these emissions were presented, but also indications on how they were calculated and the premises adopted. For the approach of accounting discussion, it was considered if these methods were presented and discussed in their main aspects and eventually compared to others. A total of 64 articles passed this screening, with their main subject covering energy-related emissions, GHG emission accounting discussion, or both approaches. Figure 3.26 presents how the articles that passed the second screening are distributed among the main approaches. As inferred from the final distribution, accounting discussion articles were more consistent when passing through the quality screening. On the other hand, many energy-related emissions papers were excluded in this second screening because they only reported emissions, particularly on the city/regional/national level, or they didn't disclose sufficient information regarding calculation procedures.

Figure 3.26 – Articles' main approach after the second screening

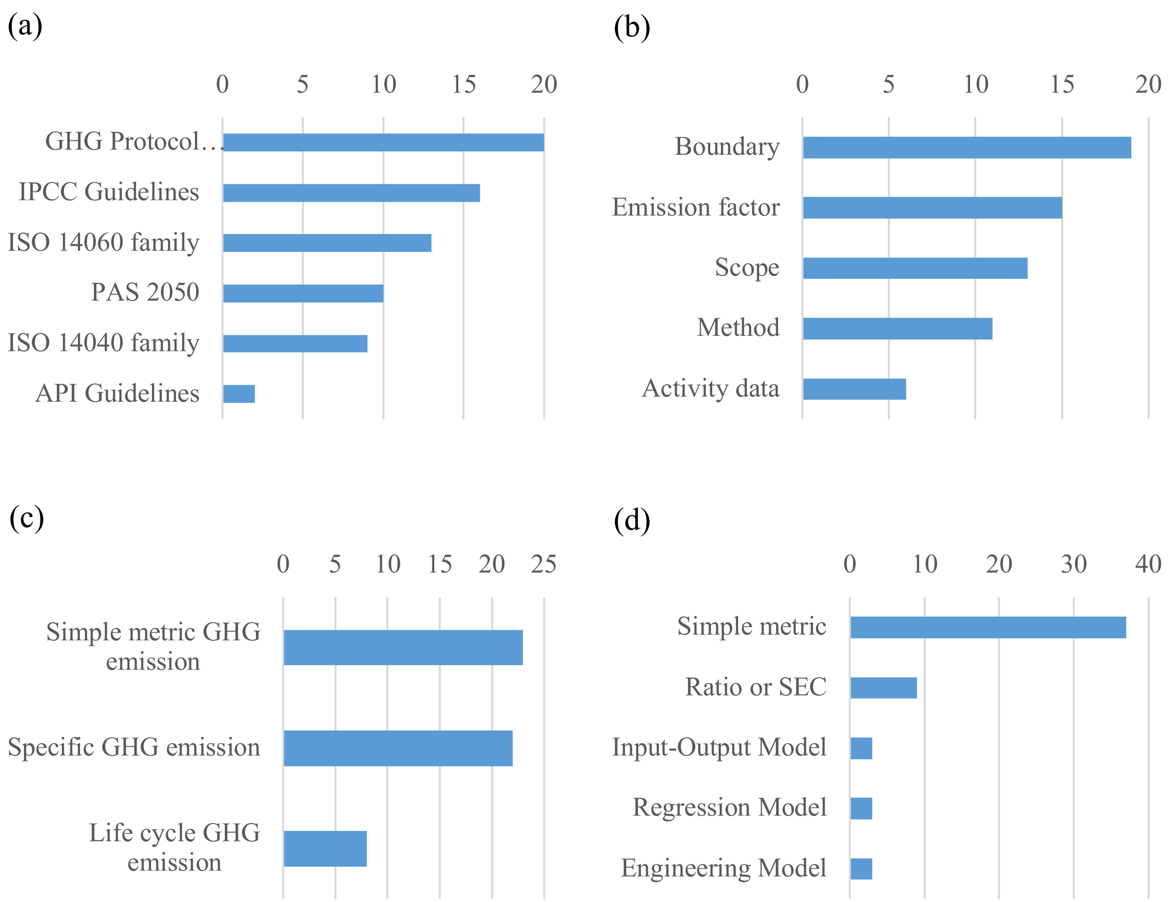



Source: Author's elaboration

These final selected articles passed through a data extraction process, where four main topics were covered: GHG accounting method mentioned; GHG accounting element discussed; Energy-related emission indicator; Energy-related activity data. Consolidated findings of data extraction are presented in Figure 3.27. Detailed information regarding the final selected papers is exhibited in Table A.16 (list of final selected articles), Table A.17 (main approach and sectoral distribution), Table A.18 (Figure 3.27 (a) by article), Table A.19 (Figure 3.27 (b) by article), and Table A.20 (Figure 3.27 (c) and Figure 3.27 (d) by article). Among the methods mentioned, GHG Protocol Standards and Guidance are the most frequent followed by IPCC Guidelines. Standard families follow these methods, including LCA related, and only one sectoral guideline was mentioned (API Guidelines).

Regarding accounting discussion, the boundary was the most frequent discussion element, covering both life cycle and physical approaches. The emission factor was the second most discussed accounting element, focusing on Scope 2 (electricity) or the variability of values according to references. Another relevant discussion is related to the adopted method's implications, mainly focused on a debate of attributional and consequential approaches. Under the energy-related emission perspective, with the results fairly distributed among simple metric (absolute value) and specific emissions, the type of activity data used was predominantly concentrated in simple metric.

Figure 3.27 – Data extracted from final selected articles - GHG accounting method mentioned (a); GHG accounting element discussed (b); Energy-related emission indicator (c); Energy-related activity data (d)




Source: Author’s elaboration

## 3.4 Discussion

After presenting this review's findings with different analysis approaches, this discussion section covers the current state and trends on approaches adopted to greenhouse gas emissions accounting focusing on energy-related emissions. The first discussion topic is the general state of approaches adopted to greenhouse gas emissions accounting.

As a general method, the greenhouse gas emissions are estimated by multiplying activity data by an emission factor for activities that take place inside a given boundary related to a subject, which can be an organization, a product, a project, a policy, or a geographical entity (countries, regions, and cities). Since there will be a flow across the boundary in almost all situations, defining emission scopes is necessary. Direct emissions (i.e., emitted inside the boundary) from activities inside the boundary are Scope 1 emissions. Indirect emissions (i.e., emitted outside the boundary) from activities inside the boundary are Scope 2 emissions. Finally, indirect emissions from activities outside the boundary but attributed to activities from inside the boundary are Scope 3 emissions (Bastianoni, Marchi, et al., 2014; Bhatia et al., 2011; Garcia & Freire, 2014; IPCC, 2006; Ranganathan et al., 2004; Sotos, 2015; P. Wu et al., 2015).

Defining an adequate boundary is challenging since it impacts the emission scopes considered, particularly Scope 3 emissions. Establishing which sources and sinks shall be accounted for and in which scope is a task that may follow one of two main approaches. Accounting for greenhouse gas emissions and removals due to anthropogenic actions for a given boundary is an attributional approach. Quantifying emission changes occurring from a given action, decision, project, or policy is a consequential approach (BRANDER, 2022; GIBASSIER; SCHALTEGGER, 2015; PRAPASPONGSA; GHEEWALA, 2017; WEBER et al., 2009).

Choosing appropriate activity data and emission factor is also a challenge. They should be coherent with the emission scopes and with the defined boundary. To improve credibility in disclosing greenhouse gas accounting, transparency on how activity and emission factors are considered is essential. Ideally, all these factors should be time-specific, but generally, such high temporal resolution factors are not available everywhere (KHAN, 2018; LIU et al., 2022; PETER; HELMING; NENDEL, 2017; SILVA, 2021; SPORK et al., 2015).

The second discussion topic is trends in approaches adopted to greenhouse gas emissions accounting, which results from thematic evolution from network analysis. There are several significant movements observed in the timeframe from 2000 to 2022. LCA methods grew significantly in relevance from a niche theme to a basic theme. This movement is closely related to the increased occurrence of carbon footprint and, more recently, carbon neutrality. Other methods, such as LMDI and Input-Output model, appeared in specific scenarios as national inventorying, with countries or industrial sectors as subjects, but they never evolved or consolidated into basic themes (EL-HOUJEIRI; BRANDT; DUFFY, 2013; FENNER et al., 2018; PINEM; KARUNIASA; ABDINI, 2020; TIAN; ZHU, 2015; TRINH; DOH, 2018).

Thematic evolution also allowed an analysis of occurrences of economic sectors and GHG types. From a sectoral perspective, industrial and buildings are recurrent under an end-user perspective, while the energy sector standout as a critical subject due to its impacts on GHG emission accounting of the other economic sectors, particularly due to electricity in Scope 2 emissions. Finally, in terms of GHG types, the observed movement is a shift from a $CO_2$ perspective to a broad GHG perspective, with some types being relevant to some sectors, such as $CH_4$ and $N_2O$ to agriculture and $CH_4$ to the oil and gas industry (ABELLA; BERGERSON, 2012; HONDO, 2005; PAN; QIN; ZHAO, 2017).

After these two broad topics, the following discussion topic delves into some aspects from the perspective of evaluating energy-related emissions. Firstly, a process and energy mapping, including energy flows, are fundamental to help boundaries and scope definition. This basic procedure is generally applied since Scope 1 and 2 emissions related to energy use depend upon this information. Calculation challenges are associated with the consistency of activity and emission factors to reflect the subject's reality. This can be achieved by either increasing the complexity of methods or reflecting on how different assumptions might affect these factors. Going up in a tiered scaled methodology can imply moving from database standard values up to subject on-site observed numbers and increasing the temporal resolution of these factors (BRANDER, 2017; HACATOGLU; ROSEN; DINCER, 2012).

A particular case related to energy-related emissions concerns electricity. Calculating a grid electricity emission factor can be challenging, especially for interconnected electrical networks. Modeling assumptions are also highly relevant and can add uncertainty if not properly addressed. The grid electricity emission factor is location-based, i.e., it depends upon the electricity mix in the grid to which the subject is connected. Another approach is marked-based, mainly used to incorporate renewable electricity, when the subject electricity emission factor, based on a contractual relationship, differs from the grid. While avoiding challenges from the location-based approach, the market-based arise concerns, particularly if the calculations are based on attributional methods or if no additional renewable generation capacity is expected following this contractual purchase (BRANDER; GILLENWATER; ASCUI, 2018; KHAN, 2019).

Content analysis findings corroborate the relevance of these three discussed topics. Starting with standard methods, such as GHG Protocol, IPCC Guidelines, ISO 14040 family, and ISO 14060 family, the content analysis also depicts a scenario of accounting discussion focused on boundary and emission factor (focused on Scope 2 – electricity), also covering distinctions attributional and consequential approaches. The following elements from content analysis findings emphasize the energy-related emission perspective, where reporting was distributed among simple metric (absolute value) and specific emissions. At the same time, the type of activity data used was predominantly concentrated on simple metric.

These last findings from content analysis guide the discussion to a final topic, a reflection on energy use representation when estimating emissions. Particularly for the activity data, when considering energy-related emissions, there is a disseminated use of simple metric (absolute value) as the activity data, followed by specific energy consumption. The underlying challenge is the source of these values and how they truly reflect the subject reality. Considering a perspective of energy performance evaluation with indicators, these metrics can be both reporting types and modeling assumptions. Furthermore, this perspective also highlights a particular accounting discussion topic with few occurrences or baselines. For example, an adequate baseline is fundamental when comparing two inventorying periods in an attributional approach or when evaluating impacts in a consequential approach. There are some international references for specific sectors and applications, such as UNFCCC CDM methodologies, but a perspective of energy performance evaluation with indicators could also help to define these baselines (ÅDAHL; HARVEY; BERNTSSON, 2004; LEE et al., 2005).

## 3.5 Conclusions

Considering the relevance of accounting methods in reporting greenhouse gas emissions and the role played by energy-related emissions, this work conducted a systematized review of scientific publications on energy-related GHG emissions accounting methods. Scopus was identified as the most comprehensive database and used in bibliometric and network analysis to identify the current state of scientific research and trends.

After general and quality screenings, a smaller group of articles passed through a more in-deep analysis and data extraction covering four main topics: GHG accounting method mentioned; GHG accounting element discussed; Energy-related emission indicator; Energy-related activity data. The findings highlight relevant conceptions, premises, and features and report challenges and possible solutions to these issues.

Thematic evolution from network analysis provided insightful results. LCA methods grew significantly in relevance, from a niche theme to consolidating itself as a fundamental theme. Other methods, such as LMDI and Input-Output model, appeared in specific scenarios but never consolidated into basic themes. Industrial and buildings are recurrent from an end-user perspective, while the energy sector standout as a critical subject, particularly due to electricity in Scope 2 emissions.

Content analysis corroborated findings from general bibliometric and network analysis. Accounting discussion is focused on boundary and emission factors (focused on Scope 2 – electricity), also covering distinctions between attributional and consequential approaches. The following elements from content analysis findings emphasize the energy-related emission perspective, where reporting was distributed among simple metric (absolute value) and specific emissions. At the same time, the type of activity data used was predominantly concentrated on simple metric.

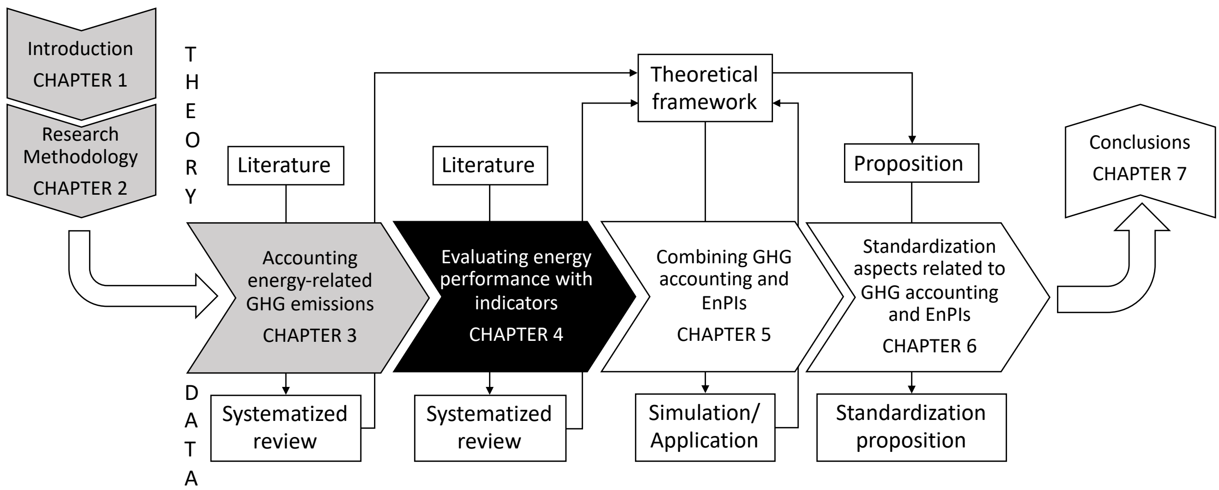
The last findings from content analysis open a discussion regarding challenges in energy-related GHG emissions accounting, particularly on energy use representation when estimating emissions. For example, activity data, temporal resolution, and baseline shall be adequately chosen and should be coherent with other elements such as boundary, scope, and emission factor. A possible approach identified was the incorporation of energy performance evaluation with indicators. Considering this systematized review, future studies could investigate the use energy performance evaluation approach to improve energy-related GHG emissions reporting, assessing the impact of different indicator modeling and reporting types and how these procedures could be stepwisely organized.

Finally, this chapter aimed to answer the following question – “Focusing on energy-related emissions, what are current state and trends on approaches adopted to greenhouse gas emissions accounting?” – using three more specific questions. The first question – “In general, what are the current state and trends on approaches adopted to greenhouse gas emissions accounting?" – was answered by the thematic evolution from network analysis, which has provided insightful results on the relevance of the approaches throughout time. The second question – "Considering these approaches, what are the ones adopted when evaluating energy-related emissions?" – and the third question – "Considering these approaches on energy-related emissions, what are the factors reflecting energy that are considered?" – were answered by the content analysis, which has collected specific data on approaches and factors regarding the GHG emission accounting.

# 4 EVALUATING ENERGY PERFORMANCE WITH INDICATORS

This Chapter presents the article submitted to Applied Energy titled “Evaluation of energy performance: a review of indicator definitions and associated methods”. The contents are from the original manuscript, but adjustments were made to adapt the article to this thesis format. Therefore, the published version may contain a different structure and changes suggested by the journal’s editor and reviewers. This chapter's contribution in the context of this thesis is highlighted in Figure 4.1.

Figure 4.1 – Overall structure of this thesis highlighting Chapter 4 contribution




Source: Author’s elaboration

## 4.1 Introduction

Fighting climate change is an urgent need, and for that, it is necessary to assess its main causes to design effective climate change mitigation strategies to keep the average global temperature rise around 1.5ºC. These causes are related to anthropogenic activities resulting in emissions to the atmosphere of greenhouse gases (GHG). Energy use is the most contributing factor anthropogenic GHG emissions, being responsible for 75% of these emissions. In 2019, energy supply was the most significant economic sector, with 34% of total emissions (20 $GtCO2_e$). However, 23 p.p. of these emissions (14 $GtCO2_e$) are associated with the final energy use of electricity and heat from industrial and buildings sectors. Therefore, considering direct and indirect emissions, the most contributing sector is industry with 34% (20 $GtCO2_e$), buildings with 16% (9.7 $GtCO2_e$), transport with 15% (8.9 $GtCO2_e$), AFOLU (Agriculture, forestry and other land use) with 22% (13 $GtCO2_e$), and energy sector with 11% (6 $GtCO2_e$). Consequently, these figures for GHG emissions associated with energy use in industry and building sectors make them the primary targets for mitigation actions (CHOUDHARY; SRIVASTAVA; DE, 2018; DHAKAL et al., 2022; UNEP, 2022; WRI, 2022).

Regarding energy demand, this priority ranking looks similar in 2021 since the industry responds for 38% (167 EJ) of global final consumption, followed by buildings accounting for 30% (132 EJ). This demand is supplied by electricity, which may have a different supply matrix by country, and fuels, which may have fossil or renewable origin. For example, in the same scenario of 2021, industry energy demand was supplied mainly by fossil fuels (67%), followed by electricity and heat (22% + 4%) and renewables (7%). On the other hand, in buildings, energy demand was supplied mainly by electricity and heat (34% + 5%), closely followed by fossil fuels (37%) and renewables (21%), which is primarily the traditional use of biomass. As there is no silver bullet solution, decarbonizing energy use will require a portfolio of solutions (IEA, 2021, 2022).

Considering the expected transition to a low-carbon electric mix with increased usage of renewable sources, most scenarios for future energy demand in industrial and building sectors envisage increased electrification and fuel switch to low-carbon fuels. However, energy efficiency, avoiding demand, and behavioral change are other critical factors in transitioning to a Net Zero (NZE) scenario. Together, these three mitigation measures account for 24% of GHG emissions reductions expected by 2030. Energy efficiency is more prominent in this time slice, representing 2/3 of the mentioned reductions. These three mitigation measures account for 22% of GHG emissions reductions expected between 2030 and 2050. However, avoiding demand and behavioral change is more prominent at this time slice, representing 2/3 of the mentioned reductions (IEA, 2021, 2022).

Energy efficiency is acknowledged as one of the quickest and most cost-effective means of mitigating $CO_2$ emissions, concurrently reducing energy costs and enhancing energy security. Despite this, energy efficiency potential is partially untapped due to various financial, behavioral, technical, and organizational barriers. This non-explored potential is usually called the energy efficiency gap, which is frequently approached from a technologist's point of view. Within this approach, energy efficiency is harnessed by technology shifts towards more efficient equipment. A complementary approach highlights another layer of energy efficiency that can be explored, achieving an extended energy efficiency potential. This further potential is referred to as the energy management gap, and with this approach, energy efficiency is harnessed by management actions to improve energy performance (BACKLUND et al., 2012; IEA, 2021; JAFFE; STAVINS, 1994).

The international community has identified energy management as a tool to overcome barriers to energy efficiency and to incorporate avoided demand and behavioral changes into the culture of organizations. In the past decade, the scientific community has shown a growing interest in energy management, tackling energy efficiency from various perspectives and incorporating several economic sectors. Using appropriate energy performance indicators (EnPIs) is one of the success factors in energy management (ANDERSSON; THOLLANDER, 2019; BEISHEIM; KRÄMER; ENGELL, 2020; MAY et al., 2017; MENGHI et al., 2019).

Numerous types of EnPIs must be developed and monitored to assist organizations in measuring and enhancing their energy performance. By implementing EnPIs for continuously monitoring energy performance, improvement opportunities may be recognized. In addition, monitoring EnPIs as an energy management strategy enables an organization to evaluate its efficiency potential and see the benefits of improvement measures. However, creating and applying meaningful energy performance indicators is a difficult task. An EnPIs is only useful if it is possible to identify the root cause of performance fluctuations, such as the impact of the current ambient temperature. However, as the process hierarchy rises, the number of variables increases, making allocating these variations more challenging, particularly for energy-intensive process sectors and complex organizations (ANDERSSON; THOLLANDER, 2019; BEISHEIM; KRÄMER; ENGELL, 2020; FICHERA; VOLPE; CUTORE, 2020; NISSEN; HARFST; GIRBIG, 2018).

Considering the relevance of evaluating energy performance in tracking global energy use and the role played by indicators, this work aims to conduct a systematized review of scientific publications related to indicator definitions and associated methods for evaluating energy performance. The scientific articles have been investigated to analyze the current state of scientific research and trends, define the relevant conceptions, premises, and features, determine the challenges reported, and identify possible solutions to these issues.

After the Introduction, Section 4.2 presents the methodology used for the systematized review, including the adopted research protocol and article selection. Section 4.3 presents the findings of bibliometric and content analysis. A critical analysis discussion is presented in

Section 4.4, wherein the challenges are also described. Finally, conclusions and implications are highlighted in Section 4.5.

## 4.2 Methods

The combination of methods applied in this work follows the overview presented in Figure 2.13. For the sake of brevity, the theory and general elements of systematized review and bibliometric analysis were presented in Section 2.3.

### 4.2.1 Adopted research protocol

Following the proposed methods, the first step was to define the research problem and associated questions. As pointed out previously, this review aimed to collect and analyze the literature related to energy performance evaluation, particularly focusing on the different indicator definitions and associated calculation methods. Based on this objective, the following research question was formulated: "What are the current state and trends on approaches adopted to energy performance improvement evaluation using indicators?". This general question was then divided into three stepwise questions:

- Q1 – "In general, how are energy performance indicators applied?"
- Q2 – "Considering these applications, what are adopted for energy performance improvement evaluation?"
- Q3 – "Considering these indicators, how are they defined (reporting type and calculation method)? Are there elements of energy management or energy saving projects present?"

Considering these secondary questions, Q1 was used to develop the search string, Q2 was used to screen the initial results, and Q3 was used to retrieve information from the articles in data extraction. After following these steps, the research protocol is completed. Considering

Q1, two base keywords should compose the search string: energy performance and indicator. These base keywords are then expanded, considering possible alternatives, as presented in Table 4.1, which includes synonyms, acronyms, and abbreviations.

Table 4.1 – Base keywords and alternatives for energy performance indicator(s)

| Base keyword | energy performance | indicator(s) |
|---|---|---|
| Considered alternatives | energy key performance<br>energy efficiency<br>energy savings<br>energy consumption | - |

Source: Author's elaboration

The second step, an initial selection of bibliographic databases, was previously accomplished in presented in Section 2.3. Within these databases, the query was performed in searching only in title, abstract, and author's keywords, when available, using search strings developed specifically for each database. Before defining these search strings, the third step for research protocol adoption was accomplished.

All criteria needed for the subsequent review phases are defined in this third step. These criteria are summarized in Table 4.2. It comprises general inclusion and exclusion criteria adopted in the search string and checking the consistency of database results. Following that, based on Q2 was developed in-deep analysis inclusion and exclusion criteria while quality criteria and related data extraction information fields were developed from Q3. Finally, preliminary information was retrieved from the brief review used to present this work subject in the introduction section, particularly for data extraction information fields. After defining these criteria, the research protocol is adopted, and the review is moved to the next phase.

Table 4.2 – Criteria for the systematized review of indicator definitions and associated methods for energy performance evaluation

| Category | Criteria (I: Inclusion / E: Exclusion) |
|---|---|
| General inclusion and exclusion criteria adopted in the search string | (I) Article types: article, conference paper, review<br>(I) Article language: English<br>(E) Article type: book, book chapter, others<br>(E) Article language: other than English |
| General inclusion and exclusion criteria to check consistency | (I) Article basic bibliometric data fully available<br>(I) Publishing year in a range from 2000 to 2022<br>(E) Article basic bibliometric data not fully available<br>(E) Publishing year prior to 2000 |

| Category | Criteria (I: Inclusion / E: Exclusion) |
|---|---|
| In-deep analysis inclusion and exclusion criteria | (I) Article fully available<br>(I) Article deal with improvement evaluation<br>(I) Article deal with indicators<br>(I) Article deal with energy management<br>(I) Article deal with EPIAs<br>(I) Article deal with benchmarking<br>(E) Article not fully available<br>(E) Article doesn't deal with improvement evaluation |
| Quality criteria | - Energy performance improvement is calculated/estimated/assessed?<br>- Different accounting methods are discussed?<br>- Different indicators are proposed/applied/analyzed? |
| Data extraction information fields | - EnPI reporting type adopted [Multiple choices: Absolute value, Specific energy consumption (SEC), other ratio (should be specified), percentage change, other (should be specified)]<br>- EnPI method (energy model) adopted [Multiple choices: Simple metric, Ratio, Statistical method (Linear Regression), Statistical method (Multivariate Linear Regression), Engineering modeling, other (should be specified)].<br>- Energy performance improvement reference document mentioned [Multiples choices: IPMVP, ISO 50001, ISO 50006, ISO 50046, ISO 50047, other (should be specified), none] |

Source: Author's elaboration

### 4.2.2 Article selection outcomes

Following the proposed methods, article selection involved composing search strings used in querying selected bibliographic databases, namely Web of Science (WoS), Scopus, and Dimensions. These strings were developed to contemplate keyword combinations and general including and excluding criteria. Search strings also considered that searching was only done in title, abstract, and keywords, when available.

The keyword combination was a sequence of loose phrases under double quotation marks combined with Boolean operators (AND, OR). Each loose phrase combines Table 4.1 base keywords and considered alternatives. Particularly regarding the keyword "accounting" and its alternatives, a modification was made to include variants using wildcards (*). Therefore, keyword combinations include 48 loose phrases and, aiming to simplify the representation, Table 4.3 includes the search strings without mentioning the keyword combination. The three bibliographic databases were queried using the respective search strings, and raw results were obtained. As presented in Table 4.2, checked results were attained using general inclusion and exclusion criteria to check the consistency. The number of raw and checked results are shown in Table 4.3 by database.

Table 4.3 – Database search strings and initial results

| **Database** | **Search string** | **Raw results** | **Checked results** |
|---|---|---|---|
| Scopus | TITLE-ABS-KEY ( keyword combinations[2] ) AND ( LIMIT-TO ( DOCTYPE , "ar" ) OR LIMIT-TO ( DOCTYPE , "re" ) OR LIMIT-TO ( DOCTYPE , "cp" ) ) AND ( LIMIT-TO ( LANGUAGE , "English" ) ) | 752 | 721 |
| Web of Science (WoS) | ( keyword combinations[2] ) (Topic) and English (Languages) and Editorial Material or Data Paper or Correction or News Item (Exclude – Document Types) | 566 | 548 |
| Dimensions[1] | ( keyword combinations[2] ) | 730 | 654 |

[1] Search string includes only keyword combination. Title and abstract were selected as "Search in" option. Article types "Article, Proceeding or Preprint" were selected as a filter.

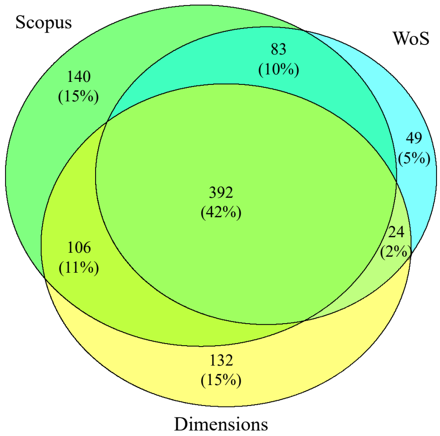
[2] Keyword combinations: loose phrases, combined with Boolean operator (AND, OR), structured as "X indicator*" where X can be energy key performance, energy efficiency, energy savings, or energy consumption.

Source: Author's elaboration

After this initial search, database coverage is assessed by evaluating how these checked results overlap. Using the function "mergeDbSources" from Bibliometrix R-package was possible to determine all values needed to solve the system of linear equations from Equation (2.1). After solving this system of linear equations, results regarding the overlapping of Scopus, WoS, and Dimensions databases are shown in Figure 4.2.

In total, 926 non-duplicated articles were found together in all three databases. Scopus database shows the more comprehensive coverage, covering almost 80% of the articles found (721 of 926), overlapping more than 85% of WoS results and 75% of Dimensions results. Dimensions results embrace almost 70% of the total (654 of 926), overlapping almost 75% of WoS results and 70% of Scopus results. WoS has the narrower results, particularly when considering unique articles, which correspond to 5% of total results, while Scopus and Dimensions unique articles correspond to 15% each.

Figure 4.2 – Overlapping search results from Scopus, WoS, and Dimensions




Source: Author's elaboration using data processed in Bibliometrix (ARIA; CUCCURULLO, 2017)

Scopus and Dimensions are candidates to be the most comprehensive database, with a slight advantage to Scopus that almost reaches Pareto Principle. However, Dimensions extracted bibliometric data doesn't contain keywords, limiting some network analysis. Therefore, Scopus was considered the most comprehensive database and used in bibliometric analysis and data visualization. The full combined results, including 926 articles, were then examined in content analysis, allowing retrieving valid information from articles found only in WoS and Dimensions.

## 4.3 Findings

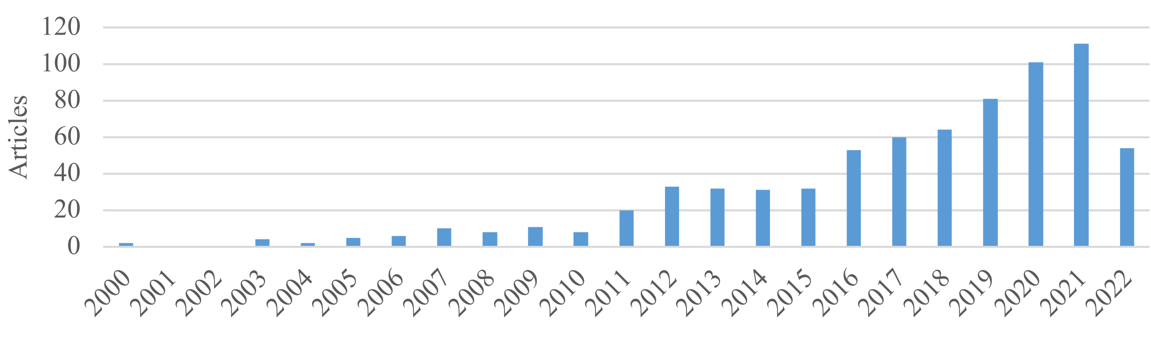
In this section are presented the findings from this systematized review execution phase. Firstly, general bibliometric data analysis is presented in subsection 4.3.1, analyzing Scopus checked results from the previous section using Bibliometrix/Biblioshiny tool. Then, network analysis is developed in subsection 4.3.2, analyzing Scopus checked results using VOSviewer and Bibliometrix/Biblioshiny tools. Finally, content analysis is performed in subsection 4.3.3, analyzing full combined results using the StArt tool.

### 4.3.1 General bibliometric data analysis

As an overview of the findings, the bibliometric analysis covered 721 articles from 2000 to 2022. These articles were originally published in 370 sources, authored by 2142 authors, 53 (2.5%) of which are authors of 60 (8.3%) single-authored articles. These last numbers show a highly collaborative environment, with an average of 3.5 authors per article and more than 13% of international collaboration. Finally, as a general indication of article contents, there are a total of 1976 authors' keywords, which may include duplicates considering misspellings, acronyms, abbreviations, and singular-plural variations.

The annual scientific production in Figure 4.3 shows how 721 articles considered are distributed temporally within the timespan from 2000 to 2022. Analyzing this graph, four different waves are noticeable, with the first covering early stages until 2010, another starting in 2010, the following beginning in 2015, and finally, the last in 2018. Incidentally, a series of events might have contributed to these waves. International discussions regarding promoting energy management to unlock energy efficiency started in 2007, involving several countries and international organizations such as ISO and UNIDO. In 2011, these efforts lead to the publication of ISO 50001, the ISO standard for Energy Management Systems (EnMS). In 2015, Paris Agreement was adopted at COP 21. Additionally, several supporting standards for ISO 50001 were published in 2014. Finally, ISO 50001 was revised in 2018, including a new structure and requirements related to energy performance improvement that underlines adequate indicators' application.

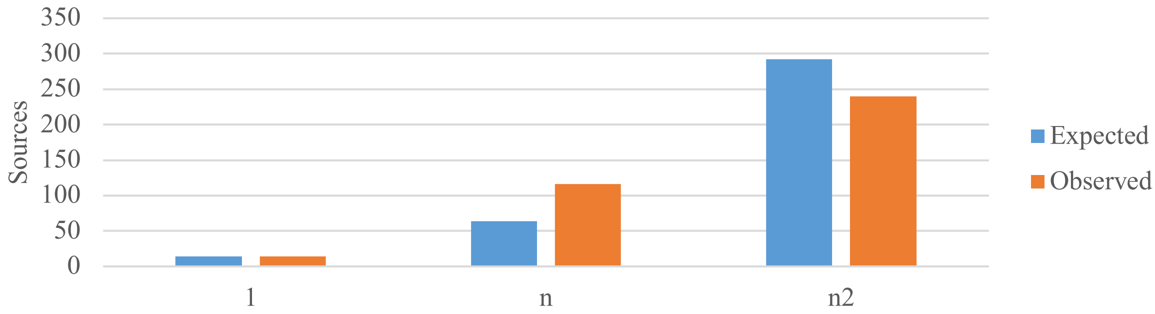
Figure 4.3 – Annual scientific production




Source: Author's elaboration using data processed in Bibliometrix (ARIA; CUCCURULLO, 2017)

After this overview, the first bibliometric data investigated are the articles' sources. Identifying core sources is done by considering Bradford's Law, which can be applied by dividing the total articles into three groups with approximately equal numbers of documents. The results in terms of number of sources, both expected and observed, according to Bradford's Law, is presented in Figure 4.4. The first zone and smaller group of sources, so-called core sources, are composed by 14 academic journals. The following two zones have 116 and 240 academic journals, respectively.

Figure 4.4 – Bradford's Law expected and observed values




Source: Author's elaboration using data processed in Bibliometrix (ARIA; CUCCURULLO, 2017)

Considering the top 10 core sources, the number of articles (N) from each academic journal in the bibliometric analysis are shown in Table 4.4. The most relevant core source is Energies, with a 30% higher frequency of the second one, Energy and Buildings. Starting from the fifth core source, there is a steady decline in frequency, which became smoother from the fourteenth source onwards. Another way to assess the relevance of the sources, as proposed in the Methods section, is to calculate total citations (TC) as well as impact indexes as h-index and g-index. These parameters for the same top 10 core sources are also presented in Table 4.4.

Table 4.4 – Top 10 core sources and their total citation, h-index and g-index

| Source (Academic journals) | N | TC | h-index | g-index | CiteScore | SNIP | SJR |
|---|---|---|---|---|---|---|---|
| Energies | 36 | 379 | 11 | 18 | 5 | 1.104 | 0.653 |
| Energy and Buildings | 28 | 1184 | 16 | 28 | 11.5 | 2.069 | 1.682 |
| Energy | 26 | 807 | 15 | 26 | 13.4 | 2.038 | 2.041 |
| Sustainability (Switzerland) | 23 | 233 | 7 | 14 | 5 | 1.31 | 0.664 |
| Energy Policy | 18 | 963 | 15 | 18 | 12.4 | 2.034 | 2.126 |
| Journal of Cleaner Production | 17 | 509 | 12 | 17 | 15.8 | 2.444 | 1.921 |
| Applied Energy | 15 | 407 | 10 | 15 | 20.4 | 2.652 | 3.062 |
| Energy Efficiency | 15 | 201 | 9 | 14 | 5.3 | 1.036 | 0.837 |
| Energy Procedia | 13 | 97 | 7 | 9 | 2.63 | 0.96 | 0.533 |
| IOP Conference Series: Materials Science and Engineering | 13 | 9 | 2 | 2 | 1.1 | 0.344 | 0.249 |

Source: Author's elaboration using data processed in Bibliometrix (ARIA; CUCCURULLO, 2017)

As expected, assessing source relevance from multiple measures may result in different results. Aiming to evaluate these results comparatively, the top 10 core sources are ranked in each measure (number of articles, total citations, h-index, and g-index). The comparative results are presented in Table 4.5.

Table 4.5 – Top 10 core sources and their ranking according to total citations, h-index and g-index

| **Source (Academic journals)** | **N rank** | **TC rank** | **h rank** | **g rank** | **CiteScore rank** | **SNIP rank** | **SJR rank** |
|---|---|---|---|---|---|---|---|
| Energies | 1 | 7 | 5 | 4 | 67 | 77 | 74 |
| Energy and Buildings | 2 | 1 | 1 | 1 | 22 | 21 | 23 |
| Energy | 3 | 3 | 3 | 2 | 14 | 23 | 16 |
| Sustainability (Switzerland) | 4 | 9 | 9 | 8 | 68 | 63 | 72 |
| Energy Policy | 5 | 2 | 2 | 3 | 16 | 24 | 14 |
| Journal of Cleaner Production | 6 | 4 | 4 | 5 | 9 | 11 | 19 |
| Applied Energy | 7 | 6 | 6 | 6 | 3 | 8 | 4 |
| Energy Efficiency | 8 | 11 | 7 | 7 | 62 | 81 | 55 |
| Energy Procedia | 9 | 17 | 10 | 10 | 113 | 87 | 86 |
| IOP Conference Series: Materials Science and Engineering | 10 | 91 | 39 | 42 | 147 | 153 | 138 |

Source: Author's elaboration using data processed in Bibliometrix (ARIA; CUCCURULLO, 2017)

Considering the first four rankings, these comparative results show that from these ten sources, eight have a consistent ranking, i.e., staying within the top 10 or top 11 regardless the measure considered. Analyzing the ranking of the considered measures, when aggregating their ranks in all measures, the following six academic journals have the lowest sums: Energies, Energy and Buildings, Energy, Sustainability (Switzerland), Energy Policy, Journal of Cleaner Production, Applied Energy, and Energy Efficiency. Regarding journal impact factors, four of the previously mentioned journals have a distinguishable position, namely, Applied Energy, Journal of Cleaner Production, Energy Policy, and Energy and Buildings.

After analyzing the sources, the second bibliometric data investigated are the articles' authors. As mentioned earlier, there are a total of 2142 authors in a total of 721 articles. Within the researched subject and constraints, many authors have published only one article, 1861 authors or 87%. The distribution of the number of authors according to the number of articles published is done by considering Lotka's Law, which is represented in Figure 4.5.

In fact, the dotted line in Figure 4.5 is a regression line with a power function ($y = a.x^p$) having an exponent (p) of approximately negative 3.5. This adheres with Lotka's Law and the empirical observations stating that this correlation has a steep decline similar to the Inverse Cube Law ($1/x^3$).

Figure 4.5 – Lotka's Law assessment with bibliometric data and regression line


Source: Author's elaboration using data processed in Bibliometrix (ARIA; CUCCURULLO, 2017)

Considering the most productive authors, as in Table 4.6, the top 10 have published 69 articles, or approximately 10% of all articles, while representing only 0.5% of all authors. Another way to assess the relevance of the authors, as proposed in the Methods section, is to calculate total citations (TC) as well as impact indexes as h-index and g-index. These parameters for the same top 10 most productive authors are also presented in Table 4.6.

Table 4.6 – Top 10 most productive authors and their total citation, h-index and g-index

| Authors | N | TC | h-index | g-index |
|---|---|---|---|---|
| Strizhak PA | 11 | 256 | 9 | 11 |
| Gheorghiu C | 8 | 6 | 2 | 2 |
| Zhu L | 7 | 54 | 4 | 7 |
| Scripcariu M | 7 | 4 | 1 | 1 |
| Thollander P | 6 | 117 | 5 | 6 |
| Tuomaala M | 6 | 159 | 4 | 6 |
| Wang S | 6 | 137 | 4 | 6 |
| Boyd GA | 6 | 82 | 3 | 6 |
| Boyd G | 6 | 133 | 2 | 6 |
| Zhang J | 6 | 24 | 2 | 4 |

Source: Author's elaboration using data processed in Bibliometrix (ARIA; CUCCURULLO, 2017)

Similarly, as observed with sources, assessing authors' relevance from multiple measures may result in different results. Aiming to evaluate these results comparatively, the top 10 most productive authors are ranked in each measure (number of articles, total citations, h-index, and g-index). The comparative results are presented in Table 4.7.

Table 4.7 – Top 10 most productive authors and their ranking according to total citations, h-index and g-index

| Authors | N rank | TC rank | h rank | g rank |
|---|---|---|---|---|
| Strizhak PA | 1 | 3 | 1 | 1 |
| Gheorghiu C | 2 | 821 | 167 | 171 |

| Authors | N rank | TC rank | h rank | g rank |
|---|---|---|---|---|
| Zhu L | 3 | 144 | 7 | 2 |
| Scripcariu M | 4 | 958 | 959 | 970 |
| Thollander P | 5 | 29 | 2 | 3 |
| Tuomaala M | 6 | 15 | 3 | 4 |
| Wang S | 7 | 22 | 4 | 5 |
| Boyd GA | 8 | 44 | 15 | 6 |
| Boyd G | 9 | 24 | 39 | 7 |
| Zhang J | 10 | 353 | 100 | 26 |

Source: Author's elaboration using data processed in Bibliometrix (ARIA; CUCCURULLO, 2017)

These comparative results show that some behaviors can be identified within ten authors. Except for the TC ranking, five authors have a consistent ranking, namely Strizhak PA, Zhu L, Thollander P, Tuomaala M and Wang S. Analyzing the ranking of the considered measures, four of these two authors (Strizhak PA, Thollander P, Tuomaala M and Wang S) have the lowest sum when aggregating their ranks in all measures. Several authors with high total citations have low publication level, as illustrated by the top 12 most cited authors in Table 4.8. Finally, when processing bibliometric data with Bibliometrix some homonymous authors might have been aggregated.

Table 4.8 – Top 12 most cited authors

| Authors | TC | Number of articles |
|---|---|---|
| Newborough M | 403 | 1 |
| Wood G | 403 | 1 |
| Strizhak PA | 256 | 11 |
| Ang BW | 254 | 2 |
| Bargigli S | 232 | 1 |
| Raugei M | 232 | 1 |
| Ulgiati S | 232 | 1 |
| Giama E | 179 | 1 |
| Papadopoulos AM | 179 | 1 |
| Fert C | 167 | 1 |
| Hatirli SA | 167 | 1 |
| Ozkan B | 167 | 1 |

Source: Author's elaboration using data processed in Bibliometrix (ARIA; CUCCURULLO, 2017)

Another approach to evaluating author-related bibliometric data involves investigating their affiliations and respective countries. Considering that one author might have more than one affiliation, the total number of mentioned affiliations might exceed the number of authors. Table 4.9 presents the top 10 most mentioned affiliations. Within top 10 most mentioned, the most part comes from China (four institutions) and Italy (three institutions).

Table 4.9 – Top 10 most mentioned affiliations

| Affiliation | Country | Mentions |
|---|---|---|
| National Research Tomsk Polytechnic University | Russian Federation | 37 |
| Universidad de La Costa | Colombia | 25 |
| North China Electric Power University | China | 28 |
| Aalto University | Finland | 26 |
| Dalian University of Technology | China | 25 |
| Enea – National Agency for New Technologies | Italy | 6 |
| University Of Rome La Sapienza | Italy | 3 |
| Yanshan University | China | 21 |
| Politecnico Di Torino | Italy | 6 |
| Chongqing University | China | 13 |

Source: Author's elaboration using data processed in Bibliometrix (ARIA; CUCCURULLO, 2017)

Another way to see the crossing between data from affiliations and countries is to expand the analysis from the top 10 to the top 50 most mentioned affiliations and their respective countries, as depicted in Table 4.10. Again, the results show that China and Italy remain the most mentioned countries while reducing their share from 40% to around 25% and from 30% to 10% respectively. Finally, the scenario became more diversified in the top 20, a trend kept from this point onwards.

Table 4.10 – Countries with most mentioned affiliations from the top 10 to the top 50

| Country | Most mentioned affiliations | | | | |
|---|---|---|---|---|---|
| | Top 10 | Top 20 | Top 30 | Top 40 | Top 50 |
| China | 4 | 6 | 10 | 13 | 13 |
| Italy | 3 | 3 | 3 | 4 | 5 |
| Russian Federation | 1 | 1 | 1 | 1 | 1 |
| Colombia | 1 | 1 | 1 | 2 | 3 |
| Finland | 1 | 1 | 1 | 1 | 1 |
| Sweden | 0 | 1 | 2 | 2 | 2 |
| Romania | 0 | 1 | 2 | 2 | 2 |
| Spain | 0 | 1 | 1 | 1 | 1 |
| Malaysia | 0 | 1 | 1 | 1 | 1 |
| Greece | 0 | 1 | 1 | 1 | 1 |
| Latvia | 0 | 1 | 1 | 1 | 1 |
| Slovenia | 0 | 1 | 1 | 1 | 1 |
| Norway | 0 | 1 | 1 | 1 | 1 |
| Iran | 0 | 0 | 1 | 1 | 1 |
| Ireland | 0 | 0 | 1 | 1 | 1 |
| Austria | 0 | 0 | 1 | 1 | 2 |
| Netherlands | 0 | 0 | 1 | 1 | 1 |
| Portugal | 0 | 0 | 0 | 1 | 1 |

| Country | Most mentioned affiliations | | | | |
|---|---|---|---|---|---|
| | Top 10 | Top 20 | Top 30 | Top 40 | Top 50 |
| Czech Republic | 0 | 0 | 0 | 1 | 1 |
| Poland | 0 | 0 | 0 | 1 | 2 |
| Brazil | 0 | 0 | 0 | 1 | 2 |
| Saudi Arabia | 0 | 0 | 0 | 1 | 1 |
| Serbia | 0 | 0 | 0 | 0 | 2 |
| Bosnia and Herzegovina | 0 | 0 | 0 | 0 | 1 |
| Germany | 0 | 0 | 0 | 0 | 1 |
| USA | 0 | 0 | 0 | 0 | 1 |

Source: Author's elaboration using data processed in Bibliometrix (ARIA; CUCCURULLO, 2017)

This discussion leads to a second approach to assess country relevance. In this case, the articles are distributed according to the corresponding author's country, being also divided between single country production (SCP) and multiple country production (MCP), and total citations (TC) of these articles. Analyzing the corresponding authors, their respective countries sum 73 in total. The top 15 (roughly 20% of total corresponding countries) are responsible for approximately 60% of the articles, deviating from the Pareto Principle, which was expected since affiliations were widely dispersed, as seen in Table 4.10. The top 15 corresponding countries and their metrics are presented in Table 4.11.

Table 4.11 – Top 15 corresponding countries and metrics of number of articles, TC, SCP, and MCP

| Country | N | TC | TC/Article | SCP | MCP | MCP/Articles |
|---|---|---|---|---|---|---|
| China | 102 | 1081 | 10.6 | 89 | 13 | 0.127 |
| Italy | 53 | 1023 | 19.3 | 46 | 7 | 0.132 |
| Germany | 33 | 253 | 7.7 | 21 | 12 | 0.364 |
| Usa | 28 | 425 | 15.2 | 24 | 4 | 0.143 |
| Spain | 27 | 452 | 16.7 | 21 | 6 | 0.222 |
| Poland | 27 | 118 | 4.4 | 26 | 1 | 0.037 |
| Colombia | 22 | 149 | 6.8 | 14 | 8 | 0.364 |
| Russian Federation | 24 | 3 | 0.1 | 23 | 1 | 0.045 |
| Romania | 21 | 133 | 6.3 | 18 | 3 | 0.143 |
| Brazil | 20 | 202 | 10.1 | 19 | 1 | 0.050 |
| France | 17 | 278 | 16.4 | 15 | 2 | 0.118 |
| Portugal | 16 | 276 | 17.3 | 13 | 3 | 0.188 |
| Sweden | 15 | 210 | 14.0 | 15 | 0 | 0.000 |
| Greece | 15 | 616 | 41.1 | 12 | 3 | 0.200 |
| Ukraine | 15 | 16 | 1.1 | 13 | 2 | 0.133 |
| China | 102 | 1081 | 10.6 | 89 | 13 | 0.127 |

Source: Author's elaboration using data processed in Bibliometrix (ARIA; CUCCURULLO, 2017)

Similarly, as observed with sources and authors, assessing countries' relevance from multiple measures may result in different results. Aiming to evaluate these results comparatively, the top 15 corresponding countries and their metrics are presented in Table 4.12.

Table 4.12 – Top 15 corresponding countries and metrics of number of articles, TC, SCP, and MCP

| **Country** | **N rank** | **TC rank** | **TC/Art. rank** | **SCP rank** | **MCP rank** | **MCP/Art. rank** |
|---|---|---|---|---|---|---|
| China | 1 | 1 | 25 | 1 | 1 | 33 |
| Italy | 2 | 2 | 12 | 2 | 4 | 32 |
| Germany | 3 | 11 | 30 | 7 | 2 | 9 |
| USA | 4 | 6 | 19 | 4 | 6 | 26 |
| Spain | 5 | 5 | 16 | 6 | 5 | 22 |
| Poland | 6 | 21 | 39 | 3 | 22 | 42 |
| Colombia | 7 | 51 | 58 | 5 | 23 | 41 |
| Russian Federation | 8 | 18 | 31 | 12 | 3 | 10 |
| Romania | 9 | 20 | 33 | 9 | 7 | 27 |
| Brazil | 10 | 15 | 26 | 8 | 24 | 40 |
| France | 11 | 9 | 17 | 10 | 14 | 38 |
| Portugal | 12 | 10 | 15 | 13 | 8 | 25 |
| Sweden | 14 | 3 | 4 | 15 | 9 | 23 |
| Greece | 15 | 40 | 51 | 14 | 15 | 31 |
| Ukraine | 13 | 14 | 21 | 11 | 43 | 43 |

Source: Author's elaboration using data processed in Bibliometrix (ARIA; CUCCURULLO, 2017)

These comparative results show that some behaviors can be identified within these sixteen countries. Except for the MCP/Articles ranking, six countries have a consistent ranking, i.e., staying around the top 15 regardless of the measure considered, namely Italy, the USA, Spain, France, Portugal, and Sweden. Analyzing the ranking of the considered measures, these same six authors have the lowest sum when aggregating their ranks in all measures. China has a very high position ranking, except in the TC/Articles ranking, due to its high productivity and difficulties keeping up high citation levels. Generally, countries' international collaboration strongly affects the MCP/Articles ranking. Considering all articles in this review, there is an average of approximately 15% multiple country productions. Analyzing MCP/Articles in Table 4.11, one-third of the top 15 corresponding countries have above-average international collaboration. However, several countries with relatively few published articles have done so through international cooperation, thus, having a high MCP/Articles rank.

After exploring bibliometric data regarding sources, authors, affiliations, and countries, a subsequent analysis comprises articles' local citations (LC) and global citations (GC). While LC reflects how often documents within the review cite another document contained in the review, GC considers citations by articles from the entire bibliographic database. Consequently, the ratio of these numbers (LC/GC) measures the article's impact outside the reviewed research field. Considering the most locally cited documents, these citation measures are presented in Table 4.13.

Table 4.13 – Top 10 local cited documents and metrics of LC, GC, and LC/GC ratio

| Document | LC | GC | LC/GC ratio |
|---|---|---|---|
| Assessment of energy efficiency performance measures in industry and their application for policy (TANAKA, 2008) | 20 | 128 | 15.6% |
| From energy targets setting to energy-aware operations control and back: An advanced methodology for energy efficient manufacturing (BENEDETTI; CESAROTTI; INTRONA, 2017) | 9 | 30 | 30.0% |
| The evolution of the ENERGY STAR® energy performance indicator for benchmarking industrial plant manufacturing energy use (BOYD; DUTROW; TUNNESSEN, 2008) | 9 | 111 | 8.1% |
| Monitoring changes in economy-wide energy efficiency: From energy–GDP ratio to composite efficiency index (ANG, 2006) | 7 | 223 | 3.1% |
| Establishing an Integration-Energy-Practice Model for Improving Energy Performance Indicators in ISO 50001 Energy Management Systems (CHIU; LO; TSAI, 2012) | 7 | 42 | 16.7% |
| A Method for Measuring the Efficiency Gap between Average and Best Practice Energy Use: The ENERGY STAR Industrial Energy Performance Indicator (BOYD, 2005) | 5 | 41 | 12.2% |
| Tools to improve forecasting and control of the electricity consumption in hotels (CABELLO ERAS et al., 2016) | 5 | 28 | 17.9% |
| A novel energy assessment of urban wastewater treatment plants (DI FRAIA; MASSAROTTI; VANOLI, 2018) | 5 | 58 | 8.6% |
| A structured approach for facilitating the implementation of ISO 50001 standard in the manufacturing sector (GOPALAKRISHNAN et al., 2014) | 5 | 42 | 11.9% |
| Constructing HVAC energy efficiency indicators (PÉREZ-LOMBARD et al., 2012) | 5 | 40 | 12.5% |

Source: Author’s elaboration using data processed in Bibliometrix (ARIA; CUCCURULLO, 2017)

Considering all local and global citations, the overall LC/GC ratio is approximately 3% and 20% (140 out of 721) of the articles have an above-average LC/GC ratio. Analyzing these LC/GC ratio results in Table 4.13, the top 10 local cited documents have an average ratio of 13.7%, more than four times the overall ratio. Within this top 10, one article has a significantly lower LC/GC ratio, (ANG, 2006), while the remaining nine have a ratio significantly above the overall ratio. Comparatively, this means that this one article has more relevance outside this review subject, while the other nine are particularly relevant to this research scope.

Finally, one last bibliometric data that can be explored are the authors’ keywords. As mentioned earlier, there are a total of 1976 keywords. The total occurrences of these keywords amount to 3044, meaning an average of approximately four keywords per article. If duplicates are removed, considering misspellings, acronyms, abbreviations, and singular-plural variations, this number is reduced to 1769. Synonyms and expressions with relatively close meaning were merged to keep the authors' original intent as much as possible. The top 10 most frequent keywords are presented in Table 4.14.

Table 4.14 – Top 10 most frequent keywords

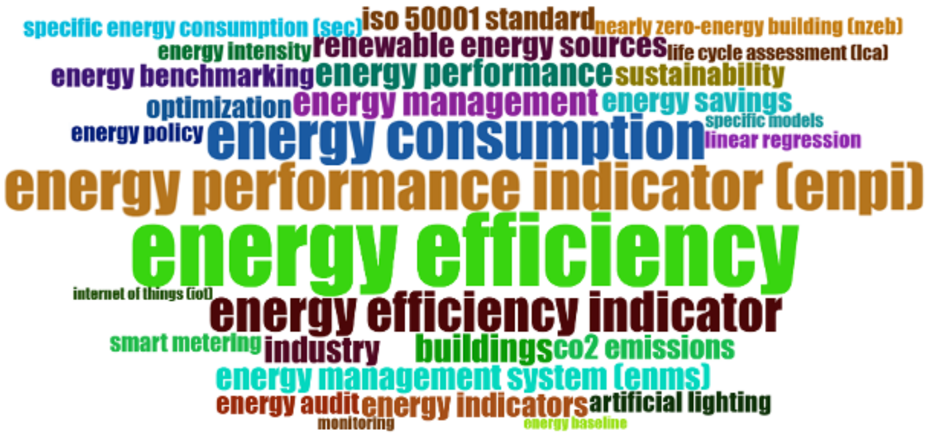
| **Keywords** | **Occurrences** |
|---|---|
| Energy efficiency | 216 |
| Energy performance indicator (EnPI) | 109 |
| Energy consumption | 86 |
| Energy efficiency indicator | 66 |
| Energy management | 32 |
| Buildings | 31 |
| Energy performance | 31 |
| Energy management system (EnMS) | 28 |
| Industry | 28 |
| Renewable energy sources | 26 |

Source: Author's elaboration using data processed in Bibliometrix (ARIA; CUCCURULLO, 2017)

Considering the last Bibliometric Law presented in the Method section, Booth-Zipf's Law, the Goffman Transition Point helps to define a semantic core group of keywords. In the present case, there is a total of 1504 keywords with occurrences equal to one. Therefore, according to Equation (2.4), the Goffman Transition Point occurs at approximately 54 occurrences. Using this information and the ranking from Table 4.14, the top 4 keywords are the constituents of this semantic core.

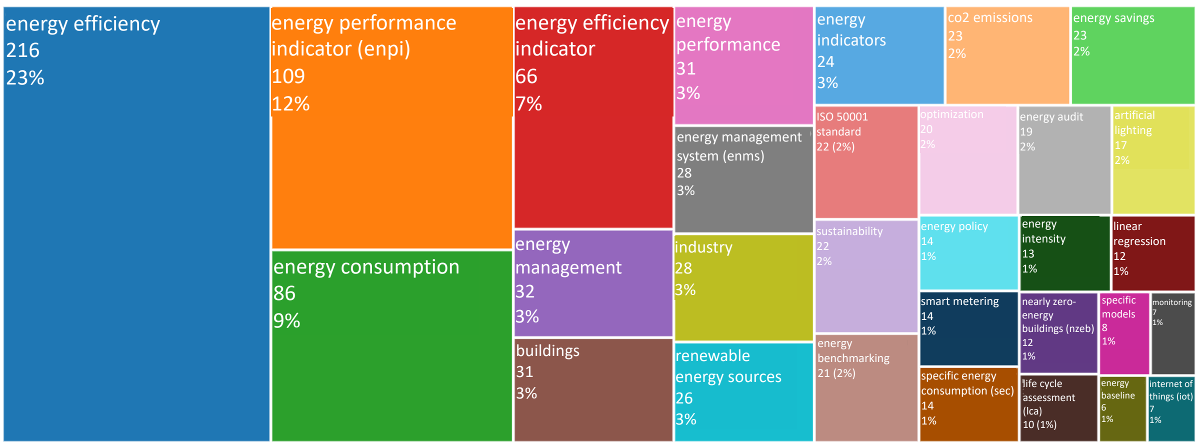
Starting from the overall ensemble of keywords, some techniques were adopted as different ways to visualize them. A keyword cloud is depicted in Figure 4.6 and a keyword treemap is shown in Figure 4.7. The keyword cloud shows how the top 4 keywords, the semantic core defined using the Goffman Transition Point, stands out in its center while several other complementary keywords surround them. The treemap also helps to localize and estimate some of these complementary subjects. For example, energy management related keywords (such as energy management, energy management systems (EnMS), ISO 50001 standard) sum 82 occurrences (8%); sectoral related keywords (industry, buildings, artificial lighting) total 76 occurrences (8%); and benchmarking and modeling related keywords (specific energy consumption (sec), energy intensity, energy benchmarking, linear regression, specific models) compute 68 occurrences (7%).

Figure 4.6 – Keyword cloud




Source: Author’s elaboration using Biblioshiny (ARIA; CUCCURULLO, 2017)

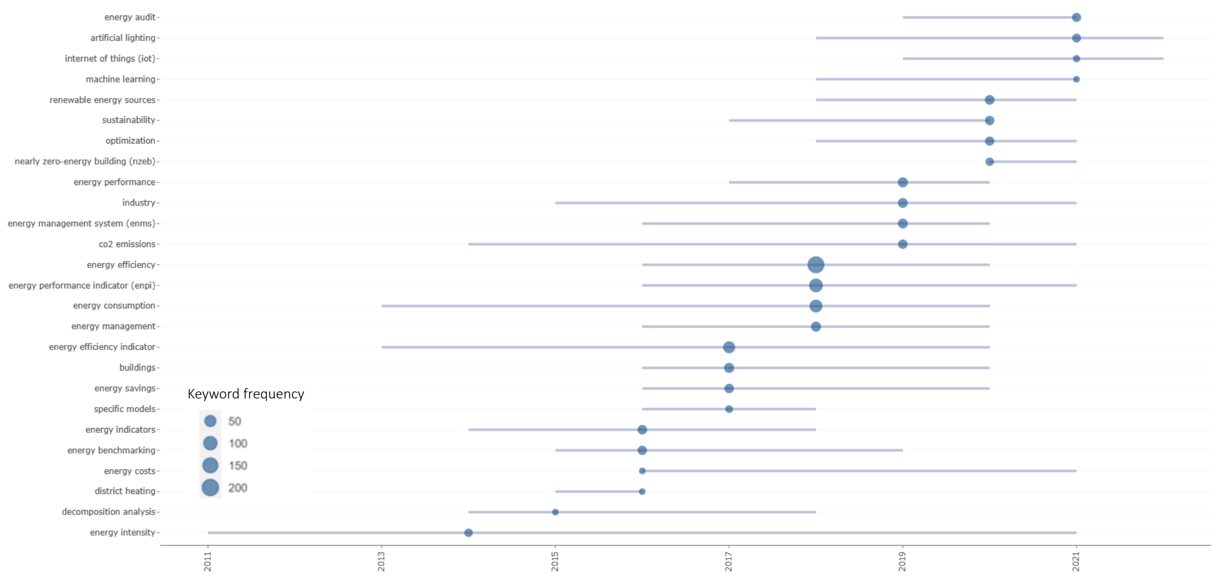
Figure 4.7 – Keyword treemap




Source: Author’s elaboration using Biblioshiny (ARIA; CUCCURULLO, 2017)

Finally, the third visualization method considered, a trend topic graph, is displayed in Figure 4.8. In this method, it is possible to visualize that some topics are temporally transversal such as energy intensity, usually present in macroeconomic discussions, while the majority have a narrower timespan. For example, energy benchmarking and related indicators discussions are more relevant around 2016, followed by debates around energy savings and energy efficiency indicators in 2017. Subsequently, energy management gain more relevance in 2018, same year of the ISO 50001 revision publication, associated with energy performance indicators (EnPI) and then, in 2019, associated with energy management systems (EnMS). From 2019 to 2020, sustainability, nearly zero energy buildings (NZEB) and renewable energy sources are new interest topics. Finally, more leading-edge trend topics ascend by 2020/2021 with machine learning and the internet of Things (IoT) to solve data processing and collecting issues, respectively.

Figure 4.8 – Keyword trend topics




Source: Author's elaboration using data processed in Bibliometrix (ARIA; CUCCURULLO, 2017)

### 4.3.2 Network analysis

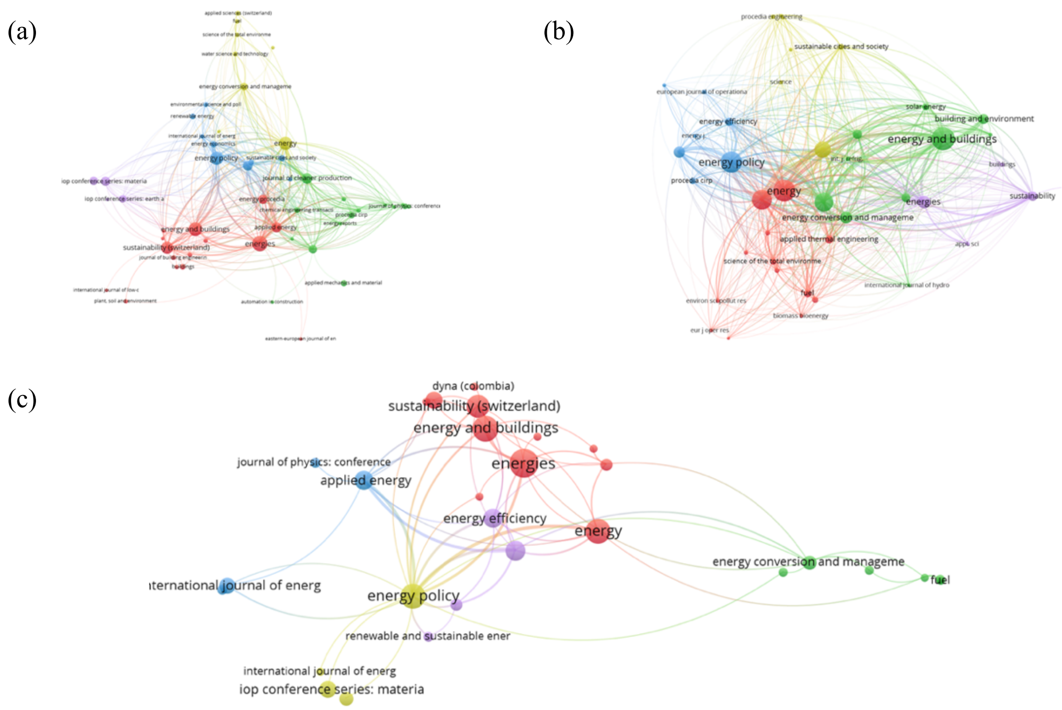
Considering the characteristics of different network analyses exposed in the methods section, different combinations of possible networks were selected. Citation and co-authorship networks were favored to analyze article authors' relationship with between their respective countries. Bibliographic coupling, citation, and co-citation networks were adopted to investigate article sources. Finally, bibliographic coupling and citation networks were considered to evaluate the relation of the articles themselves. In all these cases the objective is to use network analysis to put in perspective the previous bibliometric data covered in general analysis.

In terms of network structure, the following standards were considered. First, the vertex represents the network analysis unit, and its size reflects the number of articles associated with it. The link between vertexes depends upon the network type, and the link width is proportional to its strength, i.e., how many times the same two vertexes are connected by the same link. Consequently, total link strength (TLS) is at least equal to the number of links. For example, in bibliographic coupling with sources as analysis unit, the vertexes are sources (academic journals), and their size are the number of articles belonging to it. Third, a link represents that articles from two vertexes have cited references in common, and, finally, the strength of this link is proportional to the number of cited references in common that these articles have.

Each of these networks had their clusters investigated according to TLS (Total Link Strength), number of links, and/or number of citations. Complementary results for the top 3 vertex with highest TLS (or number of citations) for the five most relevant clusters in these networks are presented in Table B.1, Table B.2, and Table B.3. The following paragraphs describe overall findings.

Bibliographic coupling, co-citation, and citation networks with article sources as analysis unit are displayed in Figure 4.9. As expected from the top 10 core sources in Table 4.4, these sources are main vertexes of their clusters or among the largest vertexes in all three networks. The citation network even shows the top 4 (Energies, Energy and Buildings, Energy and Sustainability (Switzerland)) connected into one red cluster. The co-citation network reveals the relative importance of other sources with high TLS: Energy Conversion and Management, a green cluster vertex, and Renewable and Sustainable Energy Reviews, a yellow cluster vertex. Finally, Energy Policy plays a role in connecting different clusters in all three networks, being in a central position with a significant high TLS.

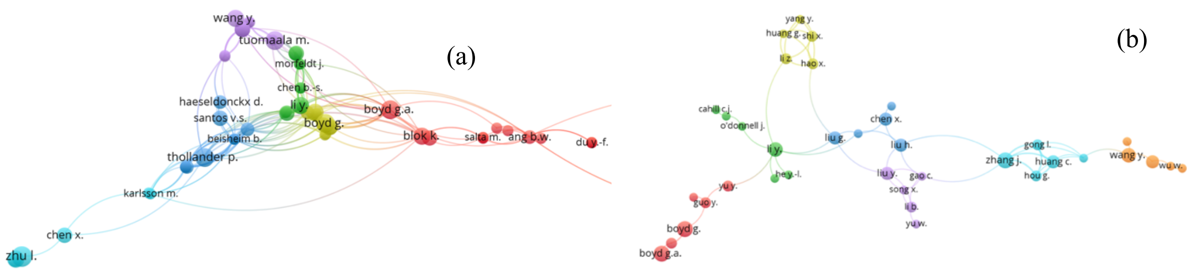
Figure 4.9 – Bibliographic coupling (a), Co-citation (b) and Citation (c) networks – Analysis unit: sources




Source: Author's elaboration using VOSviewer (VAN ECK; WALTMAN, 2010)

Citation and co-authorship networks with article authors as analysis units are displayed in Figure 4.10. Observing the top 12 most productive authors presented in Table 4.6, the citation network reveals some absences, particularly Strizhak P.A., Wang S., Gheorghiu C., Zhang J., and Scripcariu M. The last three have very low TC, while the first two have high TC, mainly coming from papers where the author is not the first author. These limitations on citation may have reduced or eliminated local citations, and thus, the author was not displayed as a vertex. On the other hand, five other authors between the topmost productive ones are displayed as large vertexes, namely Boyd G., Boyd G.A., Thollander P., Tuomaala M., and Zhu L. Co-citation network shows very separate collaboration clusters, being the red and green the most productive and the cyan and yellow the ones with the most robust collaboration (highest TLS).

Figure 4.10 – Citation (a) and Co-authorship (b) networks – Analysis unit: authors

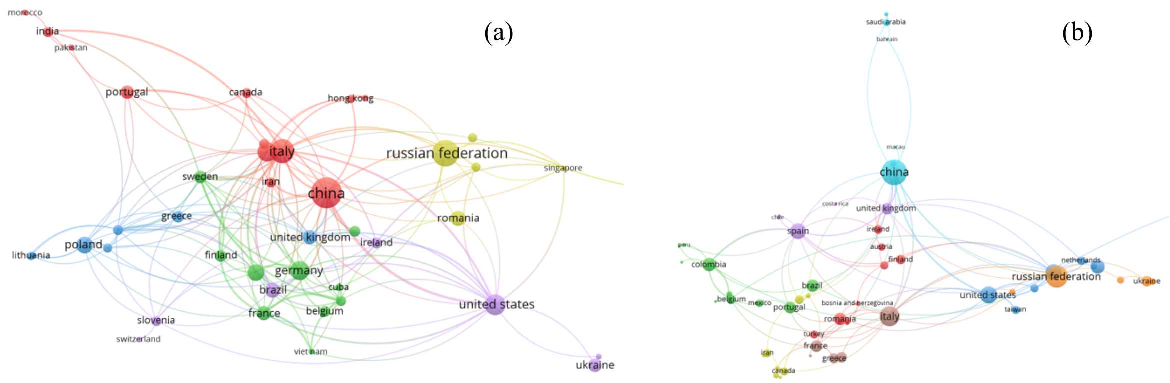



Source: Author’s elaboration using VOSviewer (VAN ECK; WALTMAN, 2010)

Citation and co-authorship networks with article authors’ countries as analysis unit are displayed in Figure 4.11. A co-authorship network geographical representation is shown in Figure 4.12. The top 2 countries with the most cited affiliations, in Table 4.10, and the top 2 corresponding countries, in Table 4.11, are consequently the three largest vertexes from citation and co-authorship networks: China and Italy. However, some patterns are different when comparing citation networks to co-authorship networks. For example, clusters in the citation network tend to group diverse regional countries, while in the co-authorship, some clusters tend to group countries by regional or language aspects.

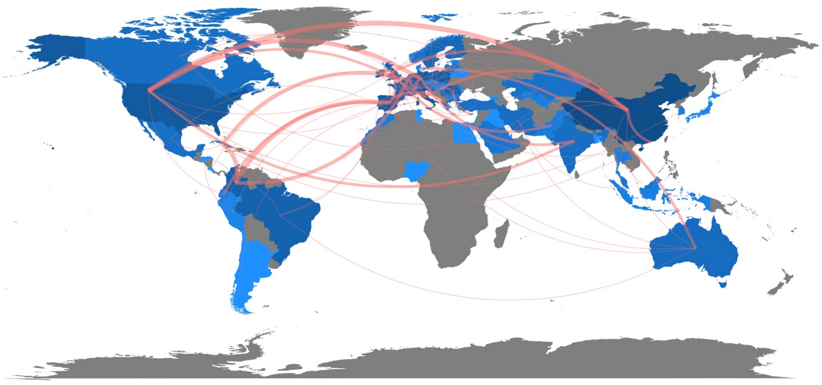
Another relevant point is the strength of this relations, particularly in co-authorship. Spain, Germany, and Italy have the highest TLS, in decreasing order, in citation network. Even though China is the largest vertex of the red cluster in this network, Spain and Italy make more and stronger connections. In the co-authorship network, Italy, China, the USA, and Germany are the most collaborative. Observing Table 4.11, it is notable that the first two have a large number of articles and a fair rate of multiple country productions (MCP). In contrast, the last one has fewer articles but a high MCP ratio. USA stands out with a high TLS because its MCP generally connects more than one country, enhancing its connections. Finally, the Russian Federation has a significant vertex due to the number of publications, but their connections are reduced and weak compared to the neighboring clusters.

Figure 4.11 – Citation (a) and Co-authorship (b) networks – Analysis unit: countries




Source: Author’s elaboration using VOSviewer (VAN ECK; WALTMAN, 2010)

Figure 4.12 – Collaboration map – Analysis unit: countries



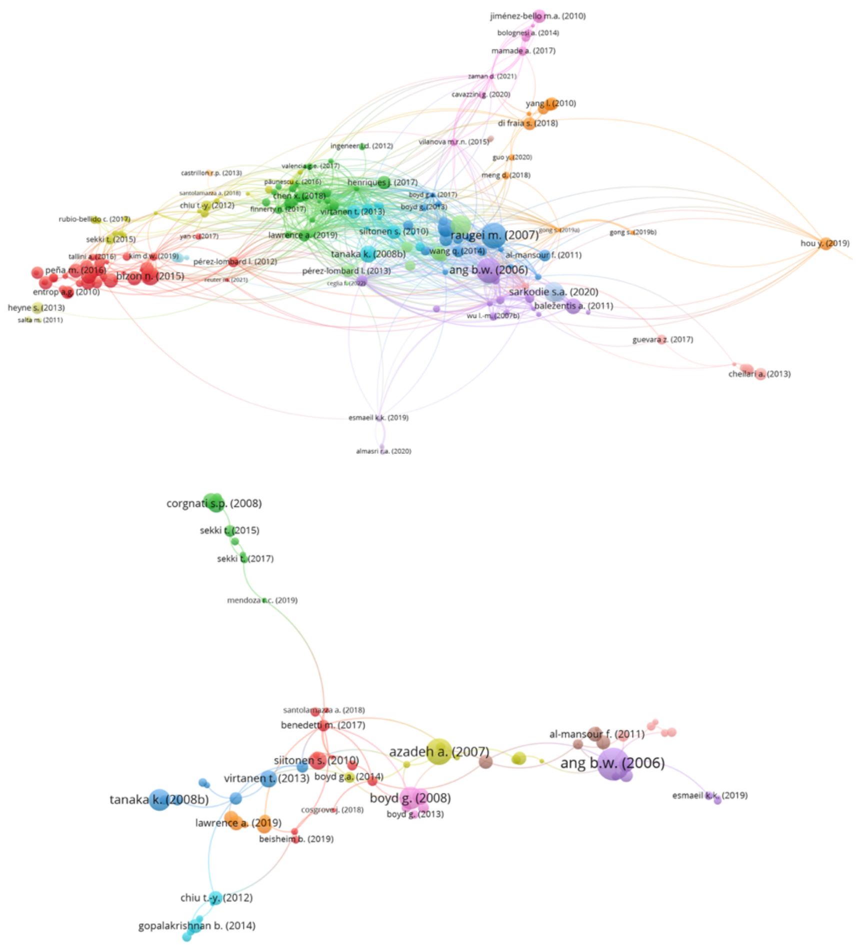
Source: Author’s elaboration using Biblioshiny (ARIA; CUCCURULLO, 2017)

Bibliographic coupling and citation networks with articles as analysis unit are displayed in Figure 4.13. Looking at both these networks, it can be found several most locally cited documents from Table 4.13 as the main vertex of their clusters, for example (TANAKA, 2008), (ANG, 2006), (DI FRAIA; MASSAROTTI; VANOLI, 2018), (AZADEH et al., 2007), (BOYD; DUTROW; TUNNESSEN, 2008), (CHIU; LO; TSAI, 2012), (PÉREZ-LOMBARD et al., 2012). Other documents that stand out in bibliographic coupling and citation networks are (RAUGEI; BARGIGLI; ULGIATI, 2007), (SARKODIE; OZTURK, 2020), (BIZON; OPROESCU; RACEANU, 2015), (SIITONEN; TUOMAALA; AHTILA, 2010), and (PEÑA et al., 2016), respectively the second, seventh, tenth, eighteenth, and twentieth most globally cited articles. In terms of TLS in the Bibliographic coupling network, several of the mentioned articles have relevant TLS, but (PERRONI et al., 2018) stand out significantly with the highest TLS.

Figure 4.13 – Bibliographic coupling (a) and Citation network (b) – Analysis unit: articles

(a)

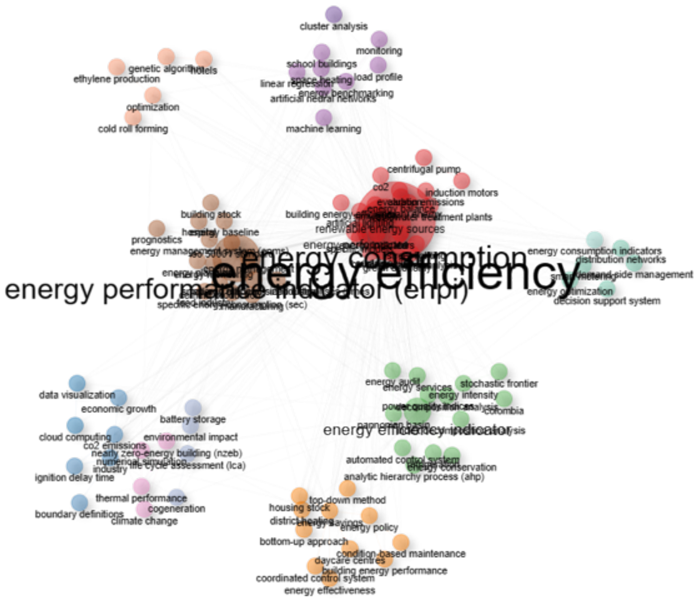
(b)




Source: Author's elaboration using VOSviewer (VAN ECK; WALTMAN, 2010)

The last bibliometric data, keywords, is approached using a different method. Initially, a co-occurrence network is presented to perform a similar perspective evaluation. Then, this evaluation is translated into a thematic map. Subsequently, a thematic evolution is performed, using five time slices to represent the systematized review period from 2000-2022. The co-occurrence network with authors' keywords as analysis unit and the corresponding thematic map are displayed in Figure 4.14 and Figure 4.15 respectively. These findings are particularly relevant to highlight how the literature is organized in thematic clusters and how these clusters relate to each other in terms of relevance and development. There are three main clusters (red, brown, and green) in basic themes' quadrant, followed by three intermediate clusters, one in the motor themes' quadrant (purple) and one in basic themes' quadrant (blue), and one in niche themes' quadrant (orange). Finally, there are four smaller clusters, three in the niche themes' quadrant (lavender, light pink and mint) and one in the emerging/declining themes' quadrant (rose). The clusters from Figure 4.15 were investigated by analyzing their associated keywords and articles. Complementary results regarding top keywords and top 3 articles associated to each cluster are presented in Table B.4 and Table B.5, respectively. The following paragraph describes the overall findings.

Figure 4.14 – Co-occurrence network – Analysis unit: authors' keywords



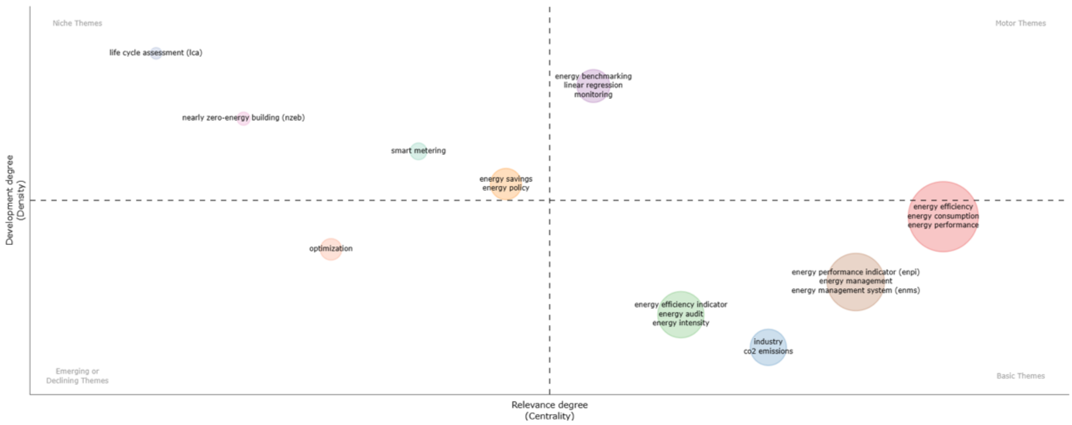

Source: Author's elaboration using Biblioshiny (ARIA; CUCCURULLO, 2017)

The three larger basic theme clusters regroup differ by either approaches and/or sectors covered. Cluster #1 (red) broadly covers energy efficiency, from appliances and processes to buildings and power generation. This cluster also includes energy efficiency policy discussions and multiple approaches are adopted, from decomposition analysis (DEA) to statistical analysis. However, there are few occurrences of improvement evaluation and indicator modeling discussion. Despite covering different economic sectors, Cluster #2 (brown) encompasses a very well-defined subject, the use of energy performance indicators (EnPIs) as a tool to evaluate energy performance from the perspective of energy management. The articles included in this cluster are distributed different categories, being the most relevant indicator proposition and discussion, energy performance evaluation case studies, and energy management application case studies. Cluster #3 (green) also has an indicator as the main subject, nonetheless, the approach is slightly different from the previous cluster. In this case, energy efficiency indicators are mainly adopted in scenarios where benchmarking is present. Several scenarios are observed, from buildings and processes to regional or national-level assessments. In a few specific cases, these indicators are used to assess energy efficiency in appliances.

The benchmarking related discussion from Cluster #3 (green) is aligned to Cluster #5 (purple), which can be described as a crossover of Cluster #2 (brown) and Cluster #3 (green), as it takes an EnPI modeling aspect (linear modeling) and an energy management aspect (monitoring) discussion from the former to be applied into the subject of benchmarking from the later. Cluster #4 (blue) is a spin-off cluster from Cluster #2 (brown), as it discusses the same subject from a narrower perspective. Mainly focused in industrial sector, roughly 2/3 of the articles, this cluster differs energy performance evaluation associated with approaches to environmental analysis, mainly GHG emissions. Finally, the last intermediate cluster, Cluster #6 (orange), covers decision-making related to energy savings, either considering a regional or national level regarding energy policy or managerial decisions within an organization.

The remaining four last clusters have a smaller impact on occurrences but present some interesting findings. The three niche theme clusters have a different approach towards energy performance. Cluster #8 (mint) focuses on technical data collection and processing aspects, mainly discussing smart metering and the Internet of Things (IoT). Cluster #9 (light pink) concentrates on a specific approach to buildings, the nearly zero-energy building, which is included in a broader discussion of Net Zero and Carbon Neutrality. Cluster #10 (lavender) discusses a modeling approach with the use of life cycle analysis (LCA), frequently used to assess energy cost in power generation. Finally, Cluster #8 (rose) is an emerging theme where optimization is integrated into energy efficiency and indicators.

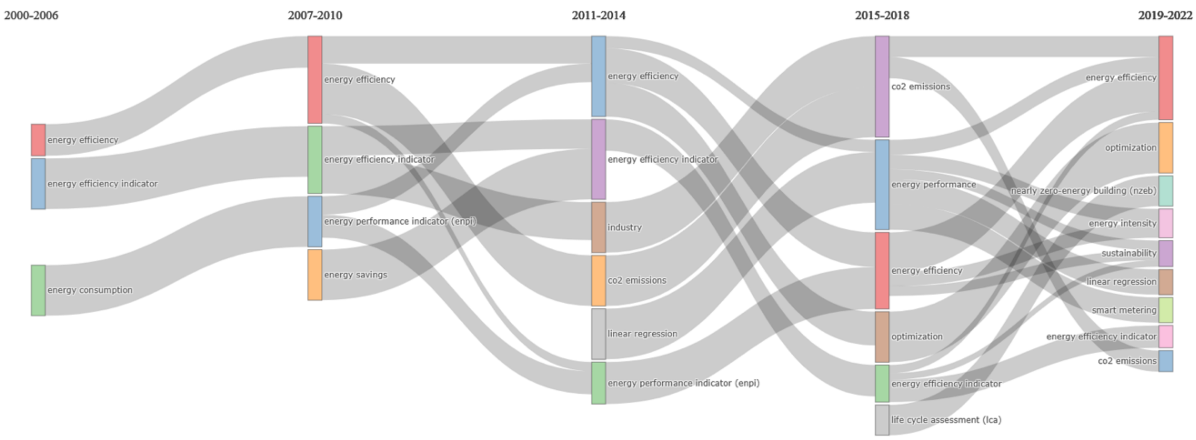
Figure 4.15 – Overall thematic map – Analysis unit: authors' keywords




Source: Author's elaboration using Biblioshiny (ARIA; CUCCURULLO, 2017)

Thematic evolution with the author's keywords as analysis unit is displayed in Figure 4.16. The thematic evolution shows an increase in the diversity of relevant aspects. As the thematic evolution moves from the first to the second time slice, the energy performance indicator (EnPI) emerges. Incidentally, the ISO 50001, published in 2011, is discussed in the second time slice. In the subsequent time slice, EnPI holds a relevant topic position while an EnPI modeling aspect emerges, linear regression. In this same time slice, GHG emissions, $CO_2$ particularly, arise as a relevant topic, gaining more relevance in the subsequent time slice. The fourth time slice presents new topics related to modelings, such as optimization and LCA. Finally, in the last time slice, the same topics are reflected in a more diverse structure, covering general elements (energy efficiency), modeling options (optimization, linear regression, energy intensity, and energy efficiency indicator), environmental aspects ($CO_2$ emissions and sustainability), technical aspects (smart metering), and sectoral solutions (NZEB).

Figure 4.16 – Thematic evolution (2000 – 2022) – Analysis unit: authors’ keywords

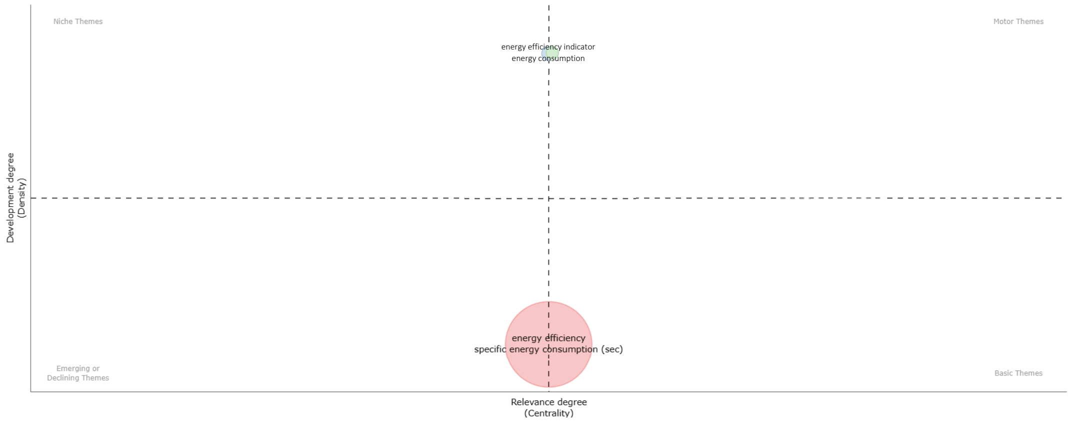



Source: Author’s elaboration using Biblioshiny (ARIA; CUCCURULLO, 2017)

For each time slice (TS) in thematic evolution, a thematic map was developed and shown subsequently in Figure 4.17 (TS1: 2000-2006), Figure 4.18 (TS2: 2007-2010), Figure 4.19 (TS3: 2011-2014), Figure 4.20 (TS4: 2015-2018), and Figure 4.21 (TS5: 2019-2022). The clusters from each time slice were investigated by analyzing their associated keywords and articles. The top keywords associated to each cluster are presented, respectively, in Table B.6, Table B.8, Table B.10, Table B.12, and Table B.14. Top 3 articles for each cluster are exhibited in Table B.7, Table B.9, Table B.11, Table B.13, and Table B.15. The following paragraphs describe overall findings.

In TS1 (2000-2006), from Figure 4.17, Cluster #1 (red) is the main cluster, with high occurrence and lower density. The main subject covered is energy benchmarking using specific energy consumption (SEC). Clusters #2 (blue) and #3 (green) are niche theme clusters covering specific case studies. All clusters go through some evolution process from TS1 to TS2.

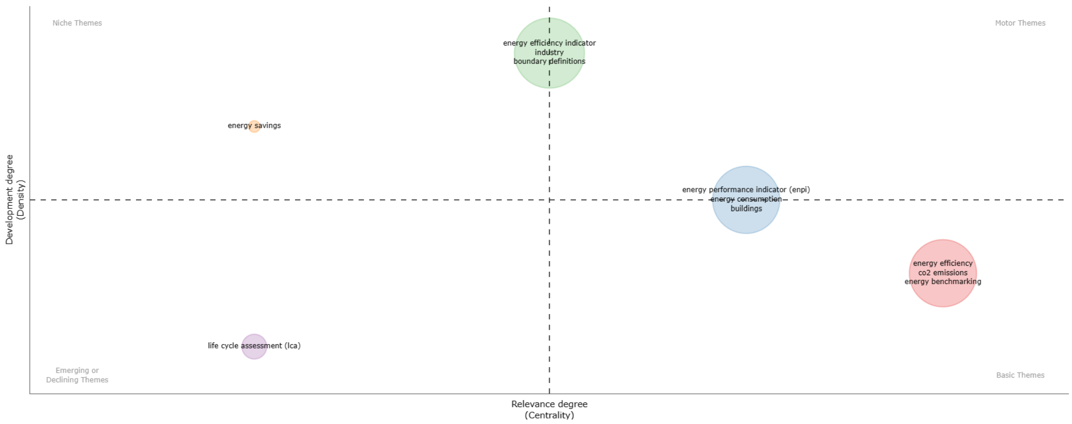
Figure 4.17 – Thematic map – 1st time slice (TS1: 2000 – 2006) – Analysis unit: authors' keywords




Source: Author's elaboration using Biblioshiny (ARIA; CUCCURULLO, 2017)

In TS2 (2007-2010), from Figure 4.18, Cluster #1 (green) is a niche theme cluster covering mainly industrial sectors, using energy efficiency indicators. This is an evolution movement since a similar cluster was in a similar position but less relevant in TS1. Another observed evolution is related to Cluster #3 (blue), moving from niche themes' quadrant in TS1 to motor and basic themes' cluster frontier, encompassing energy performance discussion with a relevant role of buildings. Cluster #1 (red) from TS1, focused on energy efficiency, moves towards the basic themes' quadrant to be Cluster #2 (red) in TS2, keeping the same approach and incorporating $CO_2$ emissions within its scope. Two new clusters emerge in TS2, Cluster #4 (purple), an emergent cluster, and Cluster #5 (orange), a niche cluster. The first discusses LCA approaches to building construction evaluation and power generation, while the second deals with specific energy savings evaluation case studies. These two last clusters fade out from TS2 to TS3, while the others present evolution movement.

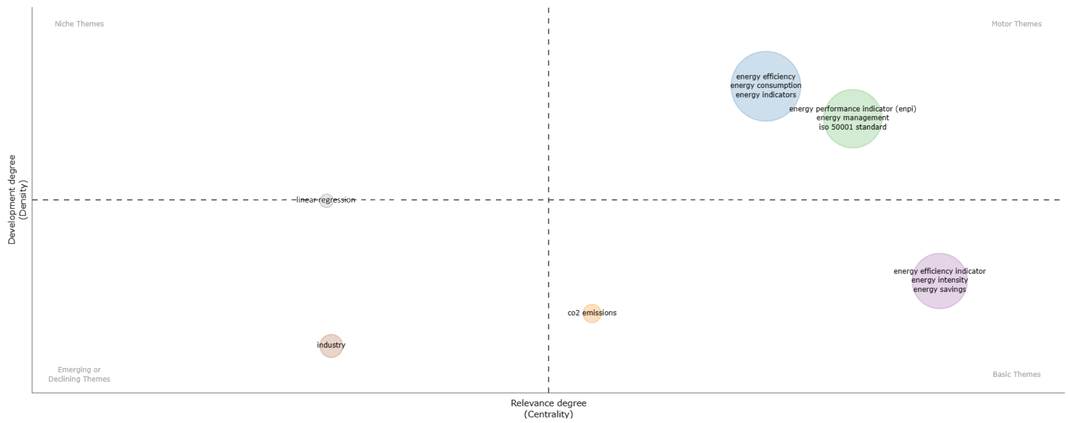
Figure 4.18 – Thematic map – 2nd time slice (TS2: 2007 – 2010) – Analysis unit: authors' keywords




Source: Author's elaboration using Biblioshiny (ARIA; CUCCURULLO, 2017)

In TS3 (2011-2014), from Figure 4.19, Cluster #1 (blue) is the major cluster in the motor themes' quadrant, an evolution movement from Cluster #1 (green) in TS2. In this time slice, this cluster discusses energy consumption and energy efficiency modeling and indicators, covering industry and building sectors. Cluster #2 (green) is the second major motor theme quadrant cluster, evolving from Cluster #3 (blue) in TS2. In this movement, the cluster incorporates the energy management perspective, and on several occasions, the ISO 50001 standard is included in discussions. Finally, the third major cluster is in the basic themes' quadrant, Cluster #3 (purple), consolidating Cluster #2 (red) position from TS2. Discussions in this cluster comprise benchmarking, energy efficiency indicator modeling, and some specific case studies, mainly in the industrial sector. Three new clusters emerge in TS3, Cluster #4 (brown), an emerging theme cluster, Cluster #5 (orange), a basic theme cluster, and Cluster #6 (grey) as an intermediate emerging-niche theme cluster. Although these clusters have low occurrence and density, their subjects are relevant to analyze the thematic evolution. Cluster #4 (brown) presents specific indicators for different industrial sectors. Cluster #5 (orange) is a spin-off cluster from Cluster #2 (red) in TS2, as the discussion of GHG emissions is not covered in Cluster #3 (purple). Finally, Cluster #6 (grey) presents discussions on modeling aspects, particularly the application of linear regressions. This last cluster fades out from TS3 to TS4, while the others present evolution movements.

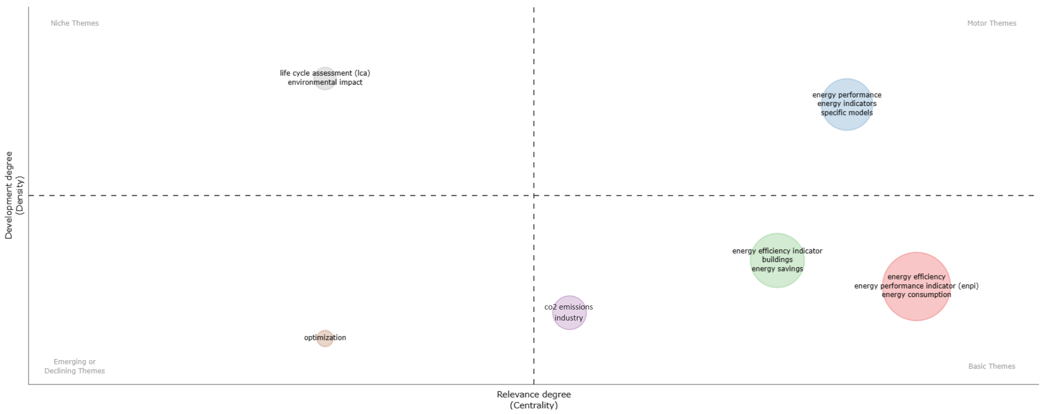
Figure 4.19 – Thematic map – 3rd time slice (TS3: 2011 – 2014) – Analysis unit: authors' keywords




Source: Author's elaboration using Biblioshiny (ARIA; CUCCURULLO, 2017)

In TS4 (2015 - 2018), from Figure 4.20, the three largest clusters are recombined into three new major clusters. Cluster #1 (red) is the major cluster, a crossover between Clusters #2 (green) and #3 (purple) from TS3, showing that the concept of EnPI is moving to be a consolidated basic theme. Cluster #2 (green) reflects the Cluster #3 (purple) from TS3 losing relevance facing the EnPI progress into the mainstream. Another result of EnPI concept being more widely adopted is that the motor theme cluster still contains a major cluster, Cluster #3 (blue), dedicated to specific models and energy performance, an evolution movement of Cluster #1 (blue) from TS3. The last three clusters in TS4 are the results of different thematic evolutions. Cluster #4 (purple) is the result of merging Cluster #4 (brown) and #5 (orange) from TS3. Cluster #5 (grey) emerges as a niche theme cluster and Cluster #6 (brown) is an emerging theme cluster, both discussing modeling aspects, replacing a similar cluster from TS3, Cluster #6 (grey). Cluster #5 (grey) particularly represents a reemergence and evolution of LCA, present in Cluster #4 (purple) from TS2. All clusters go through some evolution process from TS4 to TS5.

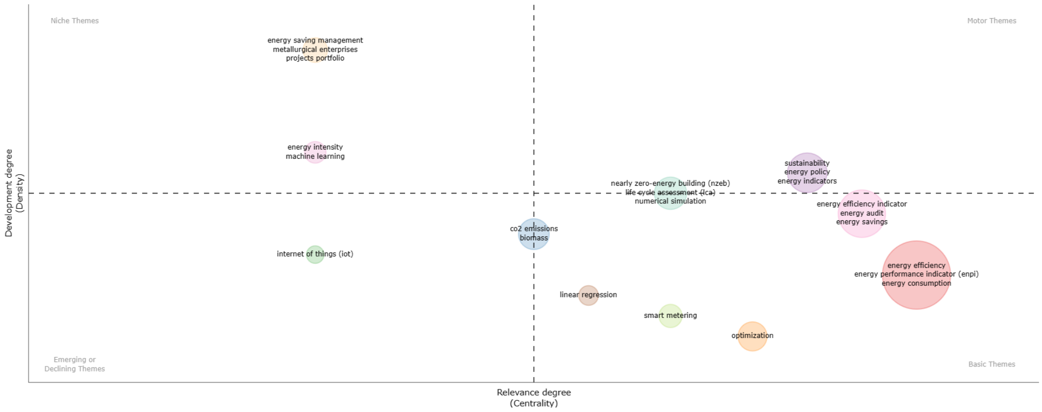
Figure 4.20 – Thematic map – 4th time slice (TS4: 2015 – 2018) – Analysis unit: authors' keywords




Source: Author's elaboration using Biblioshiny (ARIA; CUCCURULLO, 2017)

Finally, TS5 (2019-2022), from Figure 4.21, keeps in the basic themes' quadrant a cluster reinforcing the consolidation and dissemination of the EnPI concept. In both TS4 and TS5, these clusters are characterized as Cluster #1 (red). Cluster #2 (green) from TS4 moves to be a more general cluster, Cluster #2 (pink), while a spin-off related to buildings incorporates Cluster #5 (grey) from TS4 to form Cluster #4 (mint) in TS5. As highlighted through the previous time slices, energy policy is a recurring theme, and in TS5, it is developed in Cluster #3 (purple) under the perspective of sustainability. Cluster #4 (purple) from TS4 slightly reduces its relevance but gains density to become Cluster #5 (blue) in TS5. Despite still encompassing industry case studies, it now covers several biomass-related cases. Cluster #6 (brown) from TS4 and Cluster #6 (grey) from TS3 both move from an emerging theme cluster to a basic theme cluster, respectively Cluster #6 (orange) and Cluster #10 (brown) in TS5. Cluster #7 (cream) is a niche cluster that emerges in TS5, inheriting the industrial sector approach of Cluster #4 (purple) from TS4 while including an energy management perspective. Finally, the last three clusters emerge in TS5 and are interconnected. Cluster #8 (lemon) deals with smart metering as a basic theme, mainly as a tool to improve energy data collection. These technical aspects are complemented by an emerging theme cluster dedicated to the Internet of Things (IoT), Cluster #11 (green). Supplementing the data collection aspect with modeling elements, Cluster #9 (light pink) comprises the application of artificial intelligence and machine learning.

Figure 4.21 – Thematic map – 5th time slice (TS5: 2019 – 2022) – Analysis unit: authors' keywords

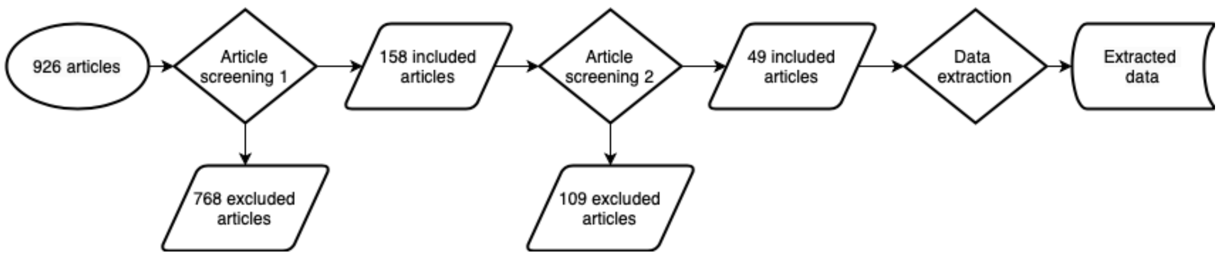



Source: Author's elaboration using Biblioshiny (ARIA; CUCCURULLO, 2017)

### 4.3.3 Content analysis

Complementing the literature's wide-ranging overview from the previous analysis, content analysis aimed to extract information from selected articles in-deep analysis. In article numbers, the content analysis processed 926 articles in two screenings before data extraction, as illustrated in Figure 4.22.

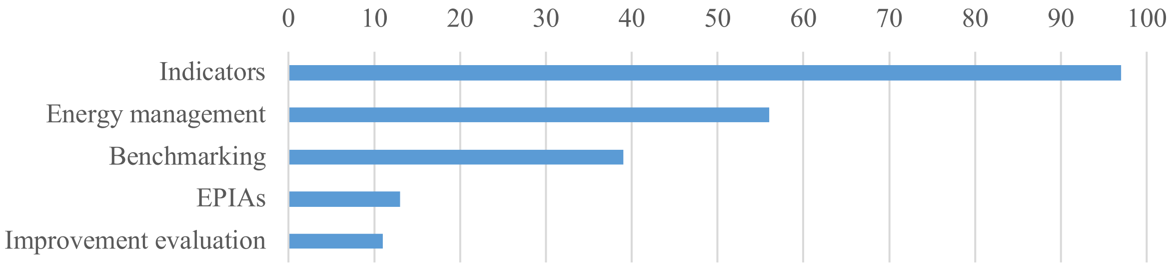
Figure 4.22 – Content analysis process flow




Source: Author's elaboration

Considering the first screening, two main approaches were investigated by analyzing the title and abstract. A total of 158 articles passed this screening, with their main subject covering one of the following approaches: Indicators, Energy management, Benchmarking, EPIAs, and Improvement evaluations. Figure 4.23 presents how the articles that passed the first screening are distributed among these approaches (one article can feature more than one approach). Again, it is observed that besides the central question in review (indicators), energy management and benchmarking are two main approaches that stand out.

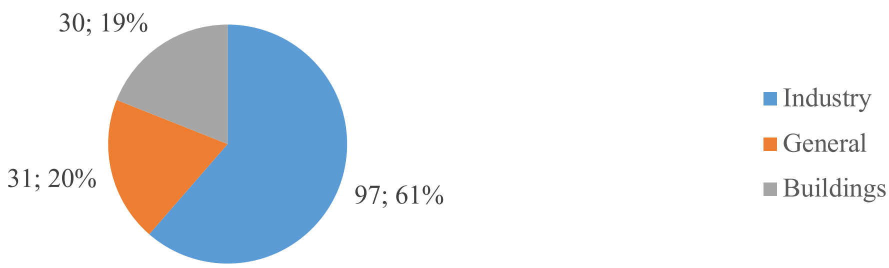
Figure 4.23 – Articles' main approach distribution after the first screening




Source: Author's elaboration

A first overview of these articles is drawn by collecting their object of analysis, mainly two economic sectors: Industry and Buildings. Figure 4.24 presents how the articles that passed the first screening are distributed among these categories, where the industrial sector dominates with a share of 61%. The "General" category summarizes 20% of the articles, mainly associated with energy management and energy performance indicator discussions not directly associated with any sector. Within the 97 articles covering the industrial sector, there are also publications not specific to any particular industry segment, thus, the article is classified into a "General" subcategory, encompassing 19 articles (or 20% of articles covering the industrial sector). More detail is presented in Figure 4.25.

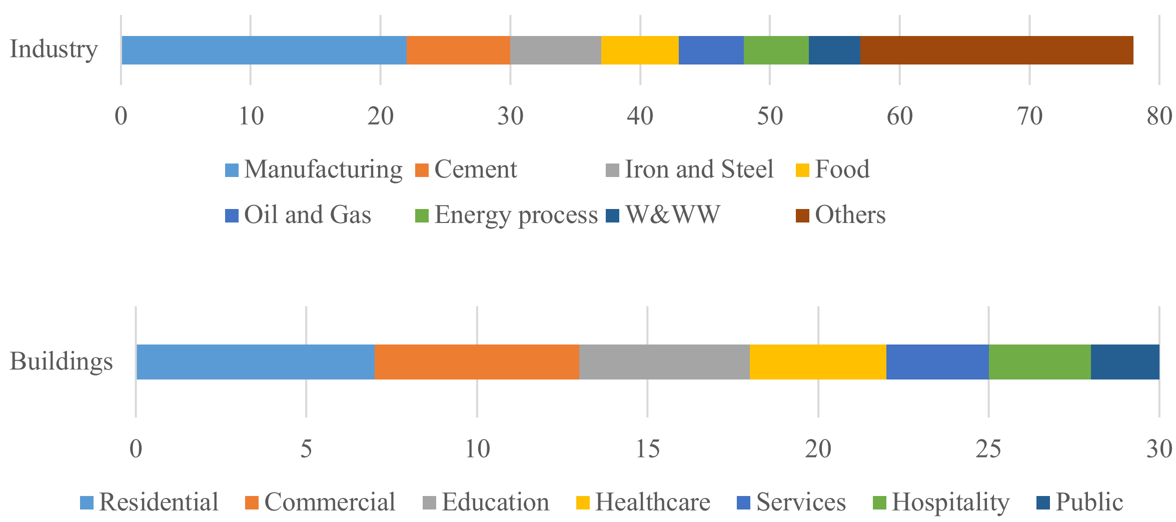
Figure 4.24 – Articles' sectoral distribution after the first screening




Source: Author's elaboration

Manufacturing industries stand out among the industrial sector, and energy-intensive industries, such as Cement, Iron and Steel, and Oil and Gas, are also relevant. However, while energy-intensive industries are sensitive to energy issues, mobilizing manufacturing industries is challenging. Therefore, it does not surprise the position of the manufacturing segment, given the need to promote energy performance improvement and energy management discussions in this segment. On the other hand, contrary to the industrial sector, the buildings sector has no preferential segment, covering the different building types with their specific challenges regarding energy demand.

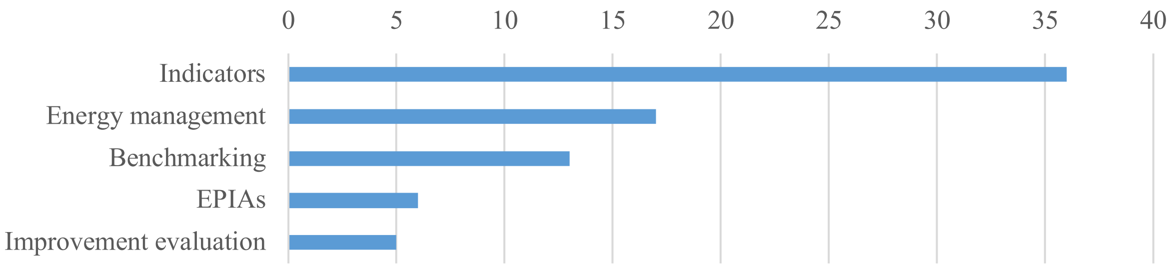
Figure 4.25 – Detailed sectoral distribution after first screening




Source: Author's elaboration

Considering the second screening, a fast full-length analysis was conducted to evaluate if the subjects of interest were just applied or described or if there was a more in-depth discussion. For the approach of indicators, it was considered if they were presented and discussed in their main aspects of reporting and modeling, eventually compared to others. For the energy management approach, it was considered if this subject was presented and discussed in their main aspects, especially indicators. For the benchmarking approach, it was considered if it was applied to a facility, sectoral or regional level, favoring the first scope. For the approach of EPIAs and improvement evaluations, if these opportunities or realized energy savings were presented in technical aspects and with indications on how they were calculated and the premises adopted. A total of 49 articles passed this screening, and Figure 4.26 presents how the articles that passed the second screening are distributed among the main approaches (one article can feature more than one approach).

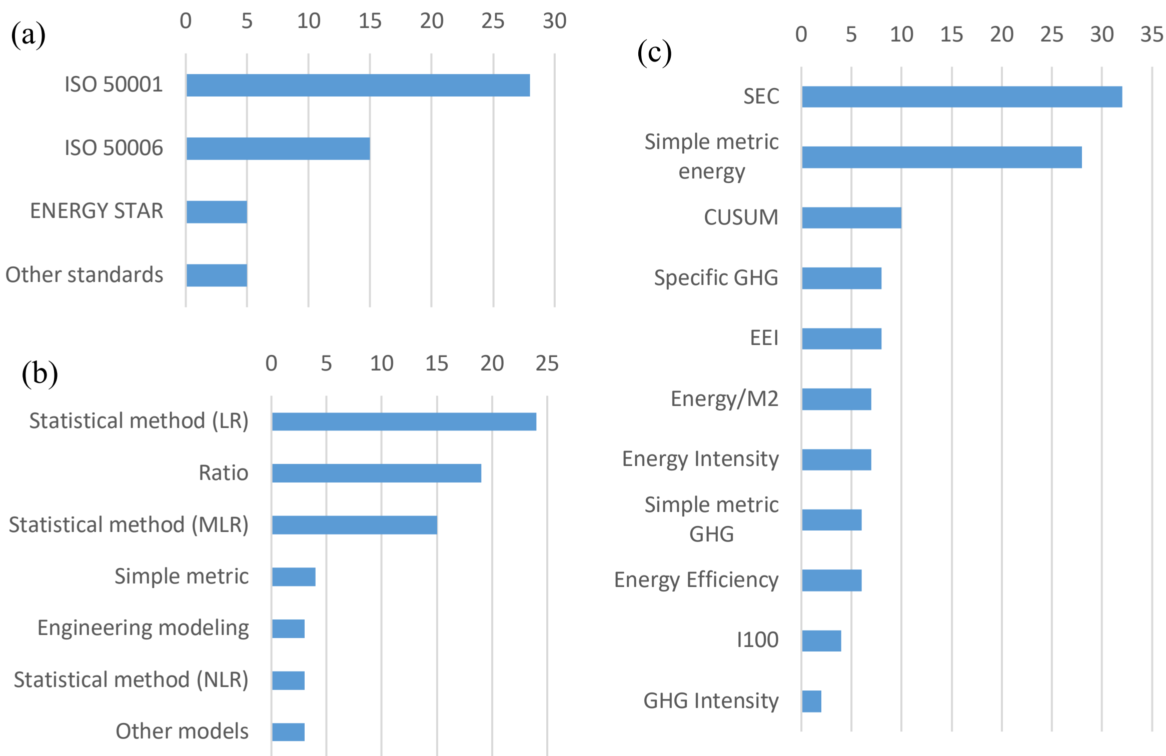
Figure 4.26 – Articles' main approach distribution after second screening




Source: Author's elaboration

As inferred from the final distribution, the final sample keeps a similar distribution after passing the quality screening. A slightly higher number of papers with approaches to energy management and indicator were excluded in this second screening because they only discussed management practices, covered regional/national level scopes, or didn't disclose sufficient information regarding calculation procedures. These final selected articles passed through a data extraction process, where four main topics were covered: Energy performance accounting method reference mentioned, Energy model, and Indicator type. Consolidated findings of data extraction are presented in Figure 4.27.

Figure 4.27 – Data extracted from final selected articles - Energy performance accounting method reference mentioned (a); Energy model (b); Indicator type (c)




Source: Author's elaboration

Detailed information regarding the final selected papers is exhibited in Table B.16 (list of final selected articles), Table B.17 (main approach), Table B.18 (sectoral distribution and Figure 4.27 (a) by article), Table B.19 (Figure 4.27 (b) by article), and Table B.20 (Figure 4.27 (c) by article).

Among the references mentioned, ISO 50001 is the most frequent, followed by ISO 50006 and ENERGY STAR, then other standards (particularly EN standards). There are 53 mentions, more than 50% of which refer to ISO 50001. The second most mentioned, ISO 50006, is consistently cited alongside ISO 50001. In fact, from 15 occurrences of ISO 50006, only one time ISO 50006 is mentioned separately. Regarding energy models, the statistical method (LR) was the most frequent, while the ratio is the second most recurrent energy model. All statistical methods combined, including non-linear (NLR) and multivariate linear (MLR), account for 60% of the occurrences. Finally, specific energy consumption (SEC) and simple metric energy (absolute value) are the most used indicator types. They are followed by CUSUM, which can be interpreted as an indicator or a method mainly used to track the cumulative difference between the EnPI and its corresponding baseline. Other complementary indicators were also identified, including different energy efficiency indexes (EEI and I100), intensity indicators, specific ratios (such as energy/$m^2$), and indicators associated with GHG emissions.

## 4.4 Discussion

After presenting this review's findings with different analysis approaches, this discussion section covers the current state and trends on approaches adopted to evaluate energy performance with indicators. The first discussion topic is the general state of approaches adopted to evaluate energy performance with indicators.

Energy performance evaluation methods can be categorized into multiple categories: energy audits, energy benchmarking, energy performance improvement evaluation, and energy saving verification. To proceed with these assessments, different approaches can be considered when formulating appropriate indicators. For example, EnPIs can be categorized according to their nature, reporting type, and energy model. However, given the wide variety of possible combinations, it is a challenge to choose an energy performance indicator (EnPI) and its corresponding baseline (EnB) appropriate for its purpose (Menghi et al., 2019; Nissen et al., 2018; Perroni et al., 2018).

An energy performance indicator is only useful if identifying the root cause of performance variations is possible. Due to an increasing number of influences when rising problem complexity, allocating these variations becomes increasingly difficult. The most recurring issues when developing EnPIs are correctly defining boundaries and baselines, data gathering and data reliability, and information technology support to gather and analyze data (NISSEN; HARFST; GIRBIG, 2018).

There are different ways to evaluate energy performance using EnPIs, the most recurrent is the comparison between normalized EnB values (or normalized target EnPI values) with measured reporting period EnPI values. Normalization of EnBs and target EnPI values is critical in evaluating energy performance. Adequate clarification of relevant variables through statistical analysis among potential ones should be made to obtain an EnPI which appropriately describes energy performance with a reasonable set of variables (Menghi et al., 2019; Nissen et al., 2018; Perroni et al., 2018).

The effort and benefit of considering each relevant variable in an EnPI statistical model should be decided separately. On the one hand, the significance and comparability of the EnPI increase with the consideration of more relevant variables. On the other hand, the efforts to collect and analyze associated data grow accordingly. Therefore, it is advisable to build EnPIs on a level of detail that either has an intended benefit that offers the least possible effort or that produces the greatest possible net benefit (Beisheim et al., 2020; Mutschler-Burghard, 2019; Nissen et al., 2018; O'Driscoll et al., 2013).

The second discussion topic is trends in approaches adopted to evaluate energy performance with indicators resulting from thematic evolution from network analysis. Two major movements are observed regarding approaches to EnPIs. Firstly, SEC is initially a fundamental theme, but it evolves into specific applications such as benchmarking or macro-geographic or sectoral modeling. On the contrary, EnPIs emerged and evolved until they consolidated themselves as a major standard, particularly pushed by ISO 50000 family. Regarding accounting methods, LCA is a promising tool to improve calculations, currently popular in the buildings sector. Statistical methods are becoming more frequent, including multivariate linear regression. Finally, more recent movements are showing trends toward digitalization and related themes such as machine learning, artificial intelligence, smart metering, and the Internet of Things (IoT) (Chiu et al., 2012; Fichera et al., 2020; Lawrence et al., 2019; Moghadasi et al., 2021; Mutschler-Burghard, 2019).

Thematic evolution movements are also observed regarding economic sectors and complementary approaches. The industry is the most frequently observed sector, either as a general sector or with the representation of specific segments. The buildings sector is also a relevant economic sector appearing in different time slices of thematic evolution and, more recently, a movement merged LCA methods to NZEB (nearly zero energy buildings) as a motor theme. Finally, complementary approaches, particularly to account for GHG emissions, emerge starting from the third time slice (2011-2014), evolving to incorporate industrial sectoral and biomass/bioenergy applications (Benedetti et al., 2017; Hoang et al., 2017; Mendoza et al., 2019; Ocampo Batlle et al., 2020; Siitonen et al., 2010).

After these two topics, the following discussion topic delves into content analysis findings from the perspective of evaluating energy performance with indicators. Starting with standard methods, ISO 50001 and ISO 50006 are dominant. However, considering that ISO 50006 mentions occurred together with ISO 50001, almost 50% of the articles analyzed didn't mention a standard or reference procedure. Prevalence of ISO 50001 was observed due to the strong interconnection of energy management and energy performance evaluation, particularly since ISO 50001 revision in 2018. From the subject perspective, most articles dealt with industrial sector applications, with significant participation of the manufacturing segment followed by energy-intensive industries. The building sector also has a relevant presence, while several publications present a more general approach. Regarding energy models, statistical methods were the most frequent, while the second most recurrent energy model was ratio. All statistical methods combined account for 60% of the occurrences. Finally, regarding indicator types, specific energy consumption (SEC) and simple metric energy (absolute value) are the most used, followed by CUSUM, which is mainly used to track the cumulative difference between the EnPI and its corresponding baseline. Other complementary indicators were also identified, from energy efficiency indexes to indicators associated with GHG emissions.

These findings discussion bring up a final topic, a reflection on effective energy performance representation, particularly due to the duality of several energy models also serving as an indicator type. Adequate comprehension of these two features of energy performance indicators is essential to allow the diffusion of different modeling techniques. This is particularly relevant to increase awareness of energy performance indicator users in terms of their EnPIs capacities and limitations, especially underlying modeling assumptions

(BEISHEIM; KRÄMER; ENGELL, 2020; BENEDETTI; CESAROTTI; INTRONA, 2017; HILLIARD; JAMIESON; JORJANI, 2014; MENGHI et al., 2019; PERRONI et al., 2018).

## 4.5 Conclusions

Considering the relevance of evaluating energy performance in tracking global energy use and the role played by indicators, this work conducted a systematized review of scientific publications related to indicator definitions and associated methods for evaluating energy performance. Scopus was identified as the most comprehensive database and used in bibliometric and network analysis to identify the current state of scientific research, and trends were presented.

After general and quality screenings, a smaller group of articles passed through a more in-deep analysis and data extraction covering four main topics: accounting method reference mentioned, EnPI reporting type, and EnPI method (energy model). The findings highlight relevant conceptions, premises, and features and report challenges and possible solutions.

Thematic evolution from network analysis provided insightful results. Firstly, SEC reduces its relevance to specific applications, while EnPIs consolidate themselves as a fundamental theme, particularly pushed by ISO 50000 family. Regarding accounting methods, statistical methods are becoming more frequent and common, LCA is a promising tool, and more recent trends point towards digitalization. The industry sector is the most frequently observed within the economic sectors, followed by the buildings sector, which includes more recent discussions such as NZEB (nearly zero energy buildings). Finally, some complementary approaches are observed, particularly to account for GHG emissions.

Content analysis corroborated findings from general bibliometric and network analysis. Starting with the prevalence of ISO 50001 and ISO 50006 as reference for methods. From the subject perspective, the industrial sector has the most significant participation, followed by the building sector. In terms of energy models, statistical methods were the most frequent, while the second most recurrent energy model was the ratio. Finally, regarding indicator types, specific energy consumption (SEC) and simple metric energy (absolute value) are the most used, while other complementary indicators were also identified.

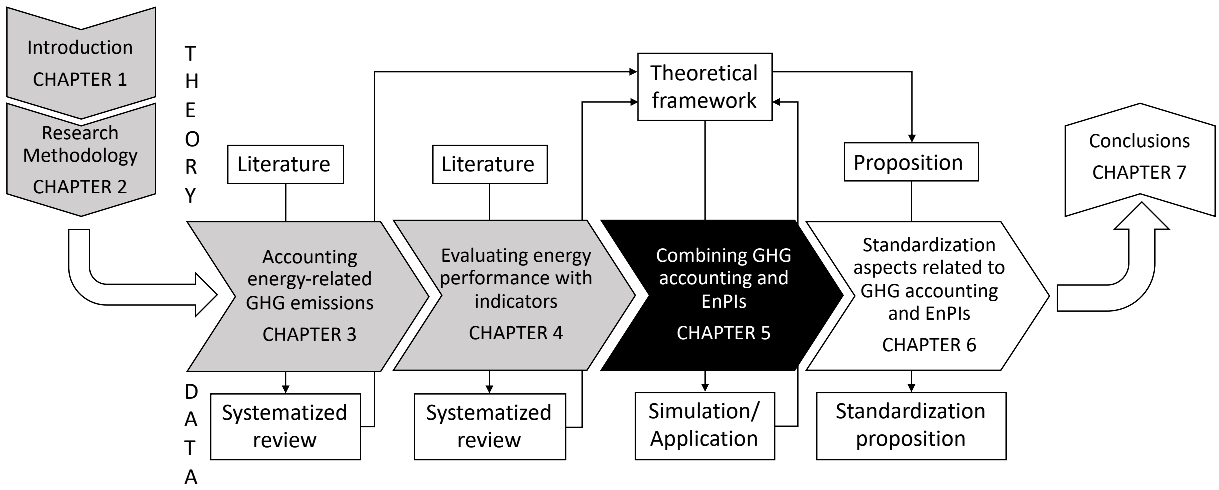
The last findings from content analysis open a discussion regarding challenges in defining appropriate EnPIs, particularly in achieving an effective energy performance representation. Boundaries, data gathering and reliability, and information technology support are relevant issues. However, adequate comprehension of EnPIs energy models and EnPIs reporting type is essential to increase awareness of EnPIs' capacities and limitations. Considering this systematized review, future studies could investigate the use of different EnPIs in the energy performance evaluation approach, assessing the impact of different indicator modeling and reporting types, and how these impacts can help increase an entity's energy performance awareness.

Finally, this chapter aimed to answer the following question – "What are the current state and trends on approaches adopted to energy performance improvement evaluation using indicators" – by means of three more specific questions. The first question – "In general, how are energy performance indicators applied?" – was answered by the thematic evolution from network analysis, which has provided insightful results on the relevance of the approaches throughout time. The second question – "Considering these applications, what are adopted for energy performance improvement evaluation?" – and the third question – "Considering these indicators, how are they defined (reporting type and calculation method)? Are there elements of energy management or energy saving projects present?" – were answered by the content analysis, which has collected specific data on approaches and factors regarding the GHG emission accounting.

# 5 COMBINING GHG EMISSION ACCOUNTING AND ENERGY PERFORMANCE INDICATORS

This Chapter presents the developments of the article: "Improving energy-related carbon emissions reporting by evaluating energy performance with indicators – A case study on the petroleum refining sector". Since this article submission is expected later in 2023, the final published version may contain changes. Adjustments were also made to adapt the article to this thesis format. This chapter's contribution in the context of this thesis is highlighted in Figure 5.1.

Figure 5.1 – Overall structure of this thesis highlighting Chapter 5 contribution




Source: Author's elaboration

## 5.1 Introduction

Given the relevance of accounting methods in reporting greenhouse gas emissions and the role played by energy-related emissions, methodological improvements are relevant to overcome challenges. From an accounting methods perspective, energy-related GHG emissions estimations can be improved by adopting activity data that adequately represents energy consumption. Choosing an emission factor coherent with the activity data, particularly in terms of temporal resolution, enhances even further these estimations. Boundary and scope definitions should also be consistent with activity and emission factors. Finally, when dealing with comparisons, suitable baselines shall be defined.

Since evaluating energy performance is a relevant method in tracking global energy use and the role played by indicators, understanding limitations and challenges is relevant to enable more disseminated usage. In summary, under modeling and reporting perspectives, energy performance evaluation can be achieved using indicators that should be carefully selected in both reporting type and energy model. An adequate indicator is based on an energy model providing meaningful results, and it is expressed by a reporting type fulfilling expected application uses.

Considering these methodology foundations regarding energy-related GHG emission accounting and energy performance evaluation with indicators, this work proposes to combine both tools, understanding their limitations and challenges, to overcome identified barriers and improve energy-related GHG emission reporting.

After the Introduction, Section 5.2 introduces the proposed combination of GHG accounting and energy performance indicators. Then, section 5.3 presents a case study in the petroleum refining sector using the proposed approach. Finally, conclusions and implications are highlighted in Section 5.4.

## 5.2 Proposed combination of GHG accounting and energy performance indicators

Aiming to evaluate the improvement in energy-related GHG emissions reporting, this work is based on methodology foundations of GHG emission accounting fundamentals and energy performance evaluation to build a proposed combination of these elements. Energy-related GHG emission accounting methodology foundations are based on the findings from Chapter 3. Energy performance evaluation methodology foundations are based on the findings from Chapter 4.

GHG emission accounting, as with the IPCC Guidelines and IPCC Good Practice Guidance, follows a common methodological approach to combine information on the extent to which human activity takes place (called activity data or AD) with coefficients that quantify the emissions or removals per unit activity (called emission factors or EF) (IPCC, 2006, 2019).

The general basic equation for GHG emission accounting, therefore, is described as Equation (5.1) below:

$$\text{Emissions}_{\text{GHG, t}} = \sum_{f} \text{AF}_{\text{f,t}} * \text{EF}_{\text{GHG,f,t}} \tag{5.1}$$

Where $\text{Emissions}_{\text{GHG,t}}$ are the accounted GHG emissions in a period t, $\text{AF}_{\text{f,t}}$ is the activity data related to the consumption of fuel f in a period t, and $\text{EF}_{\text{GHG,f,t}}$ is the GHG emission factor for fuel f consumed in a given t.

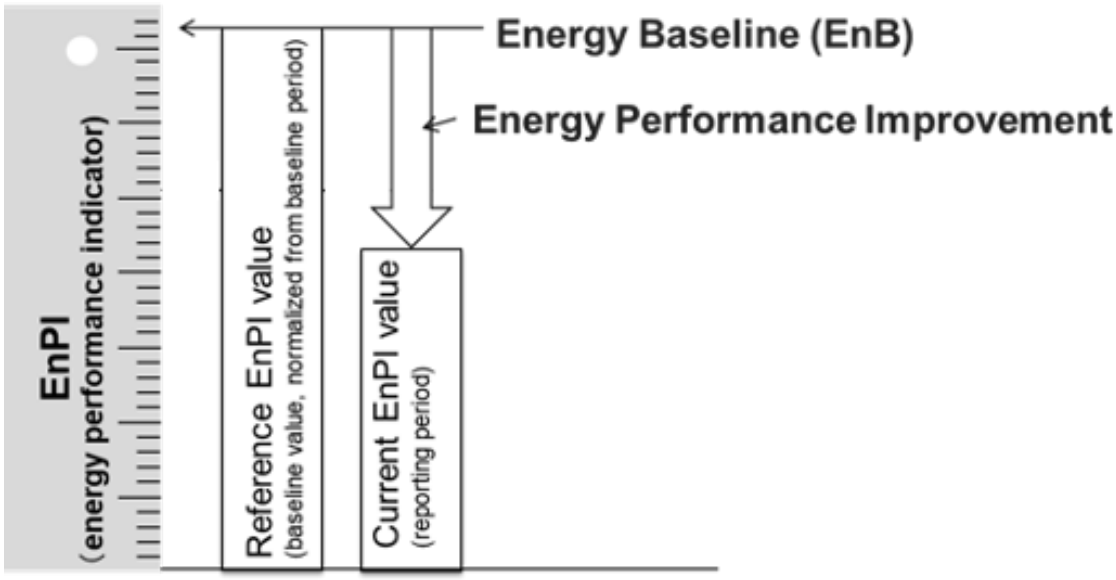
This basic equation allows for more complex modeling approaches in a tiered structure, as suggested by IPCC (2006, 2019). A tier represents a level of methodological complexity, and usually, three tiers are provided. Tier 1 is a basic method, Tier 2 is an intermediate method, and Tier 3 is the most demanding regarding complexity and data requirements. Tiers 2 and 3 are sometimes referred to as higher-tier methods and are generally considered more accurate (IPCC, 2006, 2019). This tiered structure is particularly relevant as it shapes the level of data quality regarding activity data and emission factors. Tier 1 is designed to use readily available national or international statistics in combination with the provided default emission factors. Tiers 2 and 3 step up the data quality requirements, considering more specific information (IPCC, 2006, 2019).

Considering this work subject, energy-related GHG emissions, in terms of emission factor, a Tier 1 approach would allow the use of a general national/international static average emission factor for a given energy type. For Tier 2, an estimate of a local specific emission factor for the same energy type would be required, preferably with time resolution. Finally, Tier 3 models would consider characteristics of the energy type in use to estimate the emission factor and, in some cases, include measurement systems and real-time data. Following the same pattern for activity data, Tier 1 energy activity data could be a general national/international static average SEC for a given economic activity combined with production data. For Tier 2, this SEC value would be expected to be local-based, preferably with time resolution. Finally, Tier 3 would involve facility-based SEC and production data, potentially including measurement systems and real-time data. Moving from an utterly simplified scenario (Tier 1) to more adequate estimations (Tier 2) could be achieved by considering energy performance evaluation since it could adequately represent energy consumption.

The energy performance evaluation methodology is founded based on the concept of energy performance and three other connected concepts: energy performance indicator, energy baseline, and energy performance improvement. The relation of these concepts is shown in Figure 5.2. Considering ISO 50001 – Energy management systems — Requirements with guidance for use (ISO, 2018), ISO 50004 – Energy management systems — Guidance for the implementation, maintenance, and improvement of an ISO 50001 energy management system (ISO, 2020), and ISO 50006 – Energy management systems — Measuring energy performance using energy baselines (EnB) and energy performance indicators (EnPI) — General principles and guidance (ISO, 2014), the following definitions can be highlighted:

- energy performance: measurable result(s) related to energy efficiency, energy end-use, and energy consumption;
- energy performance indicator (EnPI): measure or unit of energy performance;
- energy baseline (EnB): quantitative reference(s) providing a basis for comparison of energy performance;
- energy performance improvement: improvement in measurable results of energy efficiency, or energy consumption related to an energy end-use, compared to the energy baseline;

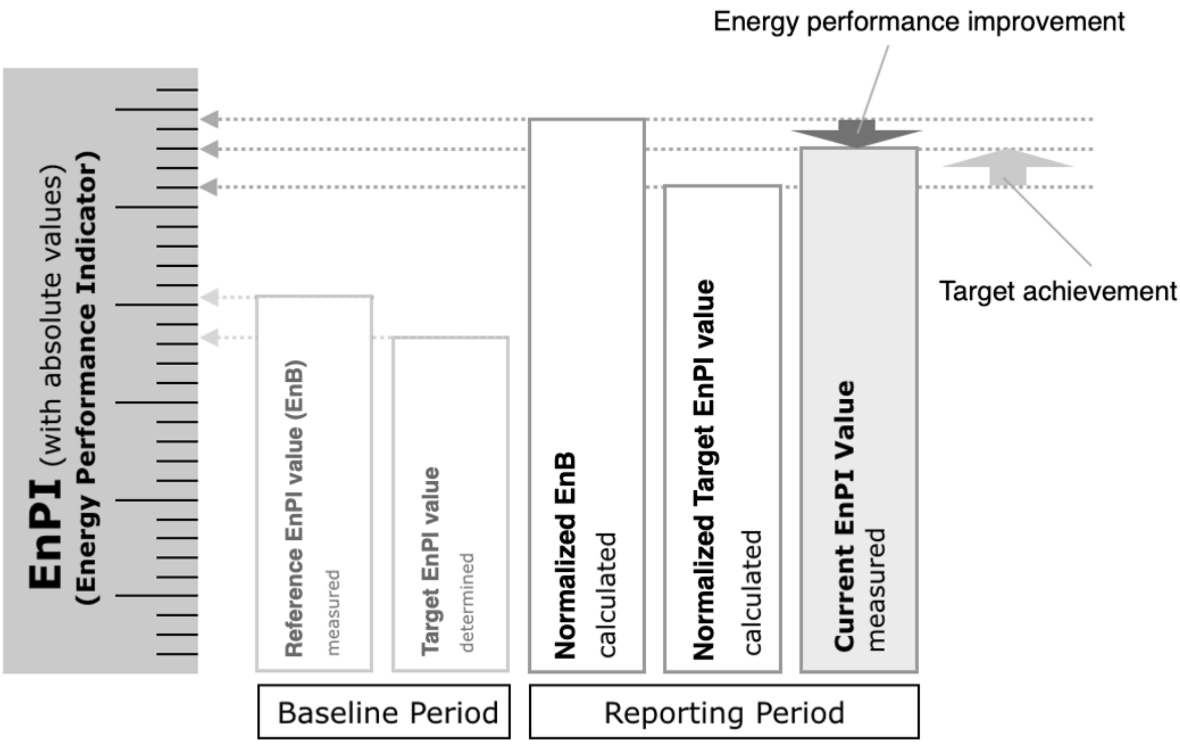
Figure 5.2 – Concepts of energy performance improvement, EnPIs, and EnBs




Source: ISO (2018)

Energy performance evaluation can be accomplished through different comparisons of the current EnPI value and a reference EnPI value. The most recurrent involves the comparison between EnB values and measured reporting period EnPI values, aiming to assess energy performance improvement. Another recurrent approach considers the comparison between target EnPI values and measured reporting period EnPI values, aiming to assess energy target achievement. A visual representation of these comparisons is presented in Figure 5.3. Normalization of EnBs and target EnPI values have a critical role in energy performance evaluation. The purpose of normalization is to enable meaningful comparisons between two sets of data by modeling energy performance under similar conditions. The baseline period data is used to determine a relationship between energy consumption and relevant variables (ISO, 2014; Nissen et al., 2018).

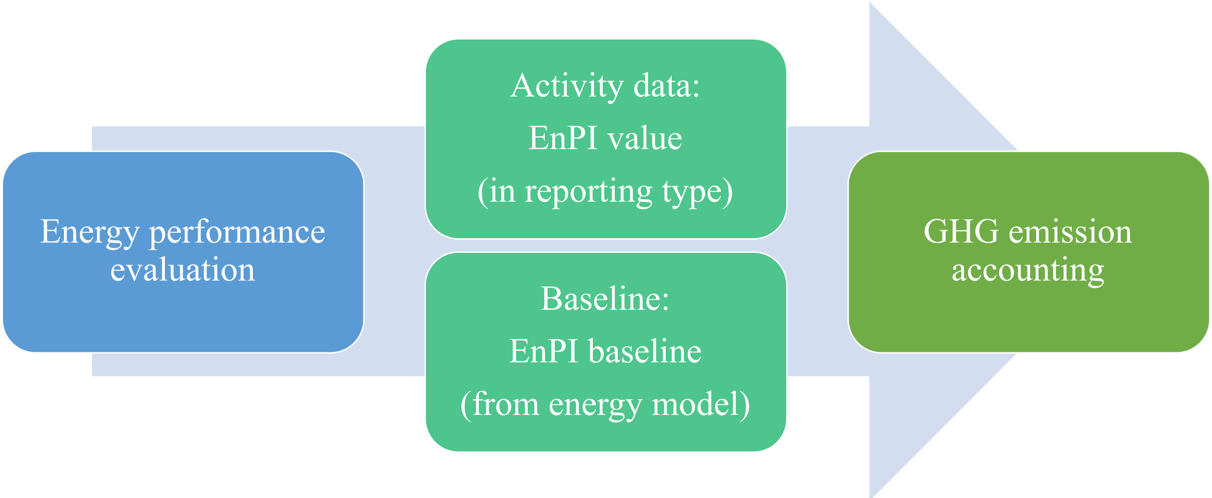
Figure 5.3 – Relationships between different EnPI values




Source : Nissen et al. (2018)

Considering these methodology foundations, this work proposes combining GHG accounting for energy-related emissions and energy performance evaluation with indicators. This combination allows energy performance evaluation to provide elements that can help GHG emission accounting. As mentioned previously, moving up in the complexity of GHG emission accounting requires to have more local and time-specific activity data, which could be provided from an EnPI value in its reporting type. Additionally, when comparing emissions between two time periods or before and after an action is made, it is necessary to have an adequate and representative emission baseline. This emission baseline could be established using an EnPI baseline, particularly its energy model, associated with an emission factor with the best available time resolution. The combination of energy performance evaluation and GHG emission accounting can be schematically shown in Figure 5.4.

Figure 5.4 – Energy performance evaluation providing elements to greenhouse gas emission accounting




Source: Author's elaboration

The concept of energy performance is central to this discussion because an improvement in energy performance can be proxied by energy savings, but the contrary is not always the case. Energy savings can be obtained by reducing activity (e.g., production reduction) or quality (e.g., illuminance reduction). However, these situations don't capture an effective improvement and can somewhat hide a performance deterioration. For example, energy efficiency improvement project activities having a lower consumption because of a lower level of activity is not an eligible CDM project (LEE et al., 2005). These observations are made considering that either activity or quality previously mentioned are adequate and not over-dimensioned.

The promotion of energy performance evaluation in the context of GHG emission accounting entails the generation and collection of appropriate data at the organizational level, which may be considered and used by national inventory compilers, as the IPCC has previously considered (IPCC, 2019). Greenhouse gas emission accounting from energy performance data at the organizational level may better reflect emission trends over time than constant factors. This methodology allows to consider operational changes and variable emission factors. However, a high-tier method like this is not always needed. The added burden of developing such an approach may not be worthwhile if the same level of quality or accuracy can be achieved more efficiently or cost-effectively by improving the primary activity dataset or updating emission factors. Energy-intensive activities should consider using energy performance indicators to evaluate greenhouse gas emissions, as they may already have this data with or without an energy management system. The next section will investigate a case study in the petroleum refining sector.

## 5.3 Case study in the petroleum refining sector

This case study in the petroleum refining sector aims to present an application of the proposed combination of GHG emission accounting for energy-related emissions and energy performance evaluation with indicators. The development of this case study has the following structure: Subsection 5.3.1 describes the motivation for evaluating this sector and presents the case overall scenario, Subsection 5.3.2 performs energy performance evaluation, Subsection 5.3.3 performs GHG emission accounting, and Subsection 5.3.4 discuss the obtained results.

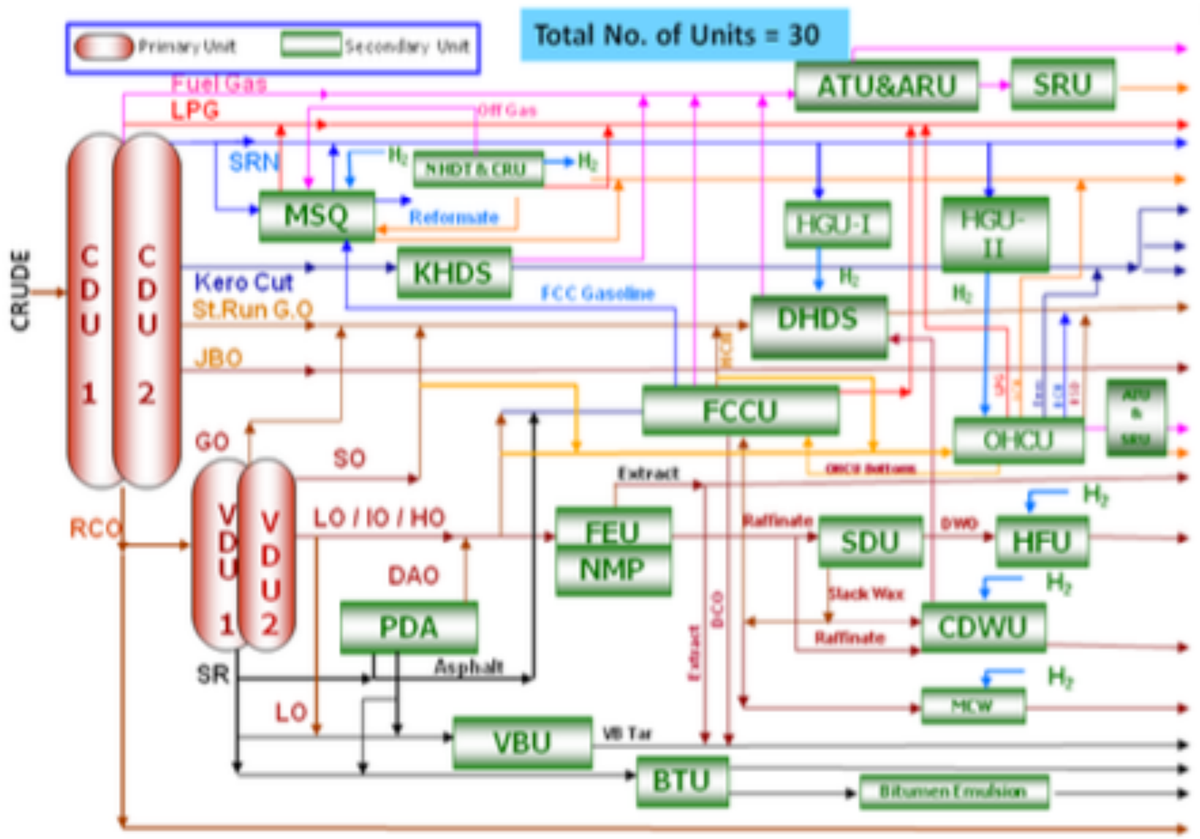
### 5.3.1 Case presentation

This case study focuses on two refineries in India, illustrated by their process flow diagrams in Figure 5.5 and Figure 5.6, based on data provided by (SSEF; CWF; ERNST & YOUNG LLP, 2013). Refining crude oil is an inherently energy-intensive process. Oil refineries aim to produce various petroleum products, primarily transport fuels, heating and industrial fuels, and chemical feedstocks. Most of the raw materials are crude oils, along with various natural or semi-processed hydrocarbon combinations. Refinery processes require energy for heating, reacting, chilling, compressing, and conveying liquid and gaseous hydrocarbon streams. In a refinery, heating is by far the largest energy consumer. Many refining processes do not necessitate high-magnitude temperatures, for which steam is the standard heat medium. In addition to requiring power for pumps, compressors, instrumentation, lights, etc., refineries may also require electricity for specific process purposes. Refineries often have a high heat recovery rate and only discard low-temperature streams with no practical use. Since there is a demand for heat and power, it is common to adopt cogeneration in refineries. Most of the refinery's energy needs are often met by fuels that are produced on-site. In practice, many refineries additionally import gas (usually natural gas), heat (mainly steam), and electricity. Some refineries export power and heat (ABELLA; BERGERSON, 2012; JOSHI; DALEI; MEHTA, 2021; WORRELL; CORSTEN; GALITSKY, 2015).

Represented in Figure 5.5, the first refinery, larger and more complex, consists of four primary units – two Crude Distillation Unit (CDU) and two Vacuum Distillation Units (VDU)

– and several secondary units such as Catalytic Reforming Unit (CRU), Hydrogen Generation Unit (HGU), and Bitumen Treating Unit (BTU). CDU treats and separates from crude oil light distillates like naphtha, kerosene, and diesel. VDU proceeds with the distillation extracting LPG and gas oils. The refining process in secondary units of CDU and VDU products generates other refinery final products (SSEF; CWF; ERNST & YOUNG LLP, 2013).

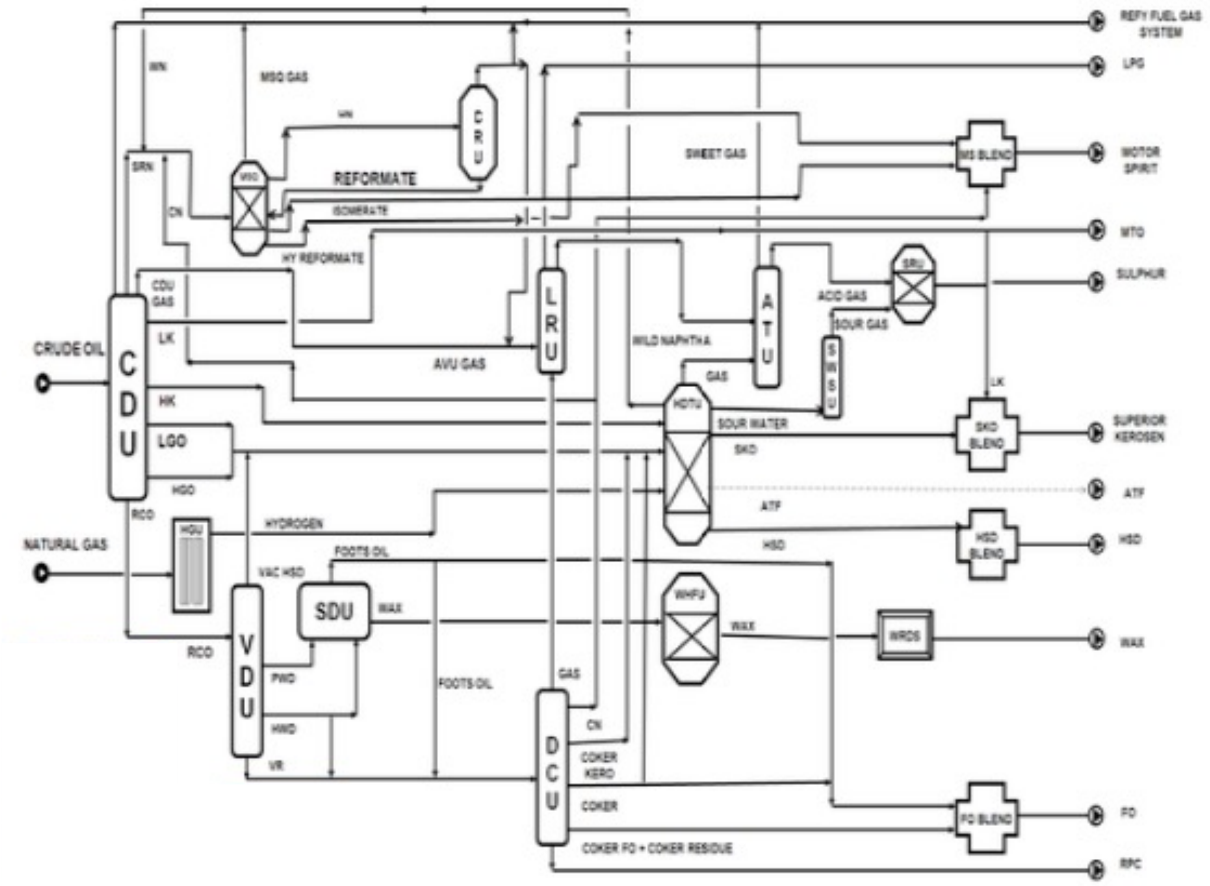
Figure 5.5 – Process flow diagram of Refinery 1 (Larger and more complex)




Source: (SSEF; CWF; ERNST & YOUNG LLP, 2013).

The second refinery, presented in Figure 5.6, is a relatively smaller and less complex one than the previous one. There are two major primary units, one CDU and one VDU. However, there is a limited number of secondary units, such as CRU, Delayed Coking Unit (DCU), and LPG Recovery Unit (LPGRU). CDU and VDU distill crude oil, and distillate products are further processed in secondary units. The reduced number of secondary units implies that fewer final product types are obtained in this refinery compared to the previous one (SSEF; CWF; ERNST & YOUNG LLP, 2013).

Figure 5.6 – Process flow diagram of Refinery 2 (smaller and less complex)




Source: (SSEF; CWF; ERNST & YOUNG LLP, 2013).

The absolute energy consumption of a refinery is defined not only by the amount of material it processes or generates but also, and to a significant degree, by its complexity, which is mainly reflected by the number of heavy streams converted into lighter products. Therefore, valid energy performance comparisons are only possible using a metric that normalizes energy data for size and complexity. Previous works have investigated the relationship between refineries' energy consumption and several factors besides the complexity of the refinery and the quantity of crude oil processed (throughput). These factors are mainly related to the crude oil quality, such as API gravity, crude oil density, Sulphur content, and hydrogen content. Particularly for the case of representing the complexity, two examples of approaches can be mentioned. First, when developing EII (Energy Intensity Index), a dimensionless index used to benchmark European refineries, a standard energy factor was attributed to each generic type of process unit used in refineries. In a similar approach supported by India's government, an overall refinery complexity factor (refinery NRGF) is calculated using a weighted average of each unit defined NRGF and its throughput (Abella & Bergerson, 2012; Elgowainy et al., 2014; Han et al., 2015; Joshi et al., 2021; SSEF et al., 2013; Worrell et al., 2015).

For these two refineries, a 60-month database is presented by (SSEF; CWF; ERNST & YOUNG LLP, 2013), covering the following data: MBN, a personalized specific energy consumption indicator; percentage of capacity utilization; density of crude processed; percentage of Sulphur content in crude processed; and refinery NRGF. The MBN is a similar approach supported by India's government compared to EII, defined as the refinery energy consumption in MBTU, divided by its throughput (in barrels) and its NRGF. Considering additional information provided by (SSEF; CWF; ERNST & YOUNG LLP, 2013), it was possible to estimate the installed capacity of each refinery and thus transform MBN into energy consumption and percentage of capacity utilization into throughput. Using appropriated energy conversion factors (DUDLEY, 2018), the considered database used in the following evaluations is presented in Table C.1.

The objective of this case study is to evaluate the refinery operation during the last 12 months of the database, comparatively to the preceding 48-month period. Therefore, an energy performance evaluation with indicators will be conducted using the first 48 months as a baseline period and the last 12 months as the reporting period. The energy performance evaluation will then be used to assess GHG emission trends. Regarding the available data, it is always important to adopt the most disaggregated data with the finest resolution possible. In this case, data was consolidated monthly for energy consumption and its relevant variables, while no detailed data for the emission factor was available, which is a limitation of this case study. Therefore, considering the tiered approach for GHG emission accounting, this case study would perform an intermediate approach between Tier 1 and Tier 2.

### 5.3.2 Energy performance evaluation with indicators

The first step in energy performance evaluation with indicators comprehends an assessment of indicator application uses. Considering the objective of calculating the change in GHG emissions throughout one year compared to a baseline, a simple metric (absolute value) reporting type is required. The value reported in this EnPI type will perform as activity data in GHG emission accounting. In the literature, however, it is common to observe reported results in SEC and specific GHG emissions. Therefore, this second EnPI type will also be considered for reporting purposes.

The second step involves defining the boundaries. This case study has two boundaries, one for each refinery, entailing the development of two EnPIs. All energy flows are considered, and, as mentioned (WORRELL; CORSTEN; GALITSKY, 2015), refineries might import and export different energy sources. Regarding data, this was already performed by (SSEF; CWF; ERNST & YOUNG LLP, 2013), and the energy consumption is already a net total value.

The following step involves the adoption of an energy model. This model describes the relationship between energy performance and variables that affect it significantly. As previously mentioned, energy consumption in a refinery is affected by several factors. Therefore, a modelling comprising multiple variables' effect is advised, for example, multiple linear regression (MLR). The current energy performance evaluation will consider as potentially relevant variables the following: refinery throughput (T), refinery complexity (NRGF), the density of crude processed (d), and the percentage of Sulphur content in crude processed (S). Consequently, the EnPI can be formulated as expressed in Equation (5.2).

$$EnPI_i = b_{0,i} + b_{1,i} * T_i + b_{2,i} * NRGF_i + b_{3,i} * d_i + b_{4,i} * S_i \quad (5.2)$$

Where $EnPI_i$ is the EnPI energy model for Refinery i (PJ/month), $b_{0,i}$ is the regression coefficient for the intercept, $T_i$ is the throughput of Refinery i (MBBL/month) with $b_{1,i}$ as its regression coefficient, $NRGF_i$ is the complexity factor for Refinery i (dimensionless) with $b_{2,i}$ as its regression coefficient, $d_i$ is the density of the crude oil processed in Refinery i (kg/m$^3$) with $b_{3,i}$ as its regression coefficient, and $S_i$ is the Sulphur content of the crude oil processed in Refinery i (%) with $b_{4,i}$ as its regression coefficient.

The value of each coefficient in Equation (5.2) and the relevance of these variables is assessed when performing the regression with the available data. Using the first 48-month data from Table C.1 and the software Statplus, multiple linear regressions were performed for Refinery 1 and Refinery 2. After the first multiple linear regression for Refinery 1, the intercept (represented by the constant value, $b_{0,1}$) fails to pass the null hypothesis test and thus is rejected. Then, a second multiple linear regression is performed, and all remaining variables pass the null hypothesis, resulting in the following energy model for Refinery 1, as expressed in Equation (5.3). Complete reports of both regression analyses are presented in Table C.2 and Table C.3.

$$EnPI_1 = 361.3 * T_1 + 476.7 * NRGF_1 - 4.2 * d_1 + 38,803.3 * S_1 \quad (5.3)$$

Where $EnPI_1$ is the EnPI energy model for Refinery 1 (PJ/month), $T_1$ is the throughput of Refinery 1 (MBBL/month), $NRGF_1$ is the complexity factor for Refinery 1 (dimensionless), $d_1$ is the density of the crude oil processed in Refinery 1 ($kg/m^3$), and $S_1$ is the Sulphur content of the crude oil processed in Refinery 1 (%).

In the case of Refinery 2, after a first multiple linear regression, both quality-related variables (density and Sulphur content) fail to pass the null hypothesis test and thus are rejected. Then, a second multiple linear regression is performed, and all remaining variables pass the null hypothesis, resulting in the following energy model for Refinery 2 as expressed in Equation (5.4). Complete reports of both regression analyses are presented in Table C.4 and Table C.5.

$$EnPI_2 = -1,9503.4 + 318.3 * T_2 + 414.9 * NRGF_2 \quad (5.4)$$

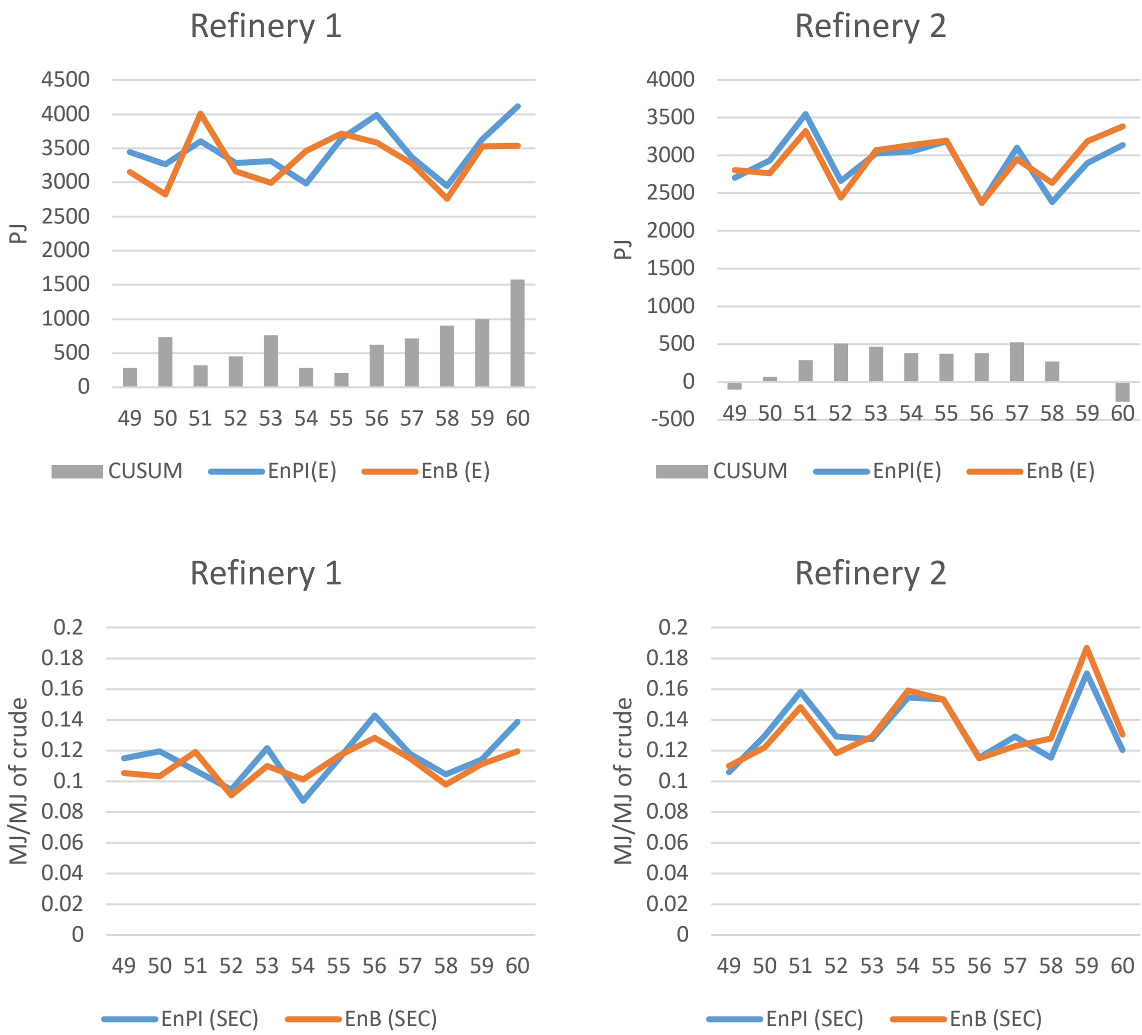
Where $EnPI_2$ is the EnPI energy model for Refinery 2 (PJ/month), $T_2$ is the throughput of Refinery 2 (MBBL/month), $NRGF_2$ is the complexity factor for Refinery 2 (dimensionless).

Considering that Refinery 1 is more complex than Refinery 2, including more and diverse secondary units, it is coherent that $EnPI_1$ has more relevant variables than $EnPI_2$. The EnPIs energy models are useful energy baselines (EnB) to evaluate the change in energy performance. This energy performance evaluation is performed for both refineries considering the following: EnPI current value, i.e. energy consumption on the last 12-month data from Table C.1, is compared to the EnB, which is calculated using the relevant variables data on the last 12-month data from Table C.1.

The cumulative difference is summed, a frequently adopted technique, to assess the trend in change of energy performance. Results for Refineries 1 and 2 are presented in Figure 5.7. Additionally, EnPIs and corresponding EnBs were also reported in SEC. Therefore, to differentiate them, the previous indicators based on a simple metric, i.e., absolute energy consumption, are indicated with "(E)" suffix. Detailed results from the energy performance evaluation reported in Figure 5.7 are presented in Table C.6 and Table C.7.

As a preliminary evaluation of these results, Refinery 1 has erratic operational behavior within the first semester that degrades over the second semester. Refinery 2 starts the year with deteriorating energy performance in the first quarter, which stabilizes over the following two subsequent quarters and starts improving again in the last quarter. These conclusions can be drawn using either EnPI (E) or EnPI (SEC). Accordingly, Refinery 1 consumption exceeds the baseline by approximately 1.5 EJ or 24 Mtoe in the reporting period, while Refinery 2 has accumulated energy savings of approximately 0.26 EJ or 6.2 Mtoe in the same reporting period. SEC values are coherent with scenarios from (ABELLA; BERGERSON, 2012).

Figure 5.7 – Energy performance evaluation for Refineries 1 and 2




Source: Author's elaboration

### 5.3.3 GHG emission accounting

As suggested in this work proposition, energy performance evaluation outputs will be used in energy-related GHG emission accounting as information to fulfill activity data and baseline needs. However, other steps are required to be completed before the calculation step.

The first step is to define boundaries and scope, including the adopted GHG accounting method approach. In terms of physical boundaries, there will be two, one for each refinery, reproducing those considered for the EnPIs. Emissions scopes 1 and 2 will be considered, direct emissions associated with energy use and indirect emissions from electricity used imported from the grid. Finally, following an attributional approach, this case study will consider only an inventorying-type accounting. Considering these definitions, the GHG emissions are estimated using the following Equation (5.5):

$$EmI_{GHG,t} = \sum_{f} AF_{f,t} * EF_{GHG,f,t} \quad (5.5)$$

Where $EmI_{GHG,t}$ is the GHG emission indicator in a period t, $AF_{f,t}$ is the activity data related to the consumption of fuel f in a period t, and $EF_{GHG,f,t}$ is the GHG emission factor for fuel f consumed in a given t.

GHG emission indicators can take a form of a simple metric, i.e. the absolute value of GHG emissions when the activity data is also in a form of a simple metric. Analogously, GHG emission indicators can take the form of specific emissions when the activity data is in the form of specific energy consumption (SEC). As discussed previously, these conditions are direct application guidance to the different EnPI reporting types. Emission factors may account for one or multiple greenhouse gases, depending on the data source, and it is specific to each fuel consumed. It is important to notice that given the emission factor fuel specificity, different modeling alternatives emerge, such as developing activity data specific to each fuel consumed, as in the previous Equation (5.5), or calculating the share of each fuel consumed for an overall activity data, as in Equation (5.6).

$$EmI_{GHG,t} = AF_{t} * \sum_{f} fs_{f,t} * EF_{GHG,f,t} = AF_{t} * EF_{GHG,t} \quad (5.6)$$

Where $EmI_{GHG,t}$ is the GHG emission indicator in a period t, $AF_{t}$ is the activity data in a period t, $fs_{f,t}$ is the fuel f share in $AF_{t}$, $EF_{GHG,f,t}$ is the GHG emission factor for fuel f consumed in a period t, and $EF_{GHG,t}$ is the GHG emission factor for the fuel mix consumed in a period t.

In the present case study, the data source (SSEF; CWF; ERNST & YOUNG LLP, 2013) doesn’t disclose energy consumption by fuel, only indicates that locally produced fuels are consumed, locally produced and imported electricity is consumed, and no mentions to steam importing. Therefore, using this information, references to fuel share consumption in refineries were investigated and reported in Table 5.1. Complementary data regarding fuel-specific emission factors were collected and reported in Table 5.2.

Table 5.1 – Refinery fuel mix references

| Region/Country | | Europe | US | Average |
|---|---|---|---|---|
| Period | | 2010 | 2008-2011 | - |
| Fuel | Natural gas | 13% | 18% | 15% |
| | Fuel gas | 49% | 33% | 41% |
| | Liquid fuels | 13% | 1% | 7% |
| | Petroleum coke | 14% | 24% | 20% |
| | Electricity and utilities | 11% | 23% | 17% |
| Reference | | (BOURGEOIS; AHMANN; ALBERTOS DE BENITO, 2012) | (EIA, 2008) | - |

Source: Author's elaboration based on cited references

Table 5.2 – Fuel specific emission factors

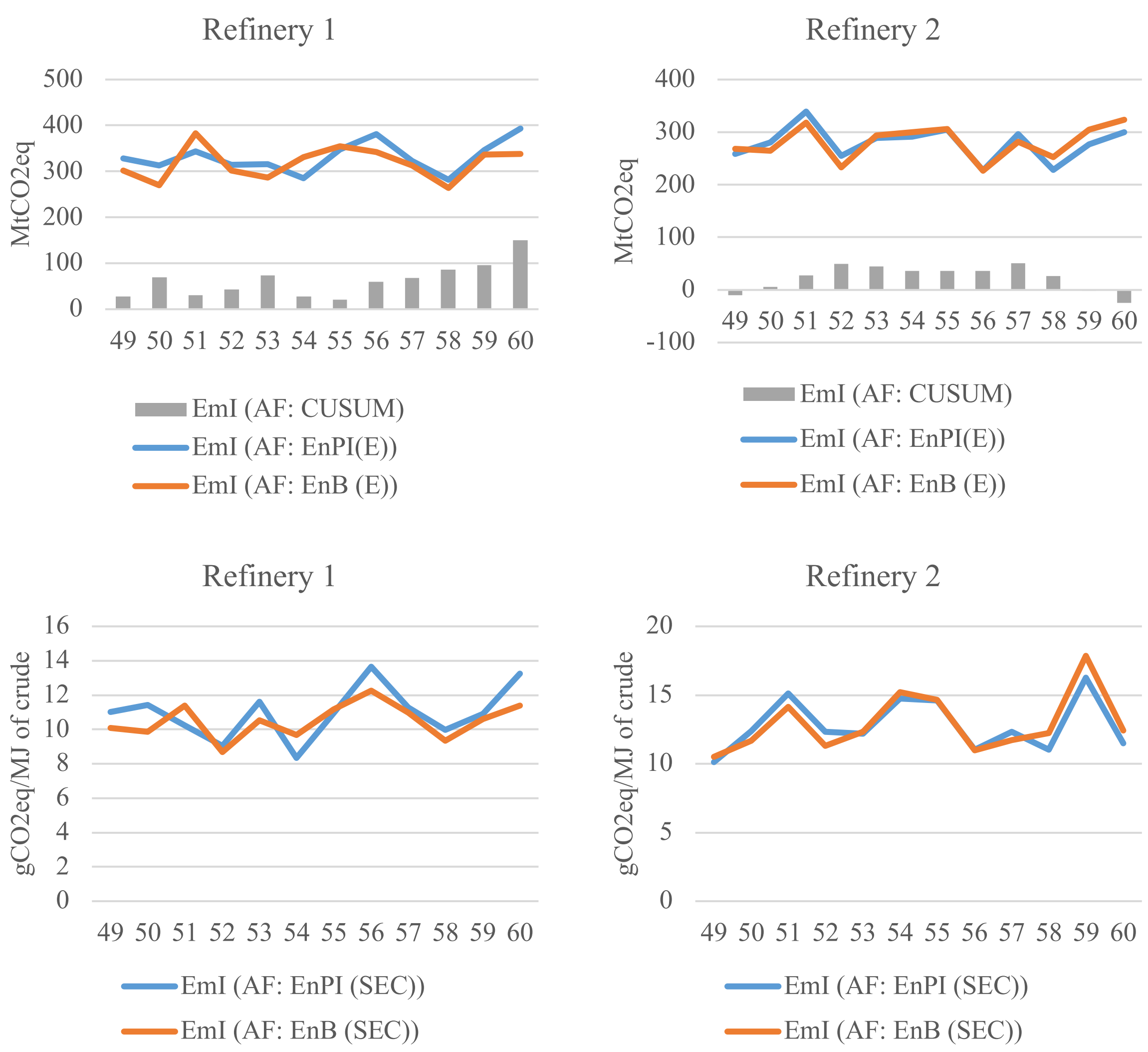
| | GHG | $CO_2$ | $CH_4$ | $N_2O$ | $CO_{2eq}$ |
|---|---|---|---|---|---|
| | GWP 100 | 1 | 27.9 | 273 | - |
| Emission factor (t/TJ) | Natural gas | 56.1 | 0.005 | 0.0001 | 56.3 |
| | Fuel gas | 57.6 | 0.005 | 0.0001 | 57.8 |
| | Liquid fuels | 73.3 | 0.01 | 0.0006 | 73.7 |
| | Petroleum coke | 97.5 | 0.01 | 0.0006 | 97.9 |
| | Electricity and utilities | - | - | - | 227.8 |
| | Reference | (Dhakal et al., 2022; IPCC, 2006) | | | (SINGH et al., 2018) * for electricity |

Source: Author's elaboration based on cited references

Based on the modeling presented in Equation (5.6), considering the average value from Table 5.1 and the fuel-specific emission factors in $CO_{2eq}$ from Table 5.2, the emission factor for the fuel mix consumed is estimated at 95.6 $t_{CO2eq}$/TJ. Finally, using this emission factor and the different EnPI reporting types from Figure 5.7, the GHG emission accounting can be reported using several indicators, as displayed in Figure 5.8. Detailed results from GHG emission accounting reported in Figure 5.8 are presented in Table C.8 and Table C.9.

In fact, since the emission factor doesn't have temporal resolution elements, i.e., it is static, the same preliminary results evaluation from Figure 5.7 are also valid for these results. Accordingly, Refinery 1 GHG emissions exceed the baseline by approximately 150 $Mt_{CO2eq}$ in the reporting period, while Refinery 2 has accumulated emissions reductions of approximately 24.8 $Mt_{CO2eq}$ in the same reporting period. Specific emissions values are coherent with scenarios from (ABELLA; BERGERSON, 2012).

Figure 5.8 – GHG emission accounting for Refineries 1 and 2




Source: Author's elaboration

### 5.3.4 Discussion

After unveiling the proposed approach results, two main subjects have significant relevance to be discussed. The first concerns the appraisal of the proposed approach with other simplified approaches to evaluate how they perform compared to each other. Under the first subject perspective, this work proposal is based on a GHG emission accounting element. Energy-related GHG emissions estimations can be improved by adopting activity data that represents adequate energy consumption. This element is complemented by the fact that energy performance evaluation can be achieved by using indicators. However, simplified approaches are usually adopted to avoid an in-depth analysis, such as energy performance evaluation, such as using average energy consumption (simple metric) or average SEC (ratio) as energy models. Considering these simplified approaches and the proposed by this work, a comparison of the results of the case study is presented in Table 5.3.

Table 5.3 – Comparison of approaches' results in energy performance evaluation and GHG emission accounting

| **Approach / Assessment** | **Refinery 1** | | **Refinery 2** | |
|---|---|---|---|---|
| | Energy (PJ) | GHG emissions (MtCO2eq) | Energy (PJ) | GHG emissions (MtCO2eq) |
| Average consumption | 455.7 | 43.6 | -333.1 | -31.8 |
| Annual average SEC | 678.9 | 64.9 | 1008.9 | 96.5 |
| Monthly average SEC | 3511.9 | 335.7 | 5929.9 | 566.9 |
| Proposed approach (CUSUM) | 1575.1 | 150.6 | -259.3 | -24.8 |

Source: Author's elaboration

SEC as an energy model produces inconsistent results, as shown in Table 5.3 and increasing SEC temporal resolution increases the inconsistency. Therefore, SEC doesn't fit as an adequate energy model. A similar situation is observed with a simple metric. These results are straightforward, considering that regression analysis was conducted, and for both refineries, the energy consumption is a function of multiple relevant variables. However, practitioners tend to adopt simplified energy models, particularly SEC, due to its ease of understanding and communicating its physical concept to other collaborators. This raises an element from energy performance evaluation: EnPIs have their energy model and reporting type, and they can differ from each other. (HILLIARD; JAMIESON; JORJANI, 2014; MUTSCHLER-BURGHARD, 2019). For example, in Figure 5.5, the same results from one EnPI energy model, multiple linear regression, are expressed by three reporting types, simple metric, SEC, and CUSUM.

Finally, a second discussion subject is the limitations found during this case study development. The major limitation concerns the emission factor since no information was available at the same data source regarding refineries' fuel consumption mix. The solution to overcome this barrier was to adopt literature values, however, they had no temporal resolution and direct relation with other variables from the EnPI energy model.

## 5.4 Conclusions

Considering methodological fundamentals of energy-related GHG emission accounting and energy performance evaluation with indicators, this work proposed a combination of both tools, understanding their limitations and challenges to overcome identified barriers and improving energy-related GHG emission reporting.

The proposed combined method aims to improve energy-related GHG emissions estimations by adopting activity data that adequately represent energy consumption and using suitable comparison baselines. Energy performance evaluation fits perfectly to provide these two elements. An adequate indicator based on an energy model provides meaningful results, expressed by a reporting type fulfilling expected application uses. The EnPI value in a given reporting type fulfills the activity data need, while the EnPI energy model is a suitable baseline for comparing activity data.

A case study was proposed in the petroleum refining sector, an inherently energy-intensive activity, applying the proposed combination of methodologies. The case study involved two refineries in India, and their energy consumption was investigated through an energy performance evaluation. Regression analyses were conducted considering four possible relevant variables, namely refinery throughput (T), refinery complexity (NRGF), the density of crude processed (d), and the percentage of Sulphur content in crude processed (S). Regression analysis of Refinery 1 resulted in an EnPI energy model with four variables but no intercept. In the case of Refinery 2, both quality-related variables (density and Sulphur content) were rejected. Considering that Refinery 1 is more complex than Refinery 2, including more diverse secondary units, it is coherent that the EnPI energy model for the first has more relevant variables than the one for Refinery 2.

Furthermore, the energy performance evaluation results allowed to evaluate how the performance of both refineries changed over one specific reporting period, using either EnPI reported as a simple metric or as SEC. In numbers, Refinery 1 consumption exceeds the baseline by approximately 1.5 EJ or 24 Mtoe in the reporting period. Refinery 2 has accumulated energy savings of roughly 0.26 EJ or 6.2 Mtoe in the same reporting period.

GHG emission accounting was then proceeded, aiming to calculate GHG emission indicators as a simple metric or a specific emission, which are conditioned to the direct application of different EnPI reporting types as activity data. On the other hand, emission factors had to be specified, as the case study data source didn't disclose the refinery fuel consumption mix, which was the major case study limitation. Since the emission factor adopted didn't have a temporal resolution, the same patterns from energy performance evaluation were observed in GHG emission indicators. In numbers, Refinery 1 GHG emissions exceed the baseline by approximately 150 MtCO2eq in the reporting period, while Refinery 2 has accumulated emissions reductions of roughly 24.8 MtCO2eq in the same reporting period.

This work proposed combining the two methodologies to improve the reporting of energy-related GHG emissions. Compared to other simplified approaches, for example, using average energy consumption (simple metric) or average SEC (ratio) as energy models, the proposed method produces more consistent results, particularly knowing that the energy consumption has relevant variables which undermine the quality of simple metric or ratio as adequate EnPIs. However, practitioners tend to adopt simplified energy models, which raises an element from energy performance evaluation. Furthermore, EnPIs have an energy model and a reporting type, and they can differ.

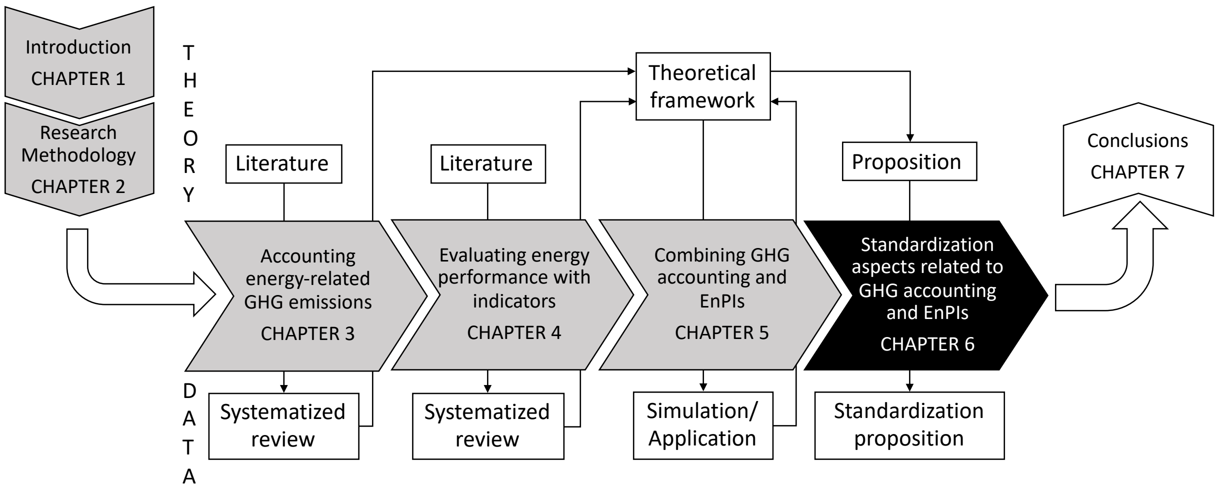
Considering the proposed method and the case study results, future studies could investigate the application of the combination of GHG emission accounting and energy performance evaluation in other cases, assessing the impact of different indicator modeling, reporting types, and more granular temporal resolution emission factors. Another research subject is raised by comparing the proposed method and simplified approaches. Future studies could investigate how increasing an entity's energy performance awareness can help promote the use of adequate energy models.

Finally, this chapter aimed to answer the following question – "What are the challenges in GHG emission accounting that energy performance evaluation with indicators can overcome and improve energy-related GHG emission reporting?". This question was answered with section 5.2, which proposes the combination of GHG emission accounting and energy performance evaluation using the latter's strengths to provide more information to the former, allowing a higher tier emission accounting. Despite the limitations, the developed case study showed that this proposed combination offers better results than a basic method/Tier 1 calculation.

# 6 STANDARDIZATION ASPECTS RELATED TO GHG EMISSION ACCOUNTING AND ENERGY PERFORMANCE EVALUATION

This Chapter presents the developments of the article: "Aligning standardization movements in GHG and Energy Management to improve energy-related carbon emissions reporting". Since this article submission is expected later in 2023, the final published version may contain changes. Adjustments were also made to adapt the article to this thesis format. This chapter's contribution in the context of this thesis is highlighted in Figure 6.1.

Figure 6.1 – Overall structure of this thesis highlighting Chapter 6 contribution




Source: Author's elaboration

## 6.1 Introduction

GHG management and energy management are two relevant fields in international standardization, each with a set of standards that experts have built over the last decades to help the international community improve practices toward sustainable development. One of the most cited Energy management international standardization forums is ISO/TC 301 – Energy management and energy savings. This forum coordinates the development of the ISO 50000 family, from the energy management system (EnMS) standard ISO 50001 (ISO, 2018b), to several guidance documents to support energy managing activities and EnMS implementation, as ISO 50004 – Energy management systems — Guidance for the implementation, maintenance, and improvement of an ISO 50001 energy management system, and ISO 50006 – Energy management systems — Measuring energy performance using energy baselines (EnB) and energy performance indicators (EnPI) — General principles and guidance. More recently, the ISO/TC 301 moved also toward Net Zero discussions, with ISO/PAS 50010 – Energy management and energy savings — Guidance for net zero energy in operations using an ISO 50001 energy management system (ISO, 2022a). This is the second ISO document covering such a topic, ISO/IWA 42 – Net zero guidelines (ISO, 2022b) was the first one, being published earlier the same year and presented at COP 27.

Under the GHG management perspective, there is an ISO discussion environment, the ISO/TC 207/SC 7 – Greenhouse gas and climate change management and related activities, and a subcommittee from ISO/TC 207 – Environmental management. This subcommittee has a critical role in the GHG emissions accounting field since it is responsible for ISO 14060 family (ISO, 2018b), from specification and guidance to quantification and reporting, to more recently approaching carbon neutrality discussion, with ISO 14068 – Greenhouse gas management and climate change management and related activities — Carbon neutrality (ISO, 2022c). In addition, other entities also developed standardized procedures, such as GHG Protocol and IPCC (IPCC, 2006; RANGANATHAN et al., 2004). Propositions from these later entities precede those from ISO, and, in general, this is the course of the standardization process since discussions in ISO structure usually take more time to reach an international agreement.

Despite these subjects being explored in parallel in these standardization forums, in the scientific literature there are, in some extent, attempts to operate both standardized processes together (GLAVAS et al., 2018; LIU; WANG; SU, 2016; O'KEEFFE; O'SULLIVAN; BRUTON, 2022; SCIPIONI et al., 2012a, 2012b; SINDEN, 2009; TURNER et al., 2012). Following this path, this work discusses alignment opportunities between energy performance evaluation with indicators, an energy management aspect, and energy-related GHG emission accounting, a GHG management aspect.

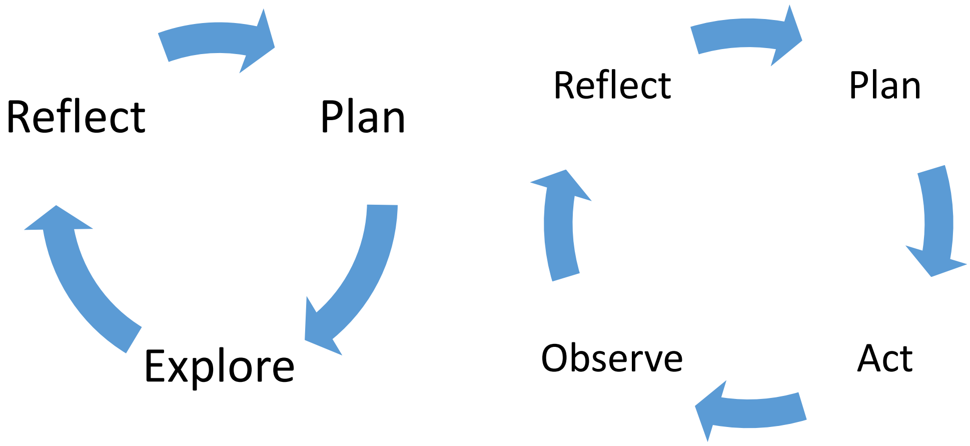
After the Introduction, Section 6.2 introduces the methodological approach used in this work. Section 6.3 presents a path to the author's participation in capturing standardization movements in energy management. Section 6.4 discusses and proposes alignment opportunities between GHG standardization movements and energy management. Finally, conclusions and implications are highlighted in Section 6.5.

## 6.2 Methods

As described in Section 2.2, the approach of this work follows a critical realistic abductive stance, axiologically biased with a participant researcher, ontologically realist (critic realism), and epistemologically constructionist. The research design follows an exploratory-descriptive perspective, aiming to explore, as a complete participant, a specific environment (Standardization forum related to energy performance evaluation with indicators) and to describe, based on the exploratory experience, how two subjects (Accounting of energy-related GHG emissions and Evaluating energy performance with indicators) can be combined.

The adopted qualitative action research method was considered to explore the author's participation in ISO/TC 301 in a longitudinal time horizon from 2018 to 2022, using this privileged observation position to extract relevant information for this research purpose. Therefore, the exploratory segment is developed throughout the action research in a sequence of exploratory and action cycles. While the first type primarily comprises three axes, planning, exploration, and reflection, the second is based on four axes, planning, action, observation, and reflection. The action cycle reproduces a PDCA (Plan-Do-Check-Act) cycle style, a widespread management tool technically present in the explored environment.

Figure 6.2 – Exploratory (right) and action (left) cycles overview



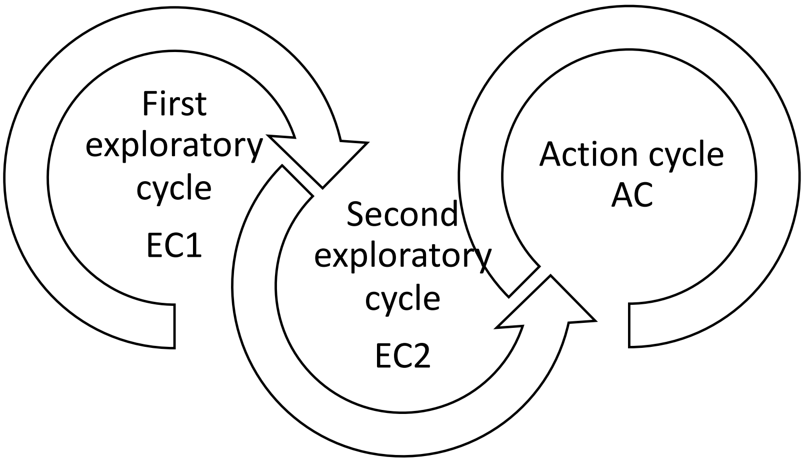

Source: Author's elaboration based on (JENSEN *et al.*, 2019; NOGESTE, 2008; SUKMAWATI, 2020)

As will be presented in the next section, this research's exploratory segment comprises two main exploratory cycles followed by an action cycle. Finally, after completing the action research cycles, the descriptive segment is a cross-sectional action that describes and suggests a final standardization proposition.

## 6.3 Capturing standardization movements in energy management

The author has attended ISO/TC 301 meetings as an expert for the past five years, composing the Brazilian delegation. In particular, the author acted as a complete participant in a working group, ISO/TC 301/WG 2 – Metrics and measurement internal to the organization. During this participation, the major discussion comprised the revision process of ISO 50006 – Energy management systems — Measuring energy performance using energy baselines (EnB) and energy performance indicators (EnPI) — General principles and guidance. Throughout his participation, the author proceeded with three action research cycles, two exploratory cycles followed by an action cycle, as illustrated in Figure 6.3.

Figure 6.3 – Exploratory action research cycles overview




Source: Author's elaboration

The first exploratory cycle (EC1) started when the author initiated his participation in the working group. Intending to use scientific knowledge to interact in the forum, his participation as an observer allowed him to identify major discussion issues and approaches. Since the beginning of the revision process, working group participants have been eager to improve the document towards more detailed guidance following the revision of ISO 50001 in 2018, establishing energy performance demonstration and normalization requirements. However, two approaches were competing during the discussions, one proposing a complete revamp of the standard, eliminating some simplified approaches. At the same time, the other wanted to keep these methods together with the new, improved proposals.

The reflections of EC1 resulted in a new plan for a second exploratory cycle (EC2). This time the author aimed to capture the technical content during the discussions to improve its scientific knowledge while keeping his participation as an observer, allowing major barriers to a technical consensus to be identified among issues and approaches. Despite some working group participants being firmly attached to one of the two approaches, the majority fluctuated between the two alternatives, trying to make a compromise and achieve a consensus. At this moment, one major issue debate, the elimination of a particular method, triggered a discussion that clarified that the barrier was in communication, not technical. Experts agreed that the method wasn't adequate for an energy model, but it could be considered a reporting type.

This final reflection from EC2 implied that an action opportunity has emerged. The author changed his position into a complete participant aiming to interact in the standardization process to propose change. In this case, aiming to change a sentence in the third paragraph of Clause 4 in ISO/DIS 50006 (see Figure 6.4), one specific proposal was made (see Figure 6.5) to promote the discussion within the working group.

Figure 6.4 – ISO/DIS 50006 extract – First paragraphs from Clause 4

## 4 Overview of EnPIs, EnBs and energy performance

An organization establishes EnPIs and EnBs to measure and monitor energy performance and demonstrate energy performance improvement.

EnPIs should be determined by an organization to provide relevant energy performance information to various interested parties (e.g. internal users, supply chain, etc), to understand its energy performance and take actions for its control and improvement.

EnPI values quantify the energy performance of the whole organization or its various parts (e.g. facilities, equipment, systems or energy using processes). Potential EnPIs need to be analysed to decide if they are appropriate before being selected. EnPIs can be expressed in units of energy consumption (e.g. GJ, kWh), dimensionless ratios (e.g. energy efficiency), etc.

Source: ISO/DIS 50006 in development in 2022

Figure 6.5 — Author's proposal to distinguish reporting type from the energy model

| **Template for comments and secretariat observations** | Date: | Document: | Project: ISO/DIS 50006 |
|---|---|---|---|

| **MB/ NC[1]** | **Line number** (e.g., 17) | **Clause/ Subclause** (e.g., 3.1) | **Paragraph/ Figure/ Table/** (e.g., Table 1) | **Type of comment[2]** | **Comments** | **Proposed change** | **Observations of the secretariat** |
|---|---|---|---|---|---|---|---|
| BR3 -097 | | 4 | 3rd § | te | In subclause 6.3 "express an indicator" means express it mathematically by means of a model. In this sentence on clause 4 a different verb would be more adequate to avoid confusion.<br>Example: One organization can have an EnPI expressed by means of a statistical method that is reported in units of energy consumption. | "EnPIs can be ~~expressed~~ reported in units of energy consumption (e.g. GJ, kWh), dimensionless ratios (e.g. energy efficiency), etc." | Accept (SE)<br>Expressed by model<br>Reported by units |

Source: Extract of addressed comments from ISO/DIS 50006 ballot in 2020

The discussions helped clarify this position even further, and the changes were incorporated into the standard (see Figure 6.6), with reflections throughout the document. In addition, since the author was engaging in GHG standardization forums, this discussion of reporting type and energy model resulted in a reflection regarding opportunities to align this document to GHG emission accounting, which will be covered in the next section. Finally, these three cycles can be summarized as displayed in Table 6.1.

Figure 6.6 – ISO/FDIS 50006 extract – First paragraphs from Clause 4

**4 Overview of EnPIs, EnBs and energy performance**

An organization establishes EnPIs and EnBs to measure and monitor energy performance and demonstrate energy performance improvement.

EnPIs provide relevant energy performance information to interested parties (e.g. internal users, supply chain), to understand its energy performance and take actions to control and improve energy performance.

EnPI values quantify the energy performance of the whole organization or its various parts (e.g. facilities, equipment, systems or energy using processes). Potential EnPIs need to be analysed to decide if they are appropriate before being selected. EnPIs can be expressed using an energy model and can be reported in units of energy consumption (e.g. GJ, kWh) or energy efficiency (e.g. km/L).

Source: ISO/FDIS 50006 in development in 2022

Table 6.1 – Exploratory action research cycles overview

| | **First exploratory cycle (EC1)** | **Second exploratory cycle (EC2)** | **Action cycle (AC)** |
|---|---|---|---|
| Standardization stages | PWI and WD stages | CD stages | DIS and FDIS stages |
| Time frame | 2018-2019 | 2020-2021 | 2022 |
| Planning | Using scientific knowledge to interact in the forum | Capturing discussions to improve scientific knowledge | Interact in standardization process to propose change |
| Exploration (EC) Action (AC) | Participation as an observer | Participation as an observer | Complete participant |
| Reflection (EC) Observation AC) | Identification of major discussion issues and approaches | Major barriers to technical consensus identified among issues and approaches | Changes incorporated into the standard |
| Reflection (AC) | - | - | Opportunities to align this document to GHG emission accounting |

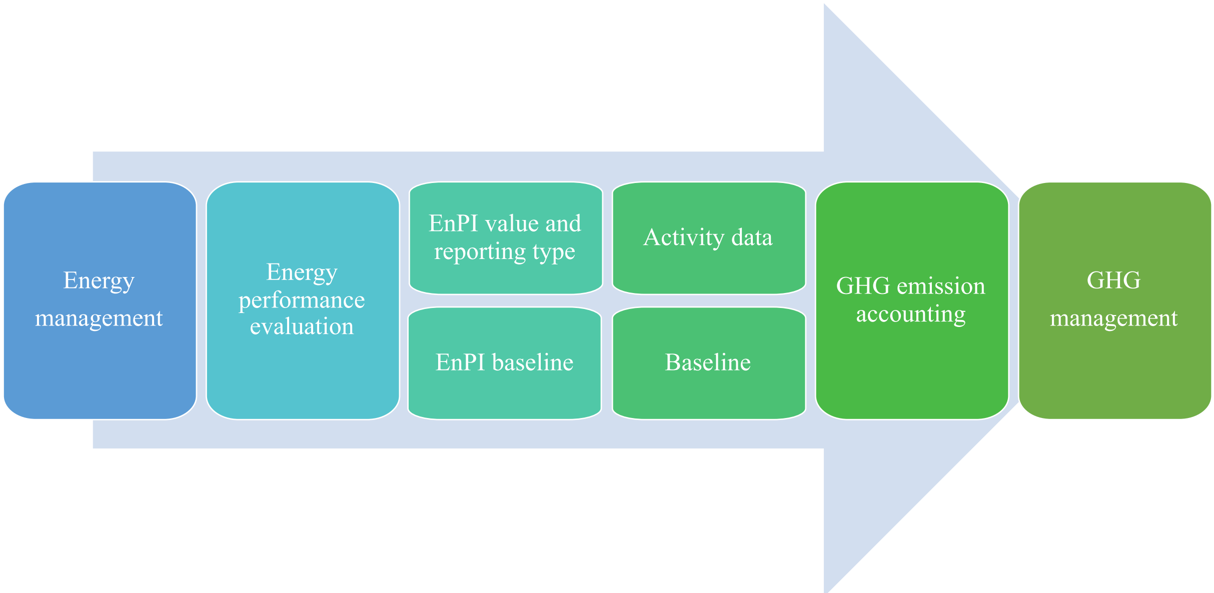
Source: Author's elaboration

## 6.4 Aligning standardization movements in GHG and energy management

Energy-related GHG emissions play a major role in the general GHG emissions context, and methodological improvements in reporting have challenges to overcome. Particularly, under the accounting methods perspective, energy-related GHG emissions estimations can be improved by adopting activity data that adequately represents energy consumption. This last subject is already challenging since defining an adequate indicator for energy performance evaluation requires carefully selecting both reporting type and energy model to provide meaningful results and fulfill expected application uses.

In this context emerges a first proposal, as depicted in Figure 6.7, to combine energy-related GHG emission accounting and energy performance evaluation with indicators, understanding their limitations and challenges to overcome identified barriers and improve energy-related GHG emission reporting. In addition, however, this proposal can extend itself to provide not only adequate activity data and a suitable baseline but a broader alignment of the two processes in terms of standardized guidance, as shown in Figure 6.8.

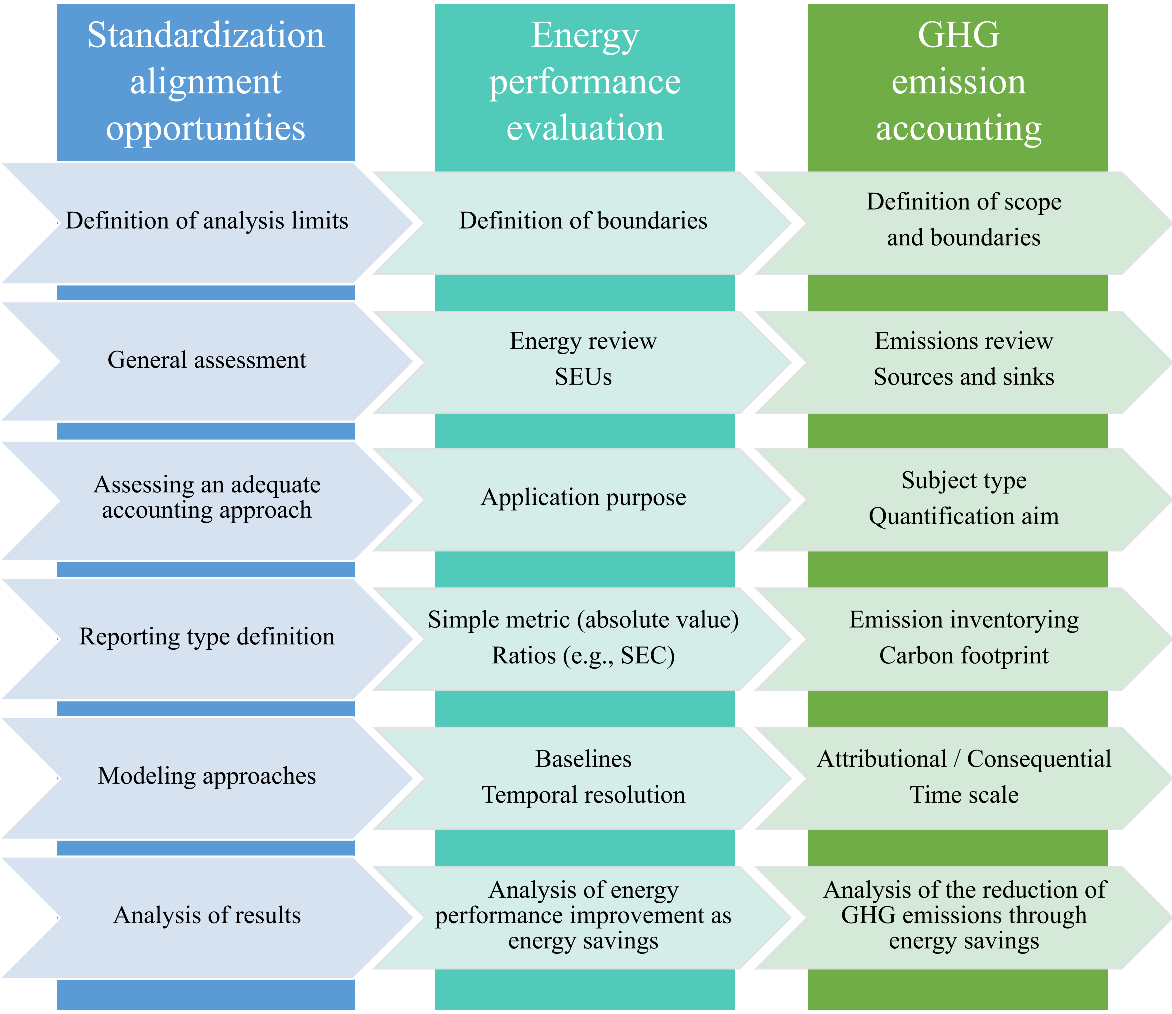
Figure 6.7 – Energy management providing elements to greenhouse gas management




Source: Author’s elaboration

Finally, standardization alignment opportunities shown in Figure 6.8 could be implemented in several forms, from informative annexes in standards covering these topics to a guidance standard, like ISO/TR 14069 – Greenhouse Gases – Quantification and Reporting of Greenhouse Gas Emissions for Organizations – Guidance for the Application of ISO 14064-1 (ISO, 2013). In this case, the standard would be a guidance to the joint application of standards related to energy performance evaluation and greenhouse gas emission accounting.

Figure 6.8 – List of possible standardization alignment opportunities between energy performance evaluation and greenhouse gas emission accounting




Source: Author's elaboration

## 6.5 Conclusions

Despite GHG and Energy management being explored in parallel in standardization forums, the scientific literature efforts to bring them together. Following this path, this work discusses the alignment opportunity, particularly between energy performance evaluation with indicators with energy-related GHG emission accounting.

Following a non-typical methodology under a critical realistic abductive stance, this work develops an exploratory-descriptive method, exploring a standardization environment and describing, based on the exploratory experience, how the highlighted subjects can be combined.

The exploratory action research was described, covering the author's participation in ISO/TC 301 from 2018 to 2022. During this participation, the major discussion was comprised of the revision process of ISO 50006. Throughout his participation, the author proceeded with three action research cycles, two exploratory cycles followed by an action cycle, allowing him to move from a participant as an observer to a complete participant.

Finally, standardization alignment opportunities are drawn from the fact that energy-related GHG emissions can be improved by the adoption of activity data that represents adequate energy consumption, and those could be achieved through energy performance evaluation, including a careful selection of both reporting type and energy model. In fact, opportunities extend themselves to provide adequate activity data, a suitable baseline, and a broader alignment of the two processes regarding standardized guidance. The implementation of these opportunities could take forms from informative annexes in standards covering these topics to a guidance standard.

Considering this work approach, future studies could investigate the application of similar methodology under different standardization topics. Regarding the opportunities for standardization alignment, the author expects that they serve as an inspiration to future interaction with the respective international standardization forums aiming to improve guidance to entities aiming to report their GHG emissions adequately and increase their energy performance awareness with the use of adequate energy models.

Finally, this chapter aimed to answer the following question – “What are the current standardization movements in GHG management and Energy management that can be triggered to promote their integration and improve energy-related GHG emission reporting?”. This question is answered by Figure 6.8, which lists possible standardization alignment opportunities between energy performance evaluation and greenhouse gas emission accounting.

# 7 CONCLUSIONS

This section contains conclusions and suggestions for future studies drawn from comments and discussions from all reported articles. An overall reading of the articles brings up some lessons regarding using energy performance indicators and, more broadly, energy performance evaluation to improve energy-related carbon emissions reporting. As discussed in Chapter 5, despite the challenges in defining appropriate energy performance indicators, adopting this approach signals adequate guidance to organizations when reporting greenhouse gas emissions associated with energy use.

Both systematized reviews, in Chapters 3 and 4, shed light on relevant conceptions and premises, identifying challenges and possible solutions. From the methods perspective, their findings were fundamental to corroborate the subsequent steps. For instance, Chapter 3 findings highlighted that one of the challenges in energy-related GHG emissions accounting was related to energy use representation, and one possible approach identified was the incorporation of energy performance evaluation with indicators. On the other hand, Chapter 4 findings identified that, under energy performance evaluation, adequate comprehension of EnPIs energy models and EnPIs reporting types is essential to increase awareness of EnPIs capacities and limitations in achieving an effective energy performance representation. In other words, systematized reviews' findings complemented each other and gave methodological fundamentals to the subsequent chapter.

Chapter 5, considering these fundamentals, described a proposal combining energy-related GHG emission accounting and energy performance evaluation with indicators to overcome identified barriers and aiming to improve energy-related GHG emission reporting. The proposed method aimed to improve energy-related GHG emissions estimations by adopting activity data that adequately represent energy consumption and using suitable comparison baselines. An EnPI value in a given reporting type fulfills the activity data need, while an EnPI energy model is a suitable baseline for comparing this activity data. Chapter 5 proceeds with a case study in the petroleum refining sector, applying the proposed combination of methods. Compared to other simplified approaches, the proposed method produces much more consistent results. Barriers to the promotion of this combination can be expected due to the use of more elaborate energy models, however, one factor can be used in its favor, the fact that EnPIs' energy model and reporting type can differ from each other.

Finally, Chapter 6 discusses the alignment opportunity, in a standardization environment, between energy performance evaluation with indicators with energy-related GHG emission accounting. Following a non-typical methodology, exploratory action research was conducted, covering the author's participation in ISO/TC 301 from 2018 to 2022, from a participant as an observer to a complete participant. Standardization alignment opportunities are outlined, and they extend themselves to provide a broader alignment of the two processes (energy performance evaluation with indicators with energy-related GHG emission accounting) in terms of standardized guidance, including adequate activity data and a suitable baseline. The implementation of these opportunities could follow different paths, from informative annexes in standards covering these topics to a guidance standard.

As suggestions for future studies, the proposed combined approach of this thesis could be applied to different case studies, particularly with more focus on collecting more data and conducting complementary statistical investigations. The concept of this thesis could also be expanded to encompass resource indicators, including agricultural indicators, water indicators, and other related sustainability indicators. Finally, the overall approach of this thesis could be applied to investigate different standardization topics.

In conclusion, this thesis is a milestone for the standardization environment, different economic sectors, and the author. The standardization environment is already seeking for connections between energy and GHG emission fields, and this thesis' opportunities for standardization alignments are relevant. There is an expectation that they could serve the international community as an inspiration, aiming to improve guidance to entities on how to report better their energy-related GHG emissions and how to increase their energy performance awareness with the use of adequate energy models. Therefore, different economic sectors could benefit from this thesis' reflections, inspiring organizations to improve their energy performance evaluation procedures and GHG emission accounting methods, and potentially they would be benefited from future outcomes from the standardization environment. Finally, the development of this work was pursued with immense personal dedication and substantial support from professors and experts from the standardization field. Allowing him to incorporate his academic research and standardization experience into a framework of interdisciplinary research, the author expects that his thesis could motivate other researchers to engage in the standardization environment.

**REFERENCES**

ABELLA, J. P.; BERGERSON, J. A. Model to Investigate Energy and Greenhouse Gas Emissions Implications of Refining Petroleum: Impacts of Crude Quality and Refinery Configuration. **Environmental Science and Technology**, v. 46, n. 24, p. 13037–13047, dez. 2012.

ABRAHAM, V. A. A.; CAUSIL, E. D. A.; SANTOS, V. S.; ANGARITA, E. N.; SARDUY, J. R. G. Identification of savings opportunities in a steel manufacturing industry. **International Journal of Energy Economics and Policy**, v. 11, n. 4, p. 43–50, jun. 2021.

ABUTABENJEH, S.; JARADAT, R. Clarification of research design, research methods, and research methodology: A guide for public administration researchers and practitioners. **Teaching Public Administration**, v. 36, n. 3, p. 237–258, 24 maio 2018. Disponível em: <https://doi.org/10.1177/0144739418775787>.

ÅDAHL, A.; HARVEY, S.; BERNTSSON, T. Process Industry Energy Retrofits: The Importance of Emission Baselines for Greenhouse Gas Reductions. **Energy Policy**, v. 32, n. 12, p. 1375–1388, ago. 2004.

ADLER, P. R.; SPATARI, S.; D'OTTONE, F.; VAZQUEZ, D.; PETERSON, L.; DEL GROSSO, S. J.; BAETHGEN, W. E.; PARTON, W. J. Legacy effects of individual crops affect $N_2O$ emissions accounting within crop rotations. **GCB Bioenergy**, v. 10, n. 2, p. 123–136, 8 fev. 2018.

AGHEMO, C.; PELLEGRINO, A.; FISANOTTI, D.; PICCABLOTTO, G.; TARAGLIO, R.; PARUZZO, A.; ROSCIO, G. Environmental and Energy Performance of Public Lighting Installations: Results of a Measurement Campaign. Em: Proceedings - 2018 IEEE International Conference on Environment and Electrical Engineering and 2018 IEEE Industrial and Commercial Power Systems Europe, EEEIC/I and CPS Europe 2018, 2018, [...]. IEEE, 2018.

AHMADI, L.; KANNANGARA, M.; BENSEBAA, F. Cost-effectiveness of small scale biomass supply chain and bioenergy production systems in carbon credit markets: A life cycle perspective. **Sustainable Energy Technologies and Assessments**, v. 37, p. 100627, fev. 2020.

ALONGE, G.; CIANCAMERLA, E.; MASTRILLI, A.; MINICHINO, M.; NICOTRA, A.; RANNO, M.; REALI, M.; REGINA, P. Towards energy efficiency of interdependent urban networks. **International Journal of Simulation and Process Modelling**, v. 11, n. 6, p. 529–546, 2016.

ALONSO, S.; MORÁN, A.; PRADA, M.; REGUERA, P.; FUERTES, J.; DOMÍNGUEZ, M. A Data-Driven Approach for Enhancing the Efficiency in Chiller Plants: A Hospital Case Study. **Energies**, v. 12, n. 5, p. 827, 2 mar. 2019.

ALVANCHI, A.; BAJALAN, Z.; IRAVANI, P. Emission Assessment of Alternative Dam Structure Types, a Novel Approach to Consider in New Dam Projects. **Construction Innovation**, v. 21, n. 2, p. 203–217, jul. 2021.

AMATUNI, L.; OTTELIN, J.; STEUBING, B.; MOGOLLÓN, J. M. Does car sharing reduce greenhouse gas emissions? Assessing the modal shift and lifetime shift rebound effects from a life cycle perspective. **Journal of Cleaner Production**, v. 266, p. 121869, set. 2020.

ANDERSSON, E.; ARFWIDSSON, O.; THOLLANDER, P. Benchmarking Energy Performance of Industrial Small and Medium-Sized Enterprises Using an Energy Efficiency Index: Results Based on an Energy Audit Policy Program. **Journal of Cleaner Production**, v. 182, p. 883–895, maio 2018.

ANDERSSON, E.; DERNEGÅRD, H.; WALLÉN, M.; THOLLANDER, P. Decarbonization of industry: Implementation of energy performance indicators for successful energy management practices in kraft pulp mills. **Energy Reports**, v. 7, p. 1808–1817, 2021. Disponível em: <https://www.sciencedirect.com/science/article/pii/S2352484721001785>.

ANDERSSON, E.; THOLLANDER, P. Key performance indicators for energy management in the Swedish pulp and paper industry. **Energy Strategy Reviews**, v. 24, p. 229–235, 1 abr. 2019.

ANG, B. W. Monitoring Changes in Economy-Wide Energy Efficiency: From Energy–GDP Ratio to Composite Efficiency Index. **Energy Policy**, v. 34, n. 5, p. 574–582, mar. 2006.

ANG, B. W.; CHOI, K. H. Boundary Problem in Carbon Emission Decomposition. **Energy Policy**, v. 30, n. 13, p. 1201–1205, out. 2002.

ANTE, L.; STEINMETZ, F.; FIEDLER, I. Blockchain and energy: A bibliometric analysis and review. **Renewable and Sustainable Energy Reviews**, v. 137, p. 110597, 2021. Disponível em: <https://www.sciencedirect.com/science/article/pii/S1364032120308819>.

ARIA, M.; CUCCURULLO, C. bibliometrix: An R-tool for comprehensive science mapping analysis. **Journal of Informetrics**, v. 11, n. 4, p. 959–975, 2017. Disponível em: <https://www.sciencedirect.com/science/article/pii/S1751157717300500>.

ARIA, M.; CUCCURULLO, C.; D’ANIELLO, L.; MISURACA, M.; SPANO, M. Thematic Analysis as a New Culturomic Tool: The Social Media Coverage on COVID-19 Pandemic in Italy. **Sustainability**, v. 14, n. 6, 2022. Disponível em: <https://www.mdpi.com/2071-1050/14/6/3643>.

ARIA, M.; MISURACA, M.; SPANO, M. Mapping the Evolution of Social Research and Data Science on 30 Years of Social Indicators Research. **Social Indicators Research**, v. 149, n. 3, p. 803–831, 2020. Disponível em: <https://doi.org/10.1007/s11205-020-02281-3>.

AŠONJA, A. N.; RAJKOVIĆ, J. Z. An energy consumption analysis on public applications in the city of novi sad. **Applied Engineering Letters**, v. 2, n. 3, p. 115–120, 2017.

AZADEH, A.; AMALNICK, M. S.; GHADERI, S. F.; ASADZADEH, S. M. An integrated DEA PCA numerical taxonomy approach for energy efficiency assessment and consumption optimization in energy intensive manufacturing sectors. **Energy Policy**, v. 35, n. 7, p. 3792–3806, 2007. Disponível em: <https://www.sciencedirect.com/science/article/pii/S0301421507000286>.

AZADEH, A.; AMALNICK, M. S.; GHADERI, S. F.; ASADZADEH, S. M. **Corrigendum to "An integrated DEA PCA numerical taxonomy approach for energy efficiency assessment and consumption optimization in energy intensive manufacturing sectors?". [Energy Policy 35 (2007) 3792-3806] (DOI:10.1016/j.enpol.2007.01.018)Energy Policy**Elsevier BV, jul. 2008.

BACKLUND, S.; THOLLANDER, P.; PALM, J.; OTTOSSON, M. Extending the energy efficiency gap. **Energy Policy**, v. 51, p. 392–396, dez. 2012.

BAI, H.; QIAO, S.; LIU, T.; ZHANG, Y.; XU, H. An inquiry into inter-provincial carbon emission difference in China: Aiming to differentiated KPIs for provincial low carbon development. **Ecological Indicators**, v. 60, p. 754–765, 2016. Disponível em: <https://www.sciencedirect.com/science/article/pii/S1470160X15004501>.

BALOUKTSI, M. Carbon metrics for cities: production and consumption implications for policies. **Buildings and Cities**, v. 1, n. 1, p. 233–259, 16 jun. 2020.

BARRETT, J.; PETERS, G.; WIEDMANN, T.; SCOTT, K.; LENZEN, M.; ROELICH, K.; LE QUÉRÉ, C. Consumption-based GHG emission accounting: a UK case study. **Climate Policy**, v. 13, n. 4, p. 451–470, 1 jul. 2013. Disponível em: <https://doi.org/10.1080/14693062.2013.788858>.

BARTOLI, A.; HAMELIN, L.; ROZAKIS, S.; BORZĘCKA, M.; BRANDÃO, M. Coupling Economic and GHG Emission Accounting Models to Evaluate the Sustainability of Biogas Policies. **Renewable and Sustainable Energy Reviews**, v. 106, p. 133–148, maio 2019.

BASARAB, J. A.; OKINE, E. K.; BARON, V. S.; MARX, T.; RAMSEY, P.; ZIEGLER, K.; LYLE, K. Methane Emissions from Enteric Fermentation in Alberta's Beef Cattle Population. **Canadian Journal of Animal Science**, v. 85, n. 4, p. 501–512, dez. 2005.

BASHMAKOV, I.; MYSHAK, A. Russian Energy Efficiency Accounting System. **Energy Efficiency**, v. 7, n. 5, p. 743–759, out. 2014.

BASTIANONI, S.; CARO, D.; BORGHESI, S.; PULSELLI, F. M. The effect of a consumption-based accounting method in national GHG inventories: A trilateral trade system application. **Frontiers in Energy Research**, v. 2, n. JAN, 2014a.

BASTIANONI, S.; MARCHI, M.; CARO, D.; CASPRINI, P.; PULSELLI, F. M. The connection between 2006 IPCC GHG inventory methodology and ISO 14064-1 certification standard - A reference point for the environmental policies at sub-national scale. **Environmental Science and Policy**, v. 44, p. 97–107, 2014b.

BEAUCHEMIN, K. A.; JANZEN, H. H.; LITTLE, S. M.; MCALLISTER, T. A.; MCGINN, S. M. Mitigation of greenhouse gas emissions from beef production in western Canada - Evaluation using farm-based life cycle assessment. **Animal Feed Science and Technology**, v. 166–167, p. 663–677, jun. 2011.

BEISHEIM, B.; KRÄMER, S.; ENGELL, S. Hierarchical aggregation of energy performance indicators in continuous production processes. **Applied Energy**, v. 264, n. February, p. 114709, 15 abr. 2020. Disponível em: <https://doi.org/10.1016/j.apenergy.2020.114709>.

BEISHEIM, B.; RAHIMI-ADLI, K.; KRÄMER, S.; ENGELL, S. Energy performance analysis of continuous processes using surrogate models. **Energy**, v. 183, p. 776–787, 15 set. 2019.

BELFIORE, A.; CUCCURULLO, C.; ARIA, M. IoT in healthcare: A scientometric analysis. **Technological Forecasting and Social Change**, v. 184, p. 122001, 2022. Disponível em: <https://www.sciencedirect.com/science/article/pii/S0040162522005224>.

BENEDETTI, M.; BONFA, F.; BERTINI, I.; INTRONA, V.; UBERTINI, S. Explorative study on Compressed Air Systems' energy efficiency in production and use: First steps towards the creation of a benchmarking system for large and energy-intensive industrial firms. **Applied Energy**, v. 227, n. January, p. 436–448, 1 out. 2018. Disponível em: <http://dx.doi.org/10.1016/j.apenergy.2017.07.100>.

BENEDETTI, M.; CESAROTTI, V.; INTRONA, V. From energy targets setting to energy-aware operations control and back: An advanced methodology for energy efficient manufacturing. **Journal of Cleaner Production**, v. 167, p. 1518–1533, 20 nov. 2017. Disponível em: <http://dx.doi.org/10.1016/j.jclepro.2016.09.213>.

BEUSKER, E.; STOY, C.; POLLALIS, S. N. Estimation Model and Benchmarks for Heating Energy Consumption of Schools and Sport Facilities in Germany. **Building and Environment**, v. 49, n. 1, p. 324–335, mar. 2012.

BHATIA, P.; CUMMIS, C.; BROWN, A.; DRAUCKER, L.; RICH, D.; LAHD, H. **GHG Protocol - Product Life Cycle Accounting and Reporting Standard**. [s.l: s.n.].

BIZON, N.; OPROESCU, M.; RACEANU, M. Efficient energy control strategies for a Standalone Renewable/Fuel Cell Hybrid Power Source. **Energy Conversion and Management**, v. 90, p. 93–110, jan. 2015.

BLONDEL, V. D.; GUILLAUME, J.-L.; LAMBIOTTE, R.; LEFEBVRE, E. Fast unfolding of communities in large networks. **Journal of statistical mechanics: theory and experiment**, v. 2008, n. 10, p. P10008, 2008.

BONACINA, F.; CORSINI, A.; DE PROPRIS, L.; MARCHEGIANI, A.; MORI, F. Industrial Energy Management Systems in Italy: State of the Art and Perspective. **Energy Procedia**, v. 82, p. 562–569, dez. 2015.

BOOTH, A. D. A Law of occurrences for words of low frequency. **Information and control**, v. 10, n. 4, p. 386–393, 1967.

BOR, Y. J. Consistent Multi-Level Energy Efficiency Indicators and Their Policy Implications. **Energy Economics**, v. 30, n. 5, p. 2401–2419, set. 2008.

BÖRNER, K.; CHEN, C.; BOYACK, K. W. Visualizing knowledge domains. **Annual Review of Information Science and Technology**, v. 37, n. 1, p. 179–255, 2003. Disponível em: <https://asistdl.onlinelibrary.wiley.com/doi/abs/10.1002/aris.1440370106>.

BORREGO, M.; FOSTER, M. J.; FROYD, J. E. Systematic Literature Reviews in Engineering Education and Other Developing Interdisciplinary Fields. **Journal of Engineering Education**, v. 103, n. 1, p. 45–76, 1 jan. 2014. Disponível em: <https://doi.org/10.1002/jee.20038>.

BORTOLUZZI, M.; CORREIA DE SOUZA, C.; FURLAN, M. Bibliometric analysis of renewable energy types using key performance indicators and multicriteria decision models. **Renewable and Sustainable Energy Reviews**, v. 143, p. 110958, 2021. Disponível em: <https://www.sciencedirect.com/science/article/pii/S1364032121002501>.

BOURGEOIS, L.; AHMANN, M.; ALBERTOS DE BENITO, F. **EU refinery energy systems and efficiency**. [s.l: s.n.].

BOYD, G. A. A Method for Measuring the Efficiency Gap between Average and Best Practice Energy Use: The ENERGY STAR Industrial Energy Performance Indicator. **Journal of Industrial Ecology**, v. 9, n. 3, p. 51–65, jul. 2005.

BOYD, G. A. Estimating the changes in the distribution of energy efficiency in the U.S. automobile assembly industry. **Energy Economics**, v. 42, p. 81–87, 2014. Disponível em: <https://www.sciencedirect.com/science/article/pii/S0140988313002703>.

BOYD, G.; DOOLIN, M.; DUTROW, E.; ZHANG, S. A new benchmark of energy performance for energy management in U.S. and Canadian integrated steel plants. Em: AISTech - Iron and Steel Technology Conference Proceedings, 2016, [...]. Association for Iron & Steel Technology, 2016. v. 3, p. 2835–2848.

BOYD, G.; DUTROW, E.; TUNNESSEN, W. The Evolution of the ENERGY STAR® Energy Performance Indicator for Benchmarking Industrial Plant Manufacturing Energy Use. **Journal of Cleaner Production**, v. 16, n. 6, p. 709–715, abr. 2008.

BOYD, G.; ZHANG, G. Measuring Improvement in Energy Efficiency of the US Cement Industry with the ENERGY STAR Energy Performance Indicator. **Energy Efficiency**, v. 6, n. 1, p. 105–116, fev. 2013.

BRADFORD, S. C. Sources of information on specific subjects. **Engineering**, v. 137, p. 85–86, 1934.

BRANDER, M. Transposing lessons between different forms of consequential greenhouse gas accounting: Lessons for consequential life cycle assessment, project-level accounting, and policy-level accounting. **Journal of Cleaner Production**, v. 112, p. 4247–4256, 2016.

BRANDER, M. Comparative analysis of attributional corporate greenhouse gas accounting, consequential life cycle assessment, and project/policy level accounting: A bioenergy case study. **Journal of Cleaner Production**, v. 167, p. 1401–1414, 20 nov. 2017.

BRANDER, M. **The most important GHG accounting concept you may not have heard of: the attributional-consequential distinctionCarbon Management**Informa UK Limited, jan. 2022.

BRANDER, M.; ASCUI, F.; SCOTT, V.; TETT, S. Carbon Accounting for Negative Emissions Technologies. **Climate Policy**, v. 21, n. 5, p. 699–717, fev. 2021.

BRANDER, M.; GILLENWATER, M.; ASCUI, F. Creative accounting: A critical perspective on the market-based method for reporting purchased electricity (scope 2) emissions. **Energy Policy**, v. 112, p. 29–33, 1 jan. 2018.

BRASCHEL, N.; POSCH, A. A Review of System Boundaries of GHG Emission Inventories in Waste Management. **Journal of Cleaner Production**, v. 44, p. 30–38, abr. 2013.

BRIN, S.; PAGE, L. The anatomy of a large-scale hypertextual Web search engine. **Computer Networks and ISDN Systems**, v. 30, n. 1, p. 107–117, 1998. Disponível em: <https://www.sciencedirect.com/science/article/pii/S016975529800110X>.

BROOKES, B. C. Bradford’s law and the bibliography of science. **Nature**, v. 224, n. 5223, p. 953–956, 1969.

BROWN, M. E. L.; DUEÑAS, A. N. A Medical Science Educator’s Guide to Selecting a Research Paradigm: Building a Basis for Better Research. **Medical Science Educator**, v. 30, n. 1, p. 545–553, 2020. Disponível em: <https://doi.org/10.1007/s40670-019-00898-9>.

BRUNI, G.; DE SANTIS, A.; HERCE, C.; LETO, L.; MARTINI, C.; MARTINI, F.; SALVIO, M.; TOCCHETTI, F. A.; TORO, C. From Energy Audit to Energy Performance Indicators (Enpi): A Methodology to Characterize Productive Sectors. the Italian Cement Industry Case Study. **Energies**, v. 14, n. 24, p. 8436, dez. 2021.

BRUTON, K.; O’DONOVAN, P.; MCGREGOR, A.; O’SULLIVAN, D. D. T. J. Design and Development of a Software Tool to Assist ISO 50001 Implementation in the Manufacturing Sector. **Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture**, v. 232, n. 10, p. 1741–1752, ago. 2018.

BUCHHOLZ, T.; HURTEAU, M. D.; GUNN, J.; SAAH, D. A Global Meta-Analysis of Forest Bioenergy Greenhouse Gas Accounting Studies. **Glob. Change Biol. Bioenergy**, v. 8, n. 2, p. 281–289, mar. 2016.

BURNS, R. T.; LI, H.; XIN, H.; GATES, R. S.; OVERHULTS, D. G.; EARNEST, J.; MOODY, L. B. Greenhouse gas (GHG) emissions from broiler houses in the southeastern United States. Em: 2008 Providence, Rhode Island, June 29–July 2, 2008, 2008, [...]. American Society of Agricultural and Biological Engineers, 2008. p. 1.

CABELLO ERAS, J. J.; GUTIÉRREZ, A. S.; SANTOS, V. S.; HERRERA, H. H.; MOREJÓN, M. B.; ORTEGA, J. S.; NORIEGA ANGARITA, E. M.; VANDECASTEELE, C. Energy Management in the Formation of Light, Starter, and Ignition Lead-Acid Batteries. **Energy Efficiency**, v. 12, n. 5, p. 1219–1236, jun. 2019.

CABELLO ERAS, J. J.; SAGASTUME GUTIÉRREZ, A.; SOUSA SANTOS, V.; CABELLO ULLOA, M. J. Energy management of compressed air systems. Assessing the production and use of compressed air in industry. **Energy**, v. 213, 15 dez. 2020.

CABELLO ERAS, J. J.; SOUSA SANTOS, V.; SAGASTUME GUTIÉRREZ, A.; GUERRA PLASENCIA, M. Á.; HAESELDONCKX, D.; VANDECASTEELE, C. Tools to improve forecasting and control of the electricity consumption in hotels. **Journal of Cleaner Production**, v. 137, p. 803–812, nov. 2016.

CADARSO, M. Á.; LÓPEZ, L. A.; GÓMEZ, N.; TOBARRA, M. Á. CO2 Emissions of International Freight Transport and Offshoring: Measurement and Allocation. **Ecological Economics**, v. 69, n. 8, p. 1682–1694, jun. 2010.

CAI, B.; ZHANG, L. Urban CO2 emissions in China: Spatial boundary and performance comparison. **Energy Policy**, v. 66, p. 557–567, 2014. Disponível em: <https://www.sciencedirect.com/science/article/pii/S0301421513010951>.

CAO, Y. C.; GAO, F.; WANG, Z. H.; GONG, X. Z.; LI, X. Q. Analysis on influence factors of greenhouse gas emissions of magnesium production process. Em: Materials Science Forum, 2016a, [...]. Trans Tech Publications, Ltd., 2016. v. 847, p. 321–327.

CAO, Z.; SHEN, L.; ZHAO, J.; LIU, L.; ZHONG, S.; SUN, Y.; YANG, Y. Toward a better practice for estimating the CO2 emission factors of cement production: An experience from China. **Journal of Cleaner Production**, v. 139, p. 527–539, 2016b. Disponível em: <https://www.sciencedirect.com/science/article/pii/S0959652616312197>.

CASTRILLON, R. P.; GONZÁLEZ, A. J.; QUISPE, E. C. Energy efficiency improvement in the cement industry by wet process through integral energy management system implementation. **DYNA (Colombia)**, v. 80, n. 177, p. 115–123, 2013.

CASTRILLÓN-MENDOZA, R.; REY-HERNÁNDEZ, J. M.; REY-MARTÍNEZ, F. J. Industrial Decarbonization by a New Energy-Baseline Methodology. Case Study. **Sustainability (Switzerland)**, v. 12, n. 5, p. 1960, mar. 2020.

CAVAZZINI, G.; PAVESI, G.; ARDIZZON, G. Optimal Assets Management of a Water Distribution Network for Leakage Minimization Based on an Innovative Index. **Sustainable Cities and Society**, v. 54, n. 101890, p. 101890, mar. 2020.

CCGG GROUP. **Trends in Atmospheric Carbon Dioxide**. [s.l: s.n.]. Disponível em: <https://gml.noaa.gov/ccgg/trends/gl_trend.html>.

CHAN, D. Y.-L.; HUANG, C.-F.; LIN, W.-C.; HONG, G.-B. Energy efficiency benchmarking of energy-intensive industries in Taiwan. **Energy Conversion and Management**, v. 77, p.

216–220, 2014. Disponível em: <https://www.sciencedirect.com/science/article/pii/S0196890413005645>.

CHAU, C. K.; LEUNG, T. M.; NG, W. Y. A review on Life Cycle Assessment, Life Cycle Energy Assessment and Life Cycle Carbon Emissions Assessment on buildings. **Applied Energy**, v. 143, p. 395–413, 2015a. Disponível em: <https://www.sciencedirect.com/science/article/pii/S030626191500029X>.

CHAU, C. K.; LEUNG, T. M.; NG, W. Y. A Review on Life Cycle Assessment, Life Cycle Energy Assessment and Life Cycle Carbon Emissions Assessment on Buildings. **Applied Energy**, v. 143, p. 395–413, abr. 2015b. Disponível em: <https://www.sciencedirect.com/science/article/pii/S030626191500029X>.

CHAVEZ, A.; RAMASWAMI, A. Progress toward low carbon cities: approaches for transboundary GHG emissions' footprinting. **Carbon Management**, v. 2, n. 4, p. 471–482, 1 ago. 2011. Disponível em: <https://doi.org/10.4155/cmt.11.38>.

CHEAH, L.; CICERI, N. D.; OLIVETTI, E.; MATSUMURA, S.; FORTERRE, D.; ROTH, R.; KIRCHAIN, R. Manufacturing-Focused Emissions Reductions in Footwear Production. **Journal of Cleaner Production**, v. 44, p. 18–29, abr. 2013.

CHEN, G. Q.; CHEN, H.; CHEN, Z. M.; ZHANG, B.; SHAO, L.; GUO, S.; ZHOU, S. Y.; JIANG, M. M. Low-carbon building assessment and multi-scale input-output analysis. **Communications in Nonlinear Science and Numerical Simulation**, v. 16, n. 1, p. 583–595, jan. 2011.

CHEN, P.; XIE, H.; MASLOV, S.; REDNER, S. Finding scientific gems with Google's PageRank algorithm. **Journal of Informetrics**, v. 1, n. 1, p. 8–15, 2007. Disponível em: <https://www.sciencedirect.com/science/article/pii/S1751157706000034>.

CHEN, Y.-S.; CHONG, P. P.; TONG, M. Y. The Simon-Yule approach to bibliometric modeling. **Information Processing & Management**, v. 30, n. 4, p. 535–556, 1994.

CHEN, Y.-S.; LEIMKUHLER, F. F. Booth's law of word frequency. **Journal of the American Society for Information Science**, v. 41, n. 5, p. 387–388, 1 jul. 1990. Disponível em: <https://doi.org/10.1002/(SICI)1097-4571(199007)41:5<387::AID-ASI10>3.0.CO>.

CHEN, Z.-M.; OHSHITA, S.; LENZEN, M.; WIEDMANN, T.; JIBORN, M.; CHEN, B.; LESTER, L.; GUAN, D.; MENG, J.; XU, S.; CHEN, G.; ZHENG, X.; XUE, J.; ALSAEDI, A.; HAYAT, T.; LIU, Z. Consumption-based greenhouse gas emissions accounting with capital stock change highlights dynamics of fast-developing countries. **Nature Communications**, v. 9, n. 1, p. 3581, 2018. Disponível em: <https://doi.org/10.1038/s41467-018-05905-y>.

CHIASSON, P. Abduction as an aspect of retroduction. **Semiotica**, v. 2005, n. 153, p. 223–242, 2005.

CHIU, T. Y.; LO, S. L.; TSAI, Y. Y. Establishing an integration-energy-practice model for improving energy performance indicators in ISO 50001 energy management systems. **Energies**, v. 5, n. 12, p. 5324–5339, 17 dez. 2012.

CHOI, D.-S.; CHUN, H.-C.; CHO, K.-H.; KIM, Y.-S.; JUNG, Y.-H. Development of Assessment Index and Assessment Technique Using a Case Analysis for Carbon Emissions in Apartment Buildings in Korea. **International Information Institute (Tokyo). Information**, v. 17, n. 7, p. 3153, 2014.

CHOU, J. S.; YEH, K. C. Life cycle carbon dioxide emissions simulation and environmental cost analysis for building construction. **Journal of Cleaner Production**, v. 101, p. 137–147, ago. 2015.

CHOUDHARY, P.; SRIVASTAVA, R. K.; DE, S. Integrating Greenhouse gases (GHG) assessment for low carbon economy path: Live case study of Indian national oil company. **Journal of Cleaner Production**, v. 198, p. 351–363, 10 out. 2018.

CIPRIANO, X.; CARBONELL, J.; CIPRIANO, J. Monitoring and modelling energy efficiency of municipal public buildings: Case study in Catalonia region. Em: International Journal of Sustainable Energy, 1–3., 2009, [...]. Informa UK Limited, 2009. v. 28, p. 3–18.

CLAUSET, A.; NEWMAN, M. E. J.; MOORE, C. Finding community structure in very large networks. **Physical Review E**, v. 70, n. 6, p. 66111, 6 dez. 2004. Disponível em: <https://link.aps.org/doi/10.1103/PhysRevE.70.066111>.

COBO, M. J.; LÓPEZ-HERRERA, A. G.; HERRERA-VIEDMA, E.; HERRERA, F. An approach for detecting, quantifying, and visualizing the evolution of a research field: A practical application to the Fuzzy Sets Theory field. **Journal of Informetrics**, v. 5, n. 1, p. 146–166, 2011. Disponível em: <https://www.sciencedirect.com/science/article/pii/S1751157710000891>.

CORGNATI, S. P.; CORRADO, V.; FILIPPI, M. A Method for Heating Consumption Assessment in Existing Buildings: A Field Survey Concerning 120 Italian Schools. **Energy and Buildings**, v. 40, n. 5, p. 801–809, jan. 2008.

COROIU, M.; CHINDRIS, M. Energy efficiency indicators and methodology for evaluation of energy performance and retained savings. Em: Proceedings of the Universities Power Engineering Conference, 2014, [...]. IEEE, 2014.

COSGROVE, J.; LITTLEWOOD, J.; WILGEROTH, P. Development of a framework of key performance indicators to identify reductions in energy consumption in a medical devices production facility. **International Journal of Ambient Energy**, v. 39, n. 2, p. 202–210, fev. 2018.

DADI, D.; INTRONA, V.; SANTOLAMAZZA, A.; SALVIO, M.; MARTINI, C.; PASTURA, T.; MARTINI, F. Private Hospital Energy Performance Benchmarking Using Energy Audit Data: An Italian Case Study. **Energies**, v. 15, n. 3, p. 806, jan. 2022.

DAI, X. wen; SUN, Z.; MÜLLER, D. Driving Factors of Direct Greenhouse Gas Emissions from China's Pig Industry from 1976 to 2016. **Journal of Integrative Agriculture**, v. 20, n. 1, p. 319–329, jan. 2021.

DAVIS, K. J.; DENG, A.; LAUVAUX, T.; MILES, N. L.; RICHARDSON, S. J.; SARMIENTO, D. P.; GURNEY, K. R.; HARDESTY, R. M.; BONIN, T. A.; BREWER, W. A.; LAMB, B. K.; SHEPSON, P. B.; HARVEY, R. M.; CAMBALIZA, M. O.; SWEENEY, C.; TURNBULL, J. C.; WHETSTONE, J.; KARION, A. The Indianapolis Flux Experiment (INFLUX): A test-bed for developing urban greenhouse gas emission measurements. **Elementa: Science of the Anthropocene**, v. 5, p. 21, 23 maio 2017. Disponível em: <https://doi.org/10.1525/elementa.188>.

DAVYDENKO, I.; EHRLER, V.; DE REE, D.; LEWIS, A.; TAVASSZY, L. Towards a global CO2 calculation standard for supply chains: Suggestions for methodological improvements. **Transportation Research Part D: Transport and Environment**, v. 32, p. 362–372, 1 out. 2014.

DE HAAS, D. W.; PEPPERELL, C.; FOLEY, J. Perspectives on Greenhouse Gas Emission Estimates Based on Australian Wastewater Treatment Plant Operating Data. **Water Science and Technology**, v. 69, n. 3, p. 451–463, 2014.

DE LUNA, P.; HAHN, C.; HIGGINS, D.; JAFFER, S. A.; JARAMILLO, T. F.; SARGENT, E. H. What would it take for renewably powered electrosynthesis to displace petrochemical processes? **Science**, v. 364, n. 6438, 26 abr. 2019.

DENISOVA, V. Energy Efficiency as a Way to Ecological Safety: Evidence From Russia. **International Journal of Energy Economics and Policy**, v. 9, n. 5, p. 32–37, 23 jul. 2019. Disponível em: <https://www.econjournals.com/index.php/ijeep/article/view/7903>.

DHAKAL, S.; MINX, J. C.; TOTH, F. L.; ABDEL-AZIZ, A.; FIGUEROA, M. J.; HUBACEK, K.; JONCKHEERE, I. G. C.; YONG-GUN, K.; NEMET, G.; PACHAURI, S. Emissions Trends and Drivers. *Em*: IPCC (INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE). **Climate Change 2022: Mitigation of Climate Change**. Cambridge, UK: Cambridge University Press, 2022.

DI FRAIA, S.; MASSAROTTI, N.; VANOLI, L. A novel energy assessment of urban wastewater treatment plants. **Energy Conversion and Management**, v. 163, p. 304–313, maio 2018.

DIEM, J. E.; RICKETTS, C. E.; DEAN, J. R. Impacts of urbanization on land-atmosphere carbon exchange within a metropolitan area in the USA. **Climate Research**, v. 30, n. 3, p. 201–213, 2006.

DING, X.; YANG, Z. Knowledge mapping of platform research: a visual analysis using VOSviewer and CiteSpace. **Electronic Commerce Research**, v. 22, n. 3, p. 787–809, 2022. Disponível em: <https://doi.org/10.1007/s10660-020-09410-7>.

DOLAN, S. L.; HEATH, G. A. Life Cycle Greenhouse Gas Emissions of Utility-Scale Wind Power. **Journal of Industrial Ecology**, v. 16, n. s1, p. S136–S154, 1 abr. 2012. Disponível em: <https://doi.org/10.1111/j.1530-9290.2012.00464.x>.

DOMINKOVIĆ, D. F.; WEINAND, J. M.; SCHELLER, F.; D'ANDREA, M.; MCKENNA, R. Reviewing two decades of energy system analysis with bibliometrics. **Renewable and Sustainable Energy Reviews**, v. 153, p. 111749, 2022. Disponível em: <https://www.sciencedirect.com/science/article/pii/S1364032121010200>.

DOMJAN, S.; PETEK, L.; ARKAR, C.; MEDVED, S. Experimental Study on Energy Efficiency of Multi-Functional BIPV Glazed Façade Structure during Heating Season. **Energies**, v. 13, n. 11, p. 2772, jun. 2020.

DONAGHY, T. Q.; STOCKMAN, L. **Comment on "lNG Supply Chains: A Supplier-Specific Life-Cycle Assessment for Improved Emission Accounting"ACS Sustainable Chemistry and Engineering**American Chemical Society (ACS), ago. 2022.

DORNBURG, V.; TERMEER, G.; FAAIJ, A. P. C. Economic and Greenhouse Gas Emission Analysis of Bioenergy Production Using Multi-Product Crops - Case Studies for the Netherlands and Poland. **Biomass and Bioenergy**, v. 28, n. 5, p. 454–474, maio 2005.

DOULOS, L. T.; SIOUTIS, I.; KONTAXIS, P.; ZISSIS, G.; FAIDAS, K. A Decision Support System for Assessment of Street Lighting Tenders Based on Energy Performance Indicators and Environmental Criteria: Overview, Methodology and Case Study. **Sustainable Cities and Society**, v. 51, n. 101759, p. 101759, nov. 2019.

DUDLEY, B. BP statistical review of world energy. **BP Statistical Review, London, UK, accessed Aug**, v. 6, n. 2018, p. 00116, 2018.

DUTTA, B.; RAGHAVAN, V. A life cycle assessment of environmental and economic balance of biochar systems in Quebec. **International Journal of Energy and Environmental Engineering**, v. 5, n. 2–3, p. 106, 8 jul. 2014.

DYBA, T.; KITCHENHAM, B. A.; JORGENSEN, M. Evidence-based software engineering for practitioners. **IEEE software**, v. 22, n. 1, p. 58–65, 2005.

EBERLE, U.; LANGE, A.; DEWAELE, J.; SCHOWANEK, D. LCA Study and Environmental Benefits for Low Temperature Disinfection Process in Commercial Laundry. **International Journal of Life Cycle Assessment**, v. 12, n. 2, p. 127–138, mar. 2007.

EGGHE, L. Theory and practise of the g-index. **Scientometrics**, v. 69, n. 1, p. 131–152, 2006. Disponível em: <https://doi.org/10.1007/s11192-006-0144-7>.

EIA. **U.S. Fuel Consumed at Refineries**. [s.l: s.n.].

EIRAUDO, S.; BARBIERATO, L.; GIANNANTONIO, R.; PORTA, A.; LANZINI, A.; BORCHIELLINI, R.; MACII, E.; PATTI, E.; BOTTACCIOLI, L. Load Profiles Clustering and Knowledge Extraction to Assess Actual Usage of Telecommunication Sites. Em: 21st IEEE

International Conference on Environment and Electrical Engineering and 2021 5th IEEE Industrial and Commercial Power System Europe, EEEIC / I and CPS Europe 2021 - Proceedings, 2021, [...]. IEEE, 2021.

ELDER-VASS, D. Pragmatism, critical realism and the study of value. **Journal of Critical Realism**, v. 21, n. 3, p. 261–287, 27 maio 2022. Disponível em: <https://doi.org/10.1080/14767430.2022.2049088>.

ELGOWAINY, A.; HAN, J.; CAI, H.; WANG, M.; FORMAN, G. S.; DIVITA, V. B. Energy Efficiency and Greenhouse Gas Emission Intensity of Petroleum Products at U.S. Refineries. **Environmental Science & Technology**, v. 48, n. 13, p. 7612–7624, 1 jul. 2014.

EL-HOUJEIRI, H. M.; BRANDT, A. R.; DUFFY, J. E. Open-source LCA tool for estimating greenhouse gas emissions from crude oil production using field characteristics. **Environmental Science and Technology**, v. 47, n. 11, p. 5998–6006, 4 jun. 2013. Disponível em: <https://doi.org/10.1021/es304570m>.

ELIE, L.; GRANIER, C.; RIGOT, S. The different types of renewable energy finance: A Bibliometric analysis. **Energy Economics**, v. 93, p. 104997, 2021. Disponível em: <https://www.sciencedirect.com/science/article/pii/S0140988320303376>.

ESPEGREN, K.; ROSENBERG, E.; FIDJE, A.; STILLER, C. Production and use of hydrogen – regional energy systems analysis of Oslo, Telemark and Rogaland. **World Electric Veh. J.**, v. 3, n. 1, p. 311–322, jun. 2009.

ESPINOZA, O.; BUEHLMANN, U.; BOND, B. H. Energy and the us hardwood industry - Part II: Responses to increasing prices. **BioResources**, v. 6, n. 4, p. 3899–3914, 2011.

FABBRI, S. C. P. F.; HERNANDES, E. M.; DI THOMMAZO, A.; BELGAMO, A.; ZAMBONI, A.; SILVA, C. Managing Literature Reviews Information through Visualization. Em: ICEIS (2), 2012, [...]. 2012. p. 36–45.

FABBRI, S.; SILVA, C.; HERNANDES, E.; OCTAVIANO, F.; DI THOMMAZO, A.; BELGAMO, A. Improvements in the StArt tool to better support the systematic review process. Em: Proceedings of the 20th international conference on evaluation and assessment in software engineering, 2016, [...]. 2016. p. 1–5.

FALK, M. W.; SHAMBLIN-GRAY, S.; BALENDHRAN, C.; NEETHLING, J. B.; TOLAND, S.; MALLOY, S. Lessons Learned from IRWD – Setting Boundary Conditions at their WWTP When Estimating GHG Emissions for Their Evaluation. **Proc. Water Environ. Fed.**, v. 2013, n. 16, p. 2250–2261, jan. 2013.

FAN, Y.; LIANG, Q. M.; WEI, Y. M.; OKADA, N. A Model for China's Energy Requirements and CO2 Emissions Analysis. **Environmental Modelling and Software**, v. 22, n. 3, p. 378–393, mar. 2007.

FEDORCZAK-CISAK, M.; KOTOWICZ, A.; RADZISZEWSKA-ZIELINA, E.; SROKA, B.; TATARA, T.; BARNAŚ, K. Multi-Criteria Optimisation of an Experimental Complex of single-Family Nearly Zero-Energy Buildings. **Energies**, v. 13, n. 7, p. 1541, mar. 2020.

FENG, C.; ZHU, R.; WEI, G.; DONG, K.; DONG, J. Typical Case of Carbon Capture and Utilization in Chinese Iron and Steel Enterprises: CO2 Emission Analysis. **Journal of Cleaner Production**, v. 363, n. 132528, p. 132528, ago. 2022.

FENNER, A. E.; KIBERT, C. J.; WOO, J.; MORQUE, S.; RAZKENARI, M.; HAKIM, H.; LU, X. The carbon footprint of buildings: A review of methodologies and applications. **Renewable and Sustainable Energy Reviews**, v. 94, p. 1142–1152, 2018. Disponível em: <https://www.sciencedirect.com/science/article/pii/S1364032118305069>.

FERNÁNDEZ-SÁEZ, A. M.; BOCCO, M. G.; ROMERO, F. P. SLR-Tool: A Tool for Performing Systematic Literature Reviews. Em: ICSOFT (2), 2010, [...]. 2010. p. 157–166.

FERREIRA, M. B.; SALVADOR, R.; BARROS, M. V.; SOUZA, J. T. de; RABELO, T. G. L.; DE FRANCISCO, A. C.; COELHO, R.; PIEKARSKI, C. M. Eco-Efficiency of the Differential Ratio Change in a Heavy-Duty Vehicle and Implications for the Automotive Industry. **Sustainable Production and Consumption**, v. 21, p. 145–155, jan. 2020.

FERREIRA, V.; FLEMING, P.; STUART, G. Identifying Potential Gas Consumption Reductions from Municipal Buildings through the Analysis of Half-Hourly Primary Gas Meter Data. **Energy Efficiency**, v. 8, n. 3, p. 545–557, jun. 2015.

FICHERA, A.; VOLPE, R.; CUTORE, E. Energy performance measurement, monitoring and control for buildings of public organizations: Standardized practises compliant with the ISO 50001 and ISO 50006. **Developments in the Built Environment**, v. 4, p. 100024, nov. 2020.

FINNERTY, N.; STERLING, R.; COAKLEY, D.; CONTRERAS, S.; COFFEY, R.; KEANE, M. M. Development of a Global Energy Management System for non-energy intensive multi-site industrial organisations: A methodology. **Energy**, v. 136, p. 16–31, 2017. Disponível em: <https://www.sciencedirect.com/science/article/pii/S0360544216314839>.

FISCHER, H. R. Abductive reasoning as a way of worldmaking. **Foundations of science**, v. 6, n. 4, p. 361–383, 2001.

FORTUNATO, S. Community detection in graphs. **Physics Reports**, v. 486, n. 3, p. 75–174, 2010. Disponível em: <https://www.sciencedirect.com/science/article/pii/S0370157309002841>.

FOSTER, M. J.; JEWELL, S. T. Introduction to Systematic Reviews. *Em*: FOSTER, M. J.; JEWELL, S. T. **Assembling the Pieces of a Systematic Review: A Guide for Librarians**. Medical Library Association Books Series. Lanham, USA: Rowman & Littlefield Publishers, 2017. p. 1–13.

GAN, L.; XIONG, W.; LI, L.; ZHU, L.; HUANG, H. Iot based energy efficiency monitoring in stamping workshop. Em: ASME 2020 15th International Manufacturing Science and

Engineering Conference, MSEC 2020, 2020, [...]. American Society of Mechanical Engineers, 2020. v. 1

GAO, R. Y.; SHAO, L.; LI, J. S.; GUO, S.; HAN, M. Y.; MENG, J.; LIU, J. B.; XU, F. X.; LIN, C. Comparison of Greenhouse Gas Emission Accounting for a Constructed Wetland Wastewater Treatment System. **Ecological Informatics**, v. 12, p. 85–92, nov. 2012.

GAO, S. W.; GONG, X. Z.; LIU, Y.; ZHANG, Q. Q. Energy consumption and carbon emission analysis of natural graphite anode material for lithium batteries. Em: Materials Science Forum, 2018, [...]. 2018. v. 913, p. 985–990.

GARCIA, R.; FREIRE, F. Carbon footprint of particleboard: A comparison between ISO/TS 14067, GHG Protocol, PAS 2050 and Climate Declaration. **Journal of Cleaner Production**, v. 66, p. 199–209, 1 mar. 2014.

GHEORGHIU, C.; GHEORGHE, Ş.; SCRIPCARIU, M.; PORUMB, R. Energy Efficiency and Power Quality Indicators of a Micro Grid. Case study: Lighting Systems. Em: Proceedings of 2019 8th International Conference on Modern Power Systems, MPS 2019, 2019a, [...]. IEEE, 2019.

GHEORGHIU, C.; SCRIPCARIU, M.; GHEORGHE, S.; SAVA, G. N. Energy performance improvement actions for power distribution networks in university campuses. Em: Proceedings of 2019 International Conference on ENERGY and ENVIRONMENT, CIEM 2019, 2019b, [...]. IEEE, 2019. p. 369–373.

GHEORGHIU, C.; SCRIPCARIU, M.; GHEORGHIU, M.; DOBRICA, A. G. Energy efficiency in the building materials industry. Case study: Brick manufacturing in Romania. **E3S Web of Conferences**, v. 286, p. 02006, 2021.

GHOSH, S.; KIM, M.; CRIST, K. Comprehensive Greenhouse Gases Inventory for the State of Ohio. Em: Proceedings of the Air and Waste Management Association's Annual Conference and Exhibition, A&WMA, 2012, San Antonio, USA. [...]. San Antonio, USA: A&WMA, 2012.

GIASSON, A. C.; PORTELA, T. T.; LAFAY, J. M. S.; MARTINELLI, L. C. Minimal energy efficiency indicators for poultry industries. **Renewable Energy and Power Quality Journal**, v. 1, n. 12, p. 360–364, abr. 2014.

GIBASSIER, D.; SCHALTEGGER, S. Carbon Management Accounting and Reporting in Practice: A Case Study on Converging Emergent Approaches. **Sustainability Accounting, Management and Policy Journal**, v. 6, n. 3, p. 340–365, set. 2015.

GIRVAN, M.; NEWMAN, M. E. J. Community structure in social and biological networks. **Proceedings of the National Academy of Sciences**, v. 99, n. 12, p. 7821–7826, 11 jun. 2002. Disponível em: <https://doi.org/10.1073/pnas.122653799>.

GLAVAS, H.; ZOVKO-RIBIC, F.; DORIC, D.; TALAPKO, D. Development of Energy Management Standards. Em: 2018 International Conference on Smart Systems and Technologies (SST), 2018, [...]. IEEE, 2018. p. 185–189.

GOFFMAN, W. Mathematical approach to the spread of scientific ideas—the history of mast cell research. **Nature**, v. 212, n. 5061, p. 449–452, 1966.

GOFFMAN, W.; NEWILL, V. A. Generalization of epidemic theory: An application to the transmission of ideas. **Nature**, v. 204, n. 4955, p. 225–228, 1964.

GÓMEZ SARDUY, J. R.; VIEGO FELIPE, P. R.; DIAZ TORRES, Y.; PLASCENCIA, M. A.-G.; SANTOS, V. S.; HAESELDONCKX, D. A New Energy Performance Indicator for Energy Management System of a Wheat Mill Plant. **International Journal of Energy Economics and Policy**, v. 8, n. 4, p. 324–330, 16 jul. 2018. Disponível em: <https://www.econjournals.com/index.php/ijeep/article/view/6753>.

GONG, S.; SHAO, C.; ZHU, L. Energy Efficiency Optimization of Ethylene Production Process with Respect to a Novel FLPEM-Based Material-Product Nexus. **International Journal of Energy Research**, v. 43, n. 8, p. 3528–3549, jun. 2019.

GONG, Y.; SONG, D. Life Cycle Building Carbon Emissions Assessment and Driving Factors Decomposition Analysis Based on LMDI—A Case Study of Wuhan City in China. **Sustainability**, v. 7, n. 12, p. 16670–16686, 17 dez. 2015.

GONZÁLEZ, A. J.; CASTRILLÓN, R.; QUISPE, E. C. Energy efficiency improvement in the cement industry through energy management. Em: IEEE Cement Industry Technical Conference (Paper), 2012, [...]. IEEE, 2012.

GOPALAKRISHNAN, B.; RAMAMOORTHY, K.; CROWE, E.; CHAUDHARI, S.; LATIF, H. A structured approach for facilitating the implementation of ISO 50001 standard in the manufacturing sector. **Sustainable Energy Technologies and Assessments**, v. 7, p. 154–165, set. 2014.

GRAHAM, L. A.; RIDEOUT, G.; ROSENBLATT, D.; HENDREN, J. Greenhouse Gas Emissions from Heavy-Duty Vehicles. **Atmos. Environ. (1994)**, v. 42, n. 19, p. 4665–4681, jun. 2008.

GRANT, M. J.; BOOTH, A. A typology of reviews: an analysis of 14 review types and associated methodologies. **Health Information & Libraries Journal**, v. 26, n. 2, p. 91–108, 1 jun. 2009. Disponível em: <https://doi.org/10.1111/j.1471-1842.2009.00848.x>.

GRIX, J. Introducing Students to the Generic Terminology of Social Research. **Politics**, v. 22, n. 3, p. 175–186, 1 set. 2002. Disponível em: <https://doi.org/10.1111/1467-9256.00173>.

GUAN, D.; LIU, Z.; GENG, Y.; LINDNER, S.; HUBACEK, K. The gigatonne gap in China's carbon dioxide inventories. **Nature Climate Change**, v. 2, n. 9, p. 672–675, 2012. Disponível em: <https://doi.org/10.1038/nclimate1560>.

GUEDES, V. L. S.; BORSCHIVER, S. Bibliometria: uma ferramenta estatística para a gestão da informação e do conhecimento, em sistemas de informação, de comunicação e de avaliação científica e tecnológica. **Encontro Nacional de Ciência da Informação**, v. 6, n. 1, p. 18, 2005.

GUL, E.; WANG, J.; ZHANG, G. Simulation and optimization model for energy efficient building and environmental assessment. Em: 2018 2nd IEEE Conference on Energy Internet and Energy System Integration (EI2), 2018, [...]. IEEE, 2018.

HACATOGLU, K.; ROSEN, M. A.; DINCER, I. Comparative life cycle assessment of hydrogen and other selected fuels. **International Journal of Hydrogen Energy**, v. 37, n. 13, p. 9933–9940, jul. 2012.

HAKALA, K.; NIKUNEN, H.-M.; SINKKO, T.; NIEMELÄINEN, O. Yields and greenhouse gas emissions of cultivation of red clover-grass leys as assessed by LCA when fertilised with organic or mineral fertilisers. **Biomass and Bioenergy**, v. 46, p. 111–124, nov. 2012.

HÄKKINEN, T.; HAAPIO, A. Principles of GHG emissions assessment of wooden building products. **International Journal of Sustainable Building Technology and Urban Development**, v. 4, n. 4, p. 306–317, dez. 2013.

HAMZA, R.; HAMODA, M. F.; ELASSAR, M. Energy and Reliability Analysis of Wastewater Treatment Plants in Small Communities in Ontario. **Water Science and Technology**, v. 85, n. 6, p. 1824–1839, mar. 2022.

HAN, J.; FORMAN, G. S.; ELGOWAINY, A.; CAI, H.; WANG, M.; DIVITA, V. B. A comparative assessment of resource efficiency in petroleum refining. **Fuel**, v. 157, p. 292–298, out. 2015.

HARZING, A.-W. **The Publish or Perish book: Your guide to effective and responsible citation analysis**. Melbourne, Australia: Tarma Software Research, 2010.

HARZING, A.-W.; ALAKANGAS, S.; ADAMS, D. hIa: an individual annual h-index to accommodate disciplinary and career length differences. **Scientometrics**, v. 99, n. 3, p. 811–821, 2014. Disponível em: <https://doi.org/10.1007/s11192-013-1208-0>.

HATIRLI, S. A.; OZKAN, B.; FERT, C. **An econometric analysis of energy input-output in Turkish agricultureRenewable and Sustainable Energy Reviews**Elsevier BV, dez. 2005.

HEEKS, R.; OSPINA, A. v; WALL, P. J. Combining Pragmatism and Critical Realism in ICT4D Research: An e-Resilience Case Example. (P. Nielsen, H. C. Kimaro) Em: Information and Communication Technologies for Development. Strengthening Southern-Driven Cooperation as a Catalyst for ICT4D, 2019, Cham. [...]. Cham: Springer International Publishing, 2019. p. 14–25.

HEINONEN, J.; KYRÖ, R.; JUNNILA, S. City level carbon mitigation strategies: What are their true impacts? **International Journal of Sustainable Building Technology and Urban Development**, v. 3, n. 1, p. 54–59, mar. 2012.

HENRY, A.; STIEGLITZ, L. An Examination of Systematic Reviews in the Engineering Literature. Em: 2020 ASEE Virtual Annual Conference Content Access, 2020, [...]. 2020.

HERNANDES, E.; ZAMBONI, A.; FABBRI, S.; THOMMAZO, A. di. Using GQM and TAM to evaluate StArt-a tool that supports Systematic Review. **CLEI Electronic Journal**, v. 15, n. 1, p. 3, 2012.

HILLIARD, A.; JAMIESON, G. A.; JORJANI, D. Communicating a Model-Based Energy Performance Indicator. **Ergonomics in Design**, v. 22, n. 4, p. 21–29, out. 2014.

HINDERKS, A.; MAYO, F. J. D.; THOMASCHEWSKI, J.; ESCALONA, M. J. An SLR-Tool: Search Process in Practice: A Tool to Conduct and Manage Systematic Literature Review (SLR). Em: Proceedings of the ACM/IEEE 42nd International Conference on Software Engineering: Companion Proceedings, 2020, New York, NY, USA. [...]. New York, NY, USA: Association for Computing Machinery, 2020. p. 81–84.

HIRSCH, J. E. An index to quantify an individual's scientific research output. **Proceedings of the National academy of Sciences**, v. 102, n. 46, p. 16569–16572, 2005.

HOANG, A.; DO, P.; IUNG, B. Energy efficiency performance-based prognostics for aided maintenance decision-making: Application to a manufacturing platform. **Journal of Cleaner Production**, v. 142, p. 2838–2857, 2017. Disponível em: <https://www.sciencedirect.com/science/article/pii/S0959652616318182>.

HONDO, H. Life cycle GHG emission analysis of power generation systems: Japanese case. **Energy**, v. 30, n. 11, p. 2042–2056, 2005. Disponível em: <https://www.sciencedirect.com/science/article/pii/S0360544204003652>.

HOROWITZ, M. J.; BERTOLDI, P. A Harmonized Calculation Model for Transforming EU Bottom-up energy Efficiency Indicators into Empirical Estimates of Policy. **Energy Econ.**, v. 51, p. 135–148, set. 2015.

HOUSER, N.; KLOESEL, C. J. W. **The essential Peirce, volume 1: selected philosophical writings (1867–1893)**. Bloomington, USA: Indiana University Press, 1992.

HUANG, P.; DE SOUSA, E. R.; WELLS, N. S.; EYRE, B. D.; GIBBES, B.; HIPSEY, M. R. A Modeling Approach for Addressing Sensitivity and Uncertainty of Estuarine Greenhouse Gas (CO2 and CH4) Dynamics. **Journal of Geophysical Research: Biogeosciences**, v. 127, n. 6, jun. 2022.

HUSSAIN, M.; JAVAID, M. I.; DRAKE, P. R. An Econometric Study of Carbon Dioxide (CO2) Emissions, Energy Consumption, and Economic Growth of Pakistan. **International Journal of Energy Sector Management**, v. 6, n. 4, p. 518–533, nov. 2012.

IEA. **Net Zero by 2050**. [s.l: s.n.]. Disponível em: <https://www.iea.org/reports/net-zero-by-2050>.

IEA. **World Energy Outlook 2022**. [s.l: s.n.]. Disponível em: <https://www.iea.org/reports/world-energy-outlook-2022>.

IONESCU, C. V.; DARIE, G. New Method to Assess the Energy Efficiency and Energy Effectiveness to the Industrial End-Users. Em: EPE 2018 - Proceedings of the 2018 10th International Conference and Expositions on Electrical And Power Engineering, 2018, [...]. IEEE, 2018. p. 718–723.

IONESCU, C. V.; DARIE, G. Energy Effectiveness-New Energy Performance Indicator to optimize the Industrial Energy Consumptions. Em: EPE 2020 - Proceedings of the 2020 11th International Conference and Exposition on Electrical And Power Engineering, 2020, [...]. IEEE, 2020. p. 462–465.

IPCC. **2006 IPCC Guidelines for National Greenhouse Gas Inventories**. [s.l: s.n.]. 2006.

IPCC. **2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories** (E. , T. K. , K. A. , B. J. , F. M. , N. S. , O. A. , P. Y. , S. P. and F. S. Calvo Buendia). [s.l: s.n.]. 2019.

IPCC. **Climate Change 2022: Mitigation of Climate Change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC)**. Cambridge, UK: Cambridge University Press, 2022.

ISLAM, K. N.; SARKER, T.; TAGHIZADEH-HESARY, F.; ATRI, A. C.; ALAM, M. S. Renewable Energy Generation from Livestock Waste for a Sustainable Circular Economy in Bangladesh. **Renewable and Sustainable Energy Reviews**, v. 139, n. 110695, p. 110695, abr. 2021.

ISO. **ISO/TR 14069 - Greenhouse gases — Quantification and reporting of greenhouse gas emissions for organizations — Guidance for the application of ISO 14064-1**. [s.l: s.n.]. 2013.

ISO. **ISO 50001 - Energy management systems - Requirements with guidance for use**. [s.l: s.n.]. 2018b.

ISO. **ISO 14064-1 - Greenhouse gases — Part 1: Specification with guidance at the organization level for quantification and reporting of greenhouse gas emissions and removals**. [s.l: s.n.]. 2018a.

ISO. **ISO/PAS 50010 - Energy management and energy savings — Guidance for net zero energy in operations using an ISO 50001 energy management system**. [s.l: s.n.]. 2022a.

ISO. **IWA 42 - Net Zero guidelines**. [s.l: s.n.]. 2022b.

ISO. **ISO/DIS 14068 – Greenhouse gas management and climate change management and related activities — Carbon neutrality**. [s.l: s.n.]. 2022c.

ISO. **ISO 50004 – Energy management systems — Guidance for the implementation, maintenance, and improvement of an ISO 50001 energy management system**. [s.l: s.n.]. 2020.

ISO. **ISO 50006 – Energy management systems — Measuring energy performance using energy baselines (EnB) and energy performance indicators (EnPI) — General principles and guidance**. [s.l: s.n.]. 2014.

ISTRATE, I. S. B.; GHEORGHIU, C.; CASTRAVETE, M. The Cost of Indecision in Energy Efficiency. A Cost of Opportunity Analysis for an Industrial Consumer. Em: 2020 55th International Scientific Conference on Information, Communication and Energy Systems and Technologies, ICEST 2020 - Proceedings, 2020, [...]. IEEE, 2020. p. 145–148.

JAFFE, A. B.; STAVINS, R. N. The energy-efficiency gap What does it mean? **Energy Policy**, v. 22, n. 10, p. 804–810, 1994.

JAKRAWATANA, N.; MOORE, S.; MACGILL, I. Economic assessment of regional bioenergy systems in Australia: A flow analysis application. **International Journal of Environment and Pollution**, v. 39, n. 1–2, p. 61–73, 2009.

JAKSIC, V.; SILIC, D.; SILIC, I. Critical realism and pragmatism in transport demand research. **Global journal of Business and Integral Security**, v. 1, n. 1, p. 1–15, 2021.

JALAL, S. K. Co-authorship and co-occurrences analysis using Bibliometrix R-package: a casestudy of India and Bangladesh. **Annals of Library and Information Studies (ALIS)**, v. 66, n. 2, p. 57–64, 2019.

JAMES, K. L.; RANDALL, N. P.; HADDAWAY, N. R. A methodology for systematic mapping in environmental sciences. **Environmental Evidence**, v. 5, n. 1, p. 7, 2016. Disponível em: <https://doi.org/10.1186/s13750-016-0059-6>.

JÄRVENSIVU, T.; TÖRNROOS, J.-Å. Case study research with moderate constructionism: Conceptualization and practical illustration. **Industrial Marketing Management**, v. 39, n. 1, p. 100–108, 2010. Disponível em: <https://www.sciencedirect.com/science/article/pii/S0019850109001448>.

JENSEN, C.; KOTAISH, M.; CHOPRA, A.; JACOB, K. A.; WIDEKAR, T. I.; ALAM, R. Piloting a Methodology for Sustainability Education: Project Examples and Exploratory Action Research Highlights. **Emerging Science Journal**, v. 3, n. 5, p. 312–326, 1 out. 2019.

JEONG, S.; HSU, Y. K.; ANDREWS, A. E.; BIANCO, L.; VACA, P.; WILCZAK, J. M.; FISCHER, M. L. A multitower measurement network estimate of California's methane emissions. **Journal of Geophysical Research Atmospheres**, v. 118, n. 19, p. 11,339-11,351, out. 2013.

JIA, F. R.; JING, W. T.; LIU, G. X.; YUE, Q.; WANG, H. M.; SHI, L. Paraffin-Based Crude Oil Refining Process Unit-Level Energy Consumption and CO2 Emissions in China. **Journal of Cleaner Production**, v. 255, n. 120347, p. 120347, maio 2020.

JIANG, J.; ZHU, S.; WANG, W.; LI, Y.; LI, N. Coupling Coordination between New Urbanisation and Carbon Emissions in China. **Science of the Total Environment**, v. 850, n. 123848, p. 123848, dez. 2022a.

JIANG, K.; SU, J. LCA energy consumption and carbon emission analysis for residential partition in hot summer and cold winter zone. Em: 2011 International Conference on Remote Sensing, Environment and Transportation Engineering, 2011, [...]. IEEE, 2011.

JIANG, S.; CHISHTI, M. Z.; RJOUB, H.; RAHIM, S. Environmental R&D and trade-adjusted carbon emissions: evaluating the role of international trade. **Environmental Science and Pollution Research**, v. 29, n. 42, p. 63155–63170, 22 set. 2022b.

JING, Q.; BAI, H.; LUO, W.; CAI, B.; XU, H. A top-bottom method for city-scale energy-related CO2 emissions estimation: A case study of 41 Chinese cities. **Journal of Cleaner Production**, v. 202, p. 444–455, 2018. Disponível em: <https://www.sciencedirect.com/science/article/pii/S0959652618325228>.

JIUSTO, S. The Differences That Methods Make: Cross-Border Power Flows and accounting for Carbon Emissions from Electricity Use. **Energy Policy**, v. 34, n. 17, p. 2915–2928, nov. 2006.

JOHNSSON, S.; ANDERSSON, E.; THOLLANDER, P.; KARLSSON, M. Energy Savings and Greenhouse Gas Mitigation Potential in the Swedish Wood Industry. **Energy**, v. 187, n. 115919, p. 115919, nov. 2019.

JOSHI, J. M.; DALEI, N. N.; MEHTA, P. Estimating the energy consumption of Indian refineries: an empirical analysis based on panel data econometrics. **International Journal of Energy Technology and Policy**, v. 17, n. 3, p. 275–298, 1 jan. 2021. Disponível em: <https://www.inderscienceonline.com/doi/abs/10.1504/IJETP.2021.116328>.

JUN, D.; MING, W. Energy performance index based on LMDI technique and decomposition analysis of Beijing’s energy consumption. Em: 2010 International Conference on Future Information Technology and Management Engineering, FITME 2010, 2010, [...]. IEEE, 2010. v. 1, p. 246–249.

JUNG, M. Future key energy monitoring [Zukunftsschlüssel Energiemonitoring]. **Productivity Management**, v. 17, n. 4, p. 62–64, 2012. Disponível em: <https://www.scopus.com/inward/record.uri?eid=2-s2.0-84868104836&partnerID=40&md5=46829a9dc5fd10246f26b739bf2b60a1>.

JUNG, T.-W.; PYEON, M.-W.; KOO, J.-H. Quantification of carbon emission reduction by U-transportation service effect: a case study of Dongtan U-city. **Journal of Marine Science and Technology**, v. 20, n. 6, p. 12, 2012.

JUODIS, E.; JABLONSKA, B.; UYTERLINDE, M. A.; KAAN, H. F. Indicators for Energy Performance Efficiency Certification in the Lithuanian Residential Buildings. **Journal of Civil Engineering and Management**, v. 9, n. 2, p. 92–97, jan. 2003.

JUSOH, L. S.; HASHIM, H. Development of a Framework for Greenhouse Gas Emissions Accounting for Industry Reporting. **Chemical Engineering Transactions**, v. 63, p. 439–444, 1 maio 2018. Disponível em: <https://www.cetjournal.it/index.php/cet/article/view/CET1863074>.

KANCHIRALLA, F. M.; JALO, N.; JOHNSSON, S.; THOLLANDER, P.; ANDERSSON, M. Energy End-Use Categorization and Performance Indicators for Energy Management in the Engineering Industry. **Energies**, v. 13, n. 2, p. 369, jan. 2020.

KANCHIRALLA, F. M.; JALO, N.; THOLLANDER, P.; ANDERSSON, M.; JOHNSSON, S. Energy Use Categorization with Performance Indicators for the Food Industry and a Conceptual Energy Planning Framework. **Applied Energy**, v. 304, n. 117788, p. 117788, dez. 2021.

KANELLOS, F. D. Optimal power management with GHG emissions limitation in all-electric ship power systems comprising energy storage systems. **IEEE Transactions on Power Systems**, v. 29, n. 1, p. 330–339, jan. 2014.

KARNIADAKI, D.; MAZZON, A.; SPATARO, C.; TRAVERSO, M. Measures for Climate Protection in Mediterranean Cities: the implementation of MedClima project by the Municipality of Palermo. Em: Proceedings of the 20th International Conference “Science and Motor Vehicles 2005 – EAEC European Automotive Congress” Yugoslav Society of Automotive Engineers, 2005, Beograd, Serbia. [...]. Beograd, Serbia: YSAE, 2005.

KAVUNCU, Y. O.; KNABB, S. D. Stabilizing Greenhouse Gas Emissions: Assessing the intergenerational Costs and Benefits of the Kyoto Protocol. **Energy Econ.**, v. 27, n. 3, p. 369–386, maio 2005.

KENNEDY, C.; PINCETL, S.; BUNJE, P. The study of urban metabolism and its applications to urban planning and design. **Environmental Pollution**, v. 159, n. 8–9, p. 1965–1973, ago. 2011.

KHALED, E.-L.; FUJITA, T.; MORIOKA, T. GIS-based assessment of CO2 emission caused by automobile tripes for shopping. **Journal of global environment engineering**, v. 10, p. 113–127, 2004.

KHAN, I. Importance of GHG Emissions Assessment in the Electricity Grid Expansion towards a Low-Carbon Future: A Time-Varying Carbon Intensity Approach. **Journal of Cleaner Production**, v. 196, p. 1587–1599, set. 2018.

KHAN, I. **Greenhouse gas emission accounting approaches in electricity generation systems: A reviewAtmospheric Environment**Elsevier Ltd, 1 mar. 2019.

KHAN, Z.; ALI, M.; KIRIKKALELI, D.; WAHAB, S.; JIAO, Z. The Impact of Technological Innovation and Public-Private Partnership Investment on Sustainable Environment in China: Consumption-Based Carbon Emissions Analysis. **Sustainable Development**, v. 28, n. 5, p. 1317–1330, set. 2020a.

KHAN, Z.; ALI, S.; UMAR, M.; KIRIKKALELI, D.; JIAO, Z. Consumption-based carbon emissions and International trade in G7 countries: The role of Environmental innovation and Renewable energy. **Science of The Total Environment**, v. 730, p. 138945, 2020b. Disponível em: <https://www.sciencedirect.com/science/article/pii/S0048969720324621>.

KHIN, E. W. S.; FUI, L. Y. Pragmatism and critical realism in management research. **Actual Problems of Economics**, v. 129, n. 3, p. 359–364, 2012.

KIKUCHI, R. CO2 recovery and reuse in the energy sector, energy resource development and others: Economic and technical evaluation of large-scale Co2 recycling. **Energy Environ.**, v. 14, n. 4, p. 383–395, jul. 2003.

KIM, D. W.; KIM, Y. M.; LEE, S. E. Development of an energy benchmarking database based on cost-effective energy performance indicators: Case study on public buildings in South Korea. **Energy and Buildings**, v. 191, p. 104–116, 2019. Disponível em: <https://www.sciencedirect.com/science/article/pii/S037877881832509X>.

KIM, I.-H. S.; LEE, B.-Y. M. Direct causal mechanisms of profit: dominant paradigm of profit seeking. **Technology Analysis & Strategic Management**, v. 31, n. 4, p. 371–387, 3 abr. 2019. Disponível em: <https://doi.org/10.1080/09537325.2018.1516863>.

KIM, S.; DALE, B. E. Environmental Aspects of Ethanol Derived from No-Tilled Corn: Nonrenewable Energy Consumption and Greenhouse Gas. **Biomass Bioenergy**, v. 28, n. 5, p. 475–489, maio 2005.

KITCHENHAM, B. A.; DYBA, T.; JORGENSEN, M. Evidence-based software engineering. Em: Proceedings. 26th International Conference on Software Engineering, 2004, [...]. IEEE, 2004. p. 273–281.

KITCHENHAM, B.; BRERETON, P. A systematic review of systematic review process research in software engineering. **Information and Software Technology**, v. 55, n. 12, p. 2049–2075, 2013. Disponível em: <https://www.sciencedirect.com/science/article/pii/S0950584913001560>.

KIVKO, S. G.; DRUZHININ, E. A.; PROKHOROV, O. v; KRITSKY, D. N. Management of energy saving project and programs at metallurgical enterprises. Em: 2019 IEEE 14th International Conference on Computer Sciences and Information Technologies (CSIT), 2019, [...]. IEEE, 2019. v. 3, p. 158–161.

KLAVANS, R.; BOYACK, K. W. Which type of citation analysis generates the most accurate taxonomy of scientific and technical knowledge? **Journal of the Association for Information Science and Technology**, v. 68, n. 4, p. 984–998, 2017.

KLEINHANS, M. G.; BUSKES, C. J. J.; DE REGT, H. W. Philosophy of earth science. *Em*: ALLHOFF, F. **Philosophies of the sciences: a guide**. Chichester, UK: Wiley-Blackwell, 2010. p. 213–236.

KONOVALOV, I. B.; BEREZIN, E. v; CIAIS, P.; BROQUET, G.; ZHURAVLEV, R. v; JANSSENS-MAENHOUT, G. Estimation of fossil-fuel CO_2 emissions using satellite measurements of ``proxy'' species. **Atmospheric Chemistry and Physics**, v. 16, n. 21, p. 13509–13540, 2016. Disponível em: <https://acp.copernicus.org/articles/16/13509/2016/>.

KOPLOW, D.; DERNBACH, J. Federal Fossil Fuel Subsidies and Greenhouse Gas Emissions: A Case Study of Increasing Transparency for Fiscal Policy. **Annual Review of Energy and the Environment**, v. 26, n. 1, p. 361–389, nov. 2001.

KOURKOUMPAS, D.-S.; BENEKOS, G.; NIKOLOPOULOS, N.; KARELLAS, S.; GRAMMELIS, P.; KAKARAS, E. A Review of Key Environmental and Energy Performance indicators for the Case of Renewable Energy Systems When Integrated with storage Solutions. **Appl. Energy**, v. 231, p. 380–398, dez. 2018.

KREZO, S.; MIRZA, O.; HE, Y.; MAKIM, P.; KAEWUNRUEN, S. Field Investigation and Parametric Study of Greenhouse Gas Emissions from Railway Plain-Line Renewals. **Transportation Research Part D: Transport and Environment**, v. 42, p. 77–90, jan. 2016.

KROLL, E.; KOSKELA, L. Explicating concepts in reasoning from function to form by two-step innovative abductions. **Artificial Intelligence for Engineering Design, Analysis and Manufacturing**, v. 30, n. 2, p. 125–137, 2016. Disponível em: <https://www.cambridge.org/core/article/explicating-concepts-in-reasoning-from-function-to-form-by-twostep-innovative-abductions/129F74A04F4B45BF4E4734CA85DD70B8>.

KUMANAYAKE, R.; LUO, H. A Tool for Assessing Life Cycle CO2 Emissions of Buildings in Sri Lanka. **Building and Environment**, v. 128, p. 272–286, jan. 2018.

KUMAR, D.; ZARE, F. A comprehensive review of maritime microgrids: System architectures, energy efficiency, power quality, and regulations. **IEEE Access**, v. 7, p. 67249–67277, 2019.

KUNNAS, J. A Dense and Sickly Mist from Thousands of Bog Fires: An Attempt to Compare the Energy Consumption in Slash-and-Burn Cultivation and Burning Cultivation of Peatlands in Finland in 1820-1920. **Environment and History**, v. 11, n. 4, p. 431–446, nov. 2005.

KWOK, K. Y. G.; STATZ, C.; WADE, B.; CHONG, W. K. O. Carbon emissions modeling for green buildings: A comprehensive study of calculations. Em: ICSDEC 2012: Developing the Frontier of Sustainable Design, Engineering, and Construction - Proceedings of the 2012 International Conference on Sustainable Design and Construction, 2013, Reston, VA. [...]. Reston, VA: American Society of Civil Engineers, 2013. p. 118–126.

KYCHKIN, A.; DERYABIN, A.; VIKENTYEVA, O.; SHESTAKOVA, L. Architecture of compressor equipment monitoring and control cyber-physical system based on influxdata platform. Em: 2019 International Conference on Industrial Engineering, Applications and Manufacturing, ICIEAM 2019, 2019, [...]. IEEE, 2019.

LAMÉ, G.; YANNOU, B.; CLUZEL, F. Analyzing RID methodology through the lens of innovative abduction. Em: 15th International Design Conference, 2018, [...]. 2018.

LANCICHINETTI, A.; FORTUNATO, S. Community detection algorithms: A comparative analysis. **Phys. Rev. E**, v. 80, n. 5, p. 56117, nov. 2009. Disponível em: <https://link.aps.org/doi/10.1103/PhysRevE.80.056117>.

LARA ALLENDE, A.; STEPHAN, A. Life cycle embodied, operational and mobility-related energy and greenhouse gas emissions analysis of a green development in Melbourne, Australia. **Applied Energy**, v. 305, p. 117886, jan. 2022.

LARSEN, A. W.; MERRILD, H.; CHRISTENSEN, T. H. Recycling of glass: accounting of greenhouse gases and global warming contributions. **Waste Management & Research: The Journal for a Sustainable Circular Economy**, v. 27, n. 8, p. 754–762, 26 nov. 2009.

LAWANI, A. Critical realism: what you should know and how to apply it. **Qualitative Research Journal**, v. 21, n. 3, p. 320–333, 1 jan. 2021. Disponível em: <https://doi.org/10.1108/QRJ-08-2020-0101>.

LAWRENCE, A.; THOLLANDER, P.; ANDREI, M.; KARLSSON, M. Specific Energy Consumption/Use (SEC) in Energy Management for improving Energy Efficiency in Industry: Meaning, Usage And. **Energies**, v. 12, n. 2, p. 247, jan. 2019.

LEE, M.-K.; SHRESTHA, R. M.; SHARMA, S.; TIMILSINA, G. R.; KUMAR, S. **Baseline methodologies for clean development mechanism projects : a guidebook**. Roskilde: Risø National Laboratory, 2005. .

LEYDESDORFF, L. Bibliometrics/citation networks. *Em*: BARNETT, G. A. **Encyclopedia of social networks**. Thousand Oaks, USA: Sage Publications, Inc, 2011. p. 72–74.

LI, H.; LI, X.; TIAN, W.; CHEN, Z.; BAI, H. CO2 Emission Calculation Model of Integrated Steel Works Based on Process Analysis. *Em*: BABA, A. A.; ZHANG, L.; GUILLEN, D. P.; NEELAMEGGHAN, N. R. ,; PENG, H.; ZHONG, Y. **Energy Technology 2021 - Carbon Dioxide Management and Other Technologies**. Cham, Switzerland: Springer, 2021. p. 29–38.

LI, L. **Integrating climate change impact in new building design process: A review of building life cycle carbon emission assessment methodologiesCleaner Engineering and Technology**Elsevier BV, dez. 2021.

LI, M.-J.; HE, Y.-L.; TAO, W.-Q. Modeling a hybrid methodology for evaluating and forecasting regional energy efficiency in China. **Applied Energy**, v. 185, p. 1769–1777, 2017. Disponível em: <https://www.sciencedirect.com/science/article/pii/S0306261915015329>.

LI, R.; SUN, T. Research on measurement of regional differences and decomposition of influencing factors of carbon emissions of china’s logistics industry. **Polish Journal of Environmental Studies**, v. 30, n. 4, p. 3137–3150, jun. 2021.

LI, S.; GAO, L.; JIN, H. Life cycle energy use and GHG emission assessment of coal-based SNG and power cogeneration technology in China. **Energy Conversion and Management**, v. 112, p. 91–100, mar. 2016.

LI, W.; SUN, S.; LI, H. Decomposing the Decoupling Relationship between Energy-Related CO2 Emissions and Economic Growth in China. **Natural Hazards**, v. 79, n. 2, p. 977–997, nov. 2015.

LI, Y. L.; CHEN, B.; HAN, M. Y.; DUNFORD, M.; LIU, W.; LI, Z. Tracking carbon transfers embodied in Chinese municipalities' domestic and foreign trade. **Journal of Cleaner Production**, v. 192, p. 950–960, 2018. Disponível em: <https://www.sciencedirect.com/science/article/pii/S0959652618312721>.

LIANG, Y.; NIU, D.; ZHOU, W.; FAN, Y. Decomposition Analysis of Carbon Emissions from Energy Consumption in Beijing-Tianjin-Hebei, China: A Weighted-Combination Model Based on Logarithmic Mean Divisia Index and Shapley Value. **Sustainability**, v. 10, n. 7, p. 2535, 19 jul. 2018.

LIMSAWASD, C. GHG emission quantification for pavement construction projects using a process-based approach. **Engineering and Applied Science Research**, v. 44, n. 1, p. 27–33, 2017.

LIPSCOMB, M. Critical realism and realist pragmatism in mixed method research: The problematics of event identity and abductive inference. Em: American Educational Research Association Annual Meeting, 2011, [...]. 2011.

LISZKA, M.; NOWAK, G.; PTASINSKI, K. J. Comparative analysis of large biomass & coal co-utilization units. Em: 23rd International Conference on Efficiency, Cost, Optimization, Simulation and Environmental Impact of Energy Systems (ECOS 2010), 2010, [...]. 2010. p. 972–979.

LIU, A.; MILLER, W.; CROMPTON, G.; MA, Y. Principles to define energy key performance indicators for the healthcare sector. Em: Proceedings - 2020 International Conference on Smart Grids and Energy Systems, SGES 2020, 2020, [...]. IEEE, 2020. p. 898–903.

LIU, J.; HAN, W.; LIU, C.; PENG, H. A New Method for the Optimal Control Problem of Path Planning for Unmanned Ground Systems. **IEEE Access**, v. 6, p. 33251–33260, 2018a.

LIU, T.; WANG, Q.; SU, B. A review of carbon labeling: Standards, implementation, and impact. **Renewable and Sustainable Energy Reviews**, v. 53, p. 68–79, jan. 2016.

LIU, X. jun; LIAO, S. ming; RAO, Z. hua; LIU, G. An Input–Output Model for Energy Accounting and Analysis of Industrial Production Processes: A Case Study of an Integrated Steel Plant. **Journal of Iron and Steel Research International**, v. 25, n. 5, p. 524–538, maio 2018b.

LIU, Z.; BERG, M.; BUSTAD, T. **Review of the existing energy labelling systems and a proposal for rail vehiclesProceedings of the Institution of Mechanical Engineers, Part F: Journal of Rail and Rapid Transit**SAGE Publications, abr. 2021.

LIU, Z.; GUAN, D.; WEI, W.; DAVIS, S. J.; CIAIS, P.; BAI, J.; PENG, S.; ZHANG, Q.; HUBACEK, K.; MARLAND, G.; ANDRES, R. J.; CRAWFORD-BROWN, D.; LIN, J.; ZHAO, H.; HONG, C.; BODEN, T. A.; FENG, K.; PETERS, G. P.; XI, F.; LIU, J.; LI, Y.; ZHAO, Y.; ZENG, N.; HE, K. Reduced carbon emission estimates from fossil fuel combustion and cement production in China. **Nature**, v. 524, n. 7565, p. 335–338, 19 ago. 2015. Disponível em: <https://doi.org/10.1038/nature14677>.

LIU, Z.; SUN, T.; YU, Y.; KE, P.; DENG, Z.; LU, C.; HUO, D.; DING, X. Near-Real-Time Carbon Emission Accounting Technology Toward Carbon Neutrality. **Engineering**, v. 14, p. 44–51, jul. 2022.

LOTKA, A. J. The frequency distribution of scientific productivity. **Journal of the Washington academy of sciences**, v. 16, n. 12, p. 317–323, 1926.

LOZANO, E. M.; LØKKE, S.; ROSENDAHL, L. A.; PEDERSEN, T. H. Production of marine biofuels from hydrothermal liquefaction of sewage sludge. Preliminary techno-economic analysis and life-cycle GHG emissions assessment of Dutch case study. **Energy Conversion and Management: X**, v. 14, p. 100178, maio 2022.

LOZANO, S.; CALZADA-INFANTE, L.; ADENSO-DÍAZ, B.; GARCÍA, S. Complex network analysis of keywords co-occurrence in the recent efficiency analysis literature. **Scientometrics**, v. 120, n. 2, p. 609–629, 2019. Disponível em: <https://doi.org/10.1007/s11192-019-03132-w>.

LU, K.; JIANG, X.; TAM, V. W. Y.; LI, M.; WANG, H.; XIA, B.; CHEN, Q. Development of a Carbon Emissions Analysis Framework Using Building Information Modeling and Life Cycle Assessment for the Construction of Hospital Projects. **Sustainability**, v. 11, n. 22, p. 6274, 8 nov. 2019.

LU, S.; WEI, S.; ZHANG, K.; KONG, X.; WU, W. Investigation and Analysis on the Energy Consumption of Starred Hotel Buildings in Hainan Province, the Tropical Region of China. **Energy Conversion and Management**, v. 75, p. 570–580, nov. 2013.

LV, G.; CAO, B.; JUN, L.; LIU, G.; DING, Y.; YU, J.; ZANG, Y.; ZHANG, D. Optimal Scheduling of Integrated Energy System under the Background of Carbon Neutrality. **Energy Reports**, v. 8, p. 1236–1248, ago. 2022.

LYUBCHENKO, V. Y.; ISKHAKOV, A. F.; PAVLYUCHENKO, D. A. Rating of Organization’s Energy Efficiency Based on Harrington’s Desirability Function. Em: 2020 International Multi-Conference on Industrial Engineering and Modern Technologies, FarEastCon 2020, 2020, [...]. IEEE, 2020.

MAKHLOUF, A.; QUARANTA, G.; KARDACHE, R. Energy Consumption and Greenhouse Gas Emission Assessment in the Algerian Sector of Fertilisers Production with Life Cycle Assessment. **International Journal of Global Warming**, v. 18, n. 1, p. 16–36, 2019.

MALÇA, J.; FREIRE, F. Uncertainty Analysis in Biofuel Systems. **Journal of Industrial Ecology**, v. 14, n. 2, p. 322–334, mar. 2010.

MARCH, L. The Logic of Design and the Question of Value. *Em*: MARCH, L. **The Architecture of Form**. Cambridge Urban and Architectural Studies. Cambridge, UK: Cambridge University Press, 1976. p. 1–40.

MARRIOTT, J.; MATTHEWS, H. S.; HENDRICKSON, C. T. Impact of Power Generation Mix on Life Cycle Assessment and Carbon Footprint Greenhouse Gas Results. **Journal of Industrial Ecology**, v. 14, n. 6, p. 919–928, dez. 2010.

MARTÍNEZ-DE-ALEGRÍA, I.; RÍO, R. M.; ZARRABEITIA, E.; ÁLVAREZ, I. Heating Demand as an Energy Performance Indicator: A Case Study of Buildings Built under the Passive House Standard in Spain. **Energy Policy**, v. 159, n. 112604, p. 112604, dez. 2021.

MARTINI, F.; OSSIDI, M.; SALVIO, M.; TORO, C. Analysis of The Energy Consumption Structure and Evaluation of Energy Performance Indicators of The Italian Ceramic Industry. Em: ECOS 2021 - 34th International Conference on Efficency, Cost, Optimization, Simulation and Environmental Impact of Energy Systems, 2021, Tokyo, Japan. [...]. Tokyo, Japan: ECOS 2021 Program Organizers, 2021. p. 1258–1268.

MARTÍN-MARTÍN, A.; THELWALL, M.; ORDUNA-MALEA, E.; DELGADO LÓPEZ-CÓZAR, E. Google Scholar, Microsoft Academic, Scopus, Dimensions, Web of Science, and OpenCitations' COCI: a multidisciplinary comparison of coverage via citations. **Scientometrics**, v. 126, n. 1, p. 871–906, 1 jan. 2021.

MAXWELL, J. A.; MITTAPALLI, K. Realism as a stance for mixed methods research. **SAGE handbook of mixed methods in social & behavioral research**, v. 2, p. 145–168, 2010.

MAY, G.; STAHL, B.; TAISCH, M.; KIRITSIS, D. Energy management in manufacturing: From literature review to a conceptual framework. **Journal of Cleaner Production**, v. 167, p. 1464–1489, 20 nov. 2017. Disponível em: <https://www.sciencedirect.com/science/article/pii/S0959652616318224>.

MCBRIDE, K.; MISNIKOV, Y.; DRAHEIM, D. Discussing the foundations for interpretivist digital government research. *Em*: **Scientific Foundations of Digital Governance and Transformation**. [s.l.] Springer, 2022. p. 121–147.

MCDONALD, J. H. **Handbook of biological statistics**. Baltimore, USA: Sparky house publishing , 2009. v. 2

MENDOZA, R. C.; HERNÁNDEZ, J. M. R.; GÓMEZ, E. V.; ALONSO, J. F. S. J.; MARTÍNEZ, F. J. R. Analysis of the Methodology to Obtain Several Key Indicators Performance (KIP), by Energy Retrofitting of the Actual Building to the District Heating Fuelled by Biomass, Focusing on NZEB Goal: Case of Study. **Energies**, v. 12, n. 1, p. 93, dez. 2019.

MENG, L.; SAGER, J. Energy consumption and energy-related CO2 emissions from China's petrochemical industry based on an environmental input-output life cycle assessment. **Energies**, v. 10, n. 10, p. 1585, out. 2017.

MENGHI, R.; PAPETTI, A.; GERMANI, M.; MARCONI, M. **Energy efficiency of manufacturing systems: A review of energy assessment methods and toolsJournal of Cleaner Production**Elsevier Ltd, 10 dez. 2019.

MENGUAL TORRES, S. G.; MAY TZUC, O.; AGUILAR-CASTRO, K. M.; CASTILLO TÉLLEZ, M.; OVANDO SIERRA, J.; CRUZ-Y CRUZ, A. del R.; BARRERA-LAO, F. J. Analysis of Energy and Environmental Indicators for Sustainable Operation of Mexican Hotels in Tropical Climate Aided by Artificial Intelligence. **Buildings**, v. 12, n. 8, p. 321, mar. 2022.

MEYER, M. D. **Greenhouse gas and climate change assessment: Framing a transportation research agendaJournal of the American Planning Association**Informa UK Limited, set. 2010.

MILLER-ROBBIE, L.; RAMASWAMI, A.; KUMAR, P. Life Cycle Energy Use and Greenhouse Gas Emission Analysis for a Water Resource Recovery Facility in India. **Water Environment Research**, v. 85, n. 7, p. 621–631, jul. 2013.

MINX, J.; BAIOCCHI, G.; WIEDMANN, T.; BARRETT, J.; CREUTZIG, F.; FENG, K.; FÖRSTER, M.; PICHLER, P.-P.; WEISZ, H.; HUBACEK, K. Carbon footprints of cities and other human settlements in the UK. **Environmental Research Letters**, v. 8, n. 3, p. 035039, 2013. Disponível em: <https://dx.doi.org/10.1088/1748-9326/8/3/035039>.

MOGHADASI, M.; IZADYAR, N.; MOGHADASI, A.; GHADAMIAN, H. Applying Machine Learning Techniques to Implement the Technical Requirements of Energy Management Systems in Accordance with ISO 50001:2018, an Industrial Case Study. **Energy Sources, Part A: Recovery, Utilization and Environmental Effects**, p. 1–18, dez. 2021.

MONTEBELO, R. P.; ORLANDO, A.; PORTO, D.; ZANIRO, D.; FABBRI, S. SRAT (Systematic Review Automatic Tool): uma ferramenta computacional de apoio à revisão sistemática. Em: V Experimental Software Engineering Latin American Workshop, ICMC-São Carlos, 2007, [...]. sn, 2007. v. 10

MOON, K.; BLACKMAN, D. A Guide to Understanding Social Science Research for Natural Scientists. **Conservation Biology**, v. 28, n. 5, p. 1167–1177, 1 out. 2014. Disponível em: <https://doi.org/10.1111/cobi.12326>.

MORAL-MUÑOZ, J. A.; HERRERA-VIEDMA, E.; SANTISTEBAN-ESPEJO, A.; COBO, M. J. Software tools for conducting bibliometric analysis in science: An up-to-date review. **El Profesional de la Información**, v. 29, n. 1, 19 jan. 2020.

MORFELDT, J.; SILVEIRA, S. Methodological differences behind energy statistics for steel production - Implications when monitoring energy efficiency. **Energy**, v. 77, p. 391–396, dez. 2014. Disponível em: <http://dx.doi.org/10.1016/j.energy.2014.09.020>.

MORFELDT, J.; SILVEIRA, S.; HIRSCH, T.; LINDQVIST, S.; NORDQVIST, A.; PETTERSSON, J.; PETTERSSON, M. Improving energy and climate indicators for the steel industry - The case of Sweden. **Journal of Cleaner Production**, v. 107, p. 581–592, 16 nov. 2015.

MORRIS, S. A.; DER VEER MARTENS, B. Mapping research specialties. **Annual Review of Information Science and Technology**, v. 42, n. 1, p. 213–295, 2008. Disponível em: <https://asistdl.onlinelibrary.wiley.com/doi/abs/10.1002/aris.2008.1440420113>.

MUNZLINGER, E.; NARCIZO, F. B.; DE QUEIROZ, J. E. R. Sistematização de revisões bibliográficas em pesquisas da área de IHC. Em: IHC (Companion), 2012, [...]. 2012. p. 51–54.

MUTSCHLER-BURGHARD, R. Improving Energy Performance Indicators with the Help of Multivariable Linear Regression. **Chemical Engineering and Technology**, v. 42, n. 9, p. 1861–1870, set. 2019.

MWASHA, A.; WILLIAMS, R. G.; IWARO, J. Modeling the Performance of Residential Building Envelope: The of Sustainable Energy Performance Indicators. **Energy Build.**, v. 43, n. 9, p. 2108–2117, set. 2011.

MWASHA, A.; WILLIAMS, R. G.; IWARO, J. Significance of Sub-Criteria in Measuring Sustainable of Building Envelope Development. **Int. J. Sustainable Dev. Plann.**, v. 8, n. 4, p. 464–484, dez. 2013.

NAIR, G.; ALLARD, I.; ÅSTRAND, A.; OLOFSSON, T. Building professionals' views on energy efficiency compliance requirements. Em: Energy Procedia, 2017, [...]. Elsevier BV, 2017. v. 132, p. 988–993.

NAKTHONG, V.; KUBAHA, K. A simplified model of energy performance indicators for sustainable energy management. **IOP Conference Series: Earth and Environmental Science**, v. 463, n. 1, p. 12046, mar. 2020.

NALLEY, L.; POPP, M.; FORTIN, C. The Impact of Reducing Greenhouse Gas Emissions in Crop Agriculture: A Spatial-and Production-Level Analysis. **Agricultural and Resource Economics Review**, v. 40, n. 1, p. 63–80, abr. 2011.

NEWMAN, M. E. J.; GIRVAN, M. Finding and evaluating community structure in networks. **Physical Review E**, v. 69, n. 2, p. 26113, 26 fev. 2004. Disponível em: <https://link.aps.org/doi/10.1103/PhysRevE.69.026113>.

NISSEN, U.; HARFST, N.; GIRBIG, P. **Energiekennzahlen auf den Unternehmenserfolg ausrichten**. 1. ed. Berlin, Germany: DIN Beuth Verlag GmbH, 2018. v. 11–166 p.

NOGESTE, K. Dual cycle action research: a professional doctorate case study. **International Journal of Managing Projects in Business**, v. 1, n. 4, p. 566–585, 12 set. 2008.

NOJOUMI, H.; DINCER, I.; NATERER, G. F. Greenhouse Gas Emissions Assessment of Hydrogen and Kerosene-Fueled Aircraft Propulsion. **International Journal of Hydrogen Energy**, v. 34, n. 3, p. 1363–1369, fev. 2009.

NUTTER, D. W.; KIM, D. S.; ULRICH, R.; THOMA, G. Greenhouse Gas Emission Analysis for USA Fluid Milk Processing Plants: Processing, Packaging, and Distribution. **International Dairy Journal**, v. 31, n. 1, p. S57–S64, abr. 2013.

Ó GALLACHÓIR, B. P.; KEANE, M.; MORRISSEY, E.; O'DONNELL, J. Using indicators to profile energy consumption and to inform energy policy in a university—A case study in

Ireland. **Energy and Buildings**, v. 39, n. 8, p. 913–922, 2007. Disponível em: <https://www.sciencedirect.com/science/article/pii/S037877880600260X>.

OCAMPO BATLLE, E. A.; ESCOBAR PALACIO, J. C.; SILVA LORA, E. E.; MARTÍNEZ REYES, A. M.; MELIAN MORENO, M.; MOREJÓN, M. B. A methodology to estimate baseline energy use and quantify savings in electrical energy consumption in higher education institution buildings: Case study, Federal University of Itajubá (UNIFEI). **Journal of Cleaner Production**, v. 244, 20 jan. 2020.

OCHOA, G. V.; FORERO, J. D.; BARRETO, D. S. Use of Energy Performance Indicators for the Energy Diagnosis of a Bottling Plant. **Contemporary Engineering Sciences**, v. 11, n. 67, p. 3315–3323, 2018.

O'DRISCOLL, E.; ÓG CUSACK, D.; O'DONNELL, G. E. The Development of Energy Performance Indicators within a Complex Manufacturing Facility. **International Journal of Advanced Manufacturing Technology**, v. 68, n. 9–12, p. 2205–2214, out. 2013.

OH, J. Understanding Scientific Inference in the Natural Sciences Based on Abductive Inference Strategies. (L. Magnani, P. Li) Em: Philosophy and Cognitive Science, 2012, Berlin, Heidelberg. [...]. Berlin, Heidelberg: Springer Berlin Heidelberg, 2012. p. 221–237.

OH, J.-Y. Understanding Natural Science Based on Abductive Inference: Continental Drift. **Foundations of Science**, v. 19, n. 2, p. 153–174, 2014. Disponível em: <https://doi.org/10.1007/s10699-013-9322-2>.

O'KEEFFE, S.; O'SULLIVAN, D.; BRUTON, K. Methodology for Carbon Emissions Neutrality in Industrial Manufacturing. **Chemical Engineering Transactions**, v. 94, p. 43–48, 1 set. 2022. Disponível em: <https://www.cetjournal.it/index.php/cet/article/view/CET2294007>.

OKESINA, M. A Critical Review of the Relationship between Paradigm, Methodology, Design and Method in Research. **Journal of Research & Method in Education**, v. 10, n. 3, p. 57–68, 2020.

OKOLI, C.; SCHABRAM, K. A guide to conducting a systematic literature review of information systems research. **Sprouts: Working Papers on Information Systems**, v. 10, n. 26, p. 1–49, 2010. Disponível em: <http://sprouts.aisnet.org/10-26>.

ONAT, N.; BAYAR. H. Turkey's energy policy and investment plans. Em: 4th WSEAS International Conference On Energy Planning, Energy Saving, Environmental Education (EPESE'10), 2010, Sousse, Tunisia. [...]. Sousse, Tunisia: WSEAS, 2010.

OSINSKA, V.; KLIMAS, R. Mapping science: tools for bibliometric and altmetric studies. **Information Research: an international electronic journal**, v. 26, n. 4, 15 dez. 2021.

PAN, W.; QIN, H.; ZHAO, Y. Challenges for energy and carbon modeling of high-rise buildings: The case of public housing in Hong Kong. **Resources, Conservation and Recycling**, v. 123, p. 208–218, ago. 2017.

PAO, M. L. Automatic text analysis based on transition phenomena of word occurrences. **Journal of the American Society for Information Science**, v. 29, n. 3, p. 121–124, 1978.

PAPADOPOULOS, A. M.; GIAMA, E. Environmental Performance Evaluation of Thermal Insulation Materials and Its Impact on the Building. **Building and Environment**, v. 42, n. 5, p. 2178–2187, maio 2007.

PARALIKAS, J.; SALONITIS, K.; CHRYSSOLOURIS, G. Robust Optimization of the Energy Efficiency of the Cold Roll Forming Process. **International Journal of Advanced Manufacturing Technology**, v. 69, n. 1–4, p. 461–481, out. 2013.

PARDO MARTÍNEZ, C. I. Energy use and energy efficiency development in the German and Colombian textile industries. **Energy for Sustainable Development**, v. 14, n. 2, p. 94–103, jun. 2010.

PEÑA, M.; BISCARRI, F.; GUERRERO, J. I.; MONEDERO, I.; LEÓN, C. Rule-Based System to Detect Energy Efficiency Anomalies in Smart Buildings, a Data Mining Approach. **Expert Systems with Applications**, v. 56, p. 242–255, set. 2016.

PEÑA, M.; BISCARRI, F.; PERSONAL ENRIQUE AND LEÓN, C. Decision Support System to Classify and Optimize the Energy in Smart Buildings: A Data Analytics Approach. **Sensors (Basel)**, v. 22, n. 4, p. 1380, fev. 2022.

PENA MARRIAGA, M. A.; DURAN CONTRERAS, M. P.; SALAS, A. P.; CHAMORRO, M. V.; BARROS ZARANTE, P. H. Calculation of Energy Performance Indicators of a Company in the Hotel Sector. **Contemporary Engineering Sciences**, v. 11, n. 73, p. 3609–3619, 2018.

PENG, T.; OU, X.; YUAN, Z.; YAN, X.; ZHANG, X. Development and application of China provincial road transport energy demand and GHG emissions analysis model. **Applied Energy**, v. 222, p. 313–328, 2018. Disponível em: <https://www.sciencedirect.com/science/article/pii/S030626191830477X>.

PENG, T.; REN, L.; DU, E.; OU, X.; YAN, X. Life Cycle Energy Consumption and Greenhouse Gas Emissions of Primary and Recycled Aluminum in China. **Processes (Basel)**, v. 10, n. 11, p. 2299, nov. 2022.

PÉREZ-LOMBARD, L.; ORTIZ, J.; MAESTRE, I. R.; CORONEL, J. F. Constructing HVAC energy efficiency indicators. **Energy and Buildings**, v. 47, p. 619–629, abr. 2012.

PÉREZ-LOMBARD, L.; ORTIZ, J.; VELÁZQUEZ, D. **Revisiting energy efficiency fundamentalsEnergy Efficiency**Springer Science and Business Media LLC, maio 2013.

PERKO, J.; TOPIĆ, D.; ŠLJIVAC, D. Providing power supply to other use cases integrated in the system of public lighting. **International Journal of Electrical and Computer Engineering Systems**, v. 8, n. 1, p. 33–39, 2017.

PERRONI, M. G.; GOUVEA DA COSTA, S. E.; PINHEIRO DE LIMA, E.; VIEIRA DA SILVA, W.; TORTATO, U. Measuring energy performance: A process based approach. **Applied Energy**, v. 222, p. 540–553, 15 jul. 2018.

PETER, C.; HELMING, K.; NENDEL, C. Do Greenhouse Gas Emission Calculations from Energy Crop Cultivation Reflect Actual Agricultural Management Practices? – A Review of Carbon Footprint Calculators. **Renewable and Sustainable Energy Reviews**, v. 67, p. 461–476, jan. 2017.

PETERS, G. P.; DAVIS, S. J.; ANDREW, R. A synthesis of carbon in international trade. **Biogeosciences**, v. 9, n. 8, p. 3247–3276, 2012. Disponível em: <https://bg.copernicus.org/articles/9/3247/2012/>.

PETERS, H.; VAN RAAN, A. Structuring scientific activities by co-author analysis: An expercise on a university faculty level. **Scientometrics**, v. 20, n. 1, p. 235–255, 1991.

PIKOŃ, K.; BOGACKA, M.; STANEK, W.; CZARNOWSKA, L. Energy efficiency evaluation of coal production. Em: International Multidisciplinary Scientific GeoConference Surveying Geology and Mining Ecology Management, SGEM, 5., 2015, [...]. 2015. v. 1, p. 259–266.

PINEM, S.; KARUNIASA, M.; ABDINI, C. Estimating GHG Emission Level from Oil and Gas Offshore Production Facility. **E3S Web of Conferences**, v. 202, p. 9004, 2020.

PITT, J. R.; LOPEZ-COTO, I.; HAJNY, K. D.; TOMLIN, J.; KAESER, R.; JAYARATHNE, T.; STIRM, B. H.; FLOERCHINGER, C. R.; LOUGHNER, C. P.; GATELY, C. K.; HUTYRA, L. R.; GURNEY, K. R.; ROEST, G. S.; LIANG, J.; GOURDJI, S.; KARION, A.; WHETSTONE, J. R.; SHEPSON, P. B. New York City Greenhouse Gas Emissions Estimated with Inverse of Aircraft Measurements. **Elementa (Wash., DC)**, v. 10, n. 1, jan. 2022.

PITTAU, F.; BANDE, L.; PASSERA, A.; BEACCO, D.; FUMAGALLI, C.; DE ANGELIS, E. Brownfields regeneration as a smart growth option and building technologies: The case study of “La Goccia Di Bovisa” in Milano. Em: 5th Brunei International Conference on Engineering and Technology (BICET 2014), 2014, [...]. IET, 2014. p. 1–7.

PONSTEIN, H. J.; GHINOI, S.; STEINER, B. How to increase sustainability in the Finnish wine supply chain? Insights from a country of origin based greenhouse gas emissions analysis. **Journal of Cleaner Production**, v. 226, p. 768–780, jul. 2019.

PONTE, V. M. R.; OLIVEIRA, M. C.; MOURA, H. J. de; BARBOSA, J. V. Análise das metodologias e técnicas de pesquisas adotadas nos estudos brasileiros sobre balanced scorecard: um estudo dos artigos publicados no período de 1999 a 2006. Em: Congresso ANPCONT, 2007, [...]. 2007. v. 1

PRADEEP, R. M. M. **How Ontology, Epistemology And Axiology Relate To Develop New Knowledge Through Research Methodology And Research Design**. [s.l: s.n.].

PRAPASPONGSA, T.; GHEEWALA, S. H. Consequential and attributional environmental assessment of biofuels: implications of modelling choices on climate change mitigation strategies. **International Journal of Life Cycle Assessment**, v. 22, n. 11, p. 1644–1657, nov. 2017.

PRICE, D. J. D. S. Networks of scientific papers: The pattern of bibliographic references indicates the nature of the scientific research front. **Science**, v. 149, n. 3683, p. 510–515, 1965.

PRITCHARD, A. Statistical bibliography or bibliometrics. **Journal of documentation**, v. 25, p. 348, 1969.

PRONTO, J. L.; GOOCH, C. A. Greenhouse gas emission reductions for seven on-farm dairy manure-based anaerobic digestion systems–final results. Em: International Symposium on Air Quality and Manure Management for Agriculture Conference Proceedings, 13-16 September 2010, Dallas, Texas, 2010, [...]. American Society of Agricultural and Biological Engineers, 2010. p. 5.

PUCKER-SINGER, J.; AICHBERGER, C.; ZUPAN\V CIČ, J.; NEUMANN, C.; BIRD, D. N.; JUNGMEIER, G.; GUBINA, A.; TUERK, A. Greenhouse Gas Emissions of Stationary Battery Installations in two Renewable Energy Projects. **Sustainability**, v. 13, n. 11, p. 6330, jun. 2021.

PUKITE, I.; GREKIS, A.; GEIPELE, I.; ZELTINS, N. Involvement of Individuals in the Development of Technical Solutions and Rules of Management for Building Renovation Projects: A Case Study of Latvia. **Latvian Journal of Physics and Technical Sciences**, v. 54, n. 4, p. 3–14, ago. 2017.

PULLIN, A. S.; STEWART, G. B. Guidelines for Systematic Review in Conservation and Environmental Management. **Conservation Biology**, v. 20, n. 6, p. 1647–1656, 1 dez. 2006. Disponível em: <https://doi.org/10.1111/j.1523-1739.2006.00485.x>.

QI, M.; XU, J.; AMUJI, N. B.; WANG, S.; XU, F.; ZHOU, H. The Nexus among Energy Consumption, Economic Growth and Trade Openness: Evidence from West Africa. **Sustainability (Switzerland)**, v. 14, n. 6, p. 3630, mar. 2022.

QIN, S.; CHANG, S. Modeling, thermodynamic and techno-economic analysis of coke production process with waste heat recovery. **Energy**, v. 141, p. 435–450, dez. 2017.

QIN, Y.; XU, Z.; WANG, X.; ŠKARE, M. Green energy adoption and its determinants: A bibliometric analysis. **Renewable and Sustainable Energy Reviews**, v. 153, p. 111780, 2022. Disponível em: <https://www.sciencedirect.com/science/article/pii/S1364032121010492>.

QIN, Z.; DUNN, J. B.; KWON, H.; MUELLER, S.; WANDER, M. M. Influence of Spatially Dependent, Modeled Soil Carbon Emission Factors on Life-cycle Greenhouse Gas Emissions of Corn and Cellulosic Ethanol. **GCB Bioenergy**, v. 8, n. 6, p. 1136–1149, nov. 2016.

RADICCHI, F.; CASTELLANO, C.; CECCONI, F.; LORETO, V.; PARISI, D.; PARISI, G. Defining and Identifying Communities in Networks. **Proceedings of the National Academy**

**of Sciences of the United States of America**, v. 101, n. 9, p. 2658–2663, 2004. Disponível em: <http://www.jstor.org/stable/3371085>.

RAMÍREZ, C. A.; BLOK, K.; NEELIS, M.; PATEL, M. Adding Apples and Oranges: The Monitoring of Energy Efficiency in the Dutch Food Industry. **Energy Policy**, v. 34, n. 14, p. 1720–1735, set. 2006.

RAMÍREZ, C. A.; PATEL, M.; BLOK, K. How much energy to process one pound of meat? A comparison of energy use and specific energy consumption in the meat industry of four European countries. **Energy**, v. 31, n. 12, p. 2047–2063, 2006a.

RAMÍREZ, C. A.; PATEL, M.; BLOK, K. From Fluid Milk to Milk Powder: Energy Use and Energy Efficiency in the European Dairy Industry. **Energy**, v. 31, n. 12, p. 1984–2004, set. 2006b.

RANGANATHAN, J.; CORBIER, L.; BHATIA, P.; SCHMITZ, S.; GAGE, P.; OREN, K. **GHG Protocol - The Corporate Accouting and Reporting Standard**. [s.l: s.n.].

RAUGEI, M.; BARGIGLI, S.; ULGIATI, S. Life Cycle Assessment and Energy Pay-Back Time of Advanced Photovoltaic Modules: CdTe and CIS Compared to Poly-Si. **Energy**, v. 32, n. 8, p. 1310–1318, ago. 2007.

RAZZAQ, A.; WANG, Y.; CHUPRADIT, S.; SUKSATAN, W.; SHAHZAD, F. Asymmetric Inter-Linkages between Green Technology Innovation and Consumption-Based Carbon Emissions in BRICS Countries Using Quantile-on-Quantile Framework. **Technology in Society**, v. 66, n. 101656, p. 101656, ago. 2021.

REJEB, A.; REJEB, K.; ABDOLLAHI, A.; AL-TURJMAN, F.; TREIBLMAIER, H. The Interplay between the Internet of Things and agriculture: A bibliometric analysis and research agenda. **Internet of Things**, v. 19, p. 100580, 2022. Disponível em: <https://www.sciencedirect.com/science/article/pii/S2542660522000701>.

RESCHER, N. **Peirce's Philosophy of Science: Critical Studies in His Theory of Induction and Scientific Method**. Notre Dame, USA: University of Notre Dame Press, 1978.

REUTER, M.; BUCHWITZ, M.; SCHNEISING, O.; KRAUTWURST, S.; O'DELL, C. W.; RICHTER, A.; BOVENSMANN, H.; BURROWS, J. P. Towards monitoring localized CO_2 emissions from space: co-located regional CO_2 and NO_2 enhancements observed by the OCO-2 and S5P satellites. **Atmospheric Chemistry and Physics**, v. 19, n. 14, p. 9371–9383, 2019. Disponível em: <https://acp.copernicus.org/articles/19/9371/2019/>.

REZA, M. S.; MANNAN, M.; WALI, S. bin; HANNAN, M. A.; JERN, K. P.; RAHMAN, S. A.; MUTTAQI, K. M.; MAHLIA, T. M. I. Energy storage integration towards achieving grid decarbonization: A bibliometric analysis and future directions. **Journal of Energy Storage**, v. 41, p. 102855, 2021. Disponível em: <https://www.sciencedirect.com/science/article/pii/S2352152X21005788>.

RICHE, J. P. LeanergyTM: How Lean Manufacturing Can Improve Energy Efficiency. **Chimia**, v. 67, n. 10, p. 700–702, 2013.

RITZ, B. Comparing abduction and retroduction in Peircean pragmatism and critical realism. **Journal of Critical Realism**, v. 19, n. 5, p. 456–465, 19 out. 2020. Disponível em: <https://doi.org/10.1080/14767430.2020.1831817>.

RODRIGUES, M. K.; VAZ, J.; OLIVEIRA ROCHA, L. A.; DOMINGUES DOS SANTOS, E.; ISOLDI, L. A. A Full Approach to Earth-Air Heat Exchanger Employing Computational Modeling, Performance Analysis and Geometric Evaluation. **Renewable Energy**, v. 191, p. 535–556, maio 2022.

ROEMER, R. C.; BORCHARDT, R. **Meaningful metrics: A 21st-century librarian's guide to bibliometrics, altmetrics, and research impact**. Chicago, USA: ACRL: Association of College and Research Libraries, 2015.

ROJAS-SÁNCHEZ, M. A.; PALOS-SÁNCHEZ, P. R.; FOLGADO-FERNÁNDEZ, J. A. Systematic literature review and bibliometric analysis on virtual reality and education. **Education and Information Technologies**, 2022. Disponível em: <https://doi.org/10.1007/s10639-022-11167-5>.

RONG-RONG, Z.; YANG, Y.; LI-QIANG, D. Greenhouse Gas Emission Analysis for Distributed Energy System. Em: 2008 2nd International Conference on Bioinformatics and Biomedical Engineering, 2008, [...]. IEEE, 2008. p. 3774–3777.

ROTH, J.; BROWN IV, H. A.; JAIN, R. K. Harnessing Smart Meter Data for a Multitiered Energy Management Performance Indicators (MEMPI) Framework: A Facility Manager Informed Approach. **Applied Energy**, v. 276, n. 115435, p. 115435, out. 2020.

SAGASTUME GUTIÉRREZ, A.; CABELLO ERAS, J. J.; SOUSA SANTOS, V.; HERNÁNDEZ HERRERA, H.; HENS, L.; VANDECASTEELE, C. Electricity management in the production of lead-acid batteries: The industrial case of a production plant in Colombia. **Journal of Cleaner Production**, v. 198, p. 1443–1458, 10 out. 2018.

SALEM SZKLO, A.; SOARES, J. B.; TOLMASQUIM, M. T. Energy Consumption Indicators and CHP Technical Potential in the Brazilian Hospital Sector. **Energy Conversion and Management**, v. 45, n. 13–14, p. 2075–2091, ago. 2004.

SALTA, M.; POLATIDIS, H.; HARALAMBOPOULOS, D. Energy use in the Greek manufacturing sector: A methodological framework based on physical indicators with aggregation and decomposition analysis. **Energy**, v. 34, n. 1, p. 90–111, 2009. Disponível em: <https://www.sciencedirect.com/science/article/pii/S0360544208002831>.

SALTA, M.; POLATIDIS, H.; HARALAMBOPOULOS, D. Industrial Combined Heat and Power (CHP) Planning: Development of a Methodology and Application in Greece. **Applied Energy**, v. 88, n. 5, p. 1519–1531, maio 2011.

SALVATORI, S.; BENEDETTI, M.; BONFÀ, F.; INTRONA, V.; UBERTINI, S. Inter-Sectorial Benchmarking of Compressed Air Generation Energy Performance: Methodology Based on Real Data Gathering in Large and Energy-Intensive Industrial Firms. **Applied Energy**, v. 217, p. 266–280, maio 2018.

SANDSTRÖM, V.; VALIN, H.; KRISZTIN, T.; HAVLÍK, P.; HERRERO, M.; KASTNER, T. The role of trade in the greenhouse gas footprints of EU diets. **Global Food Security**, v. 19, p. 48–55, dez. 2018.

SARKODIE, S. A.; OZTURK, I. Investigating the Environmental Kuznets Curve hypothesis in Kenya: A multivariate analysis. **Renewable and Sustainable Energy Reviews**, v. 117, p. 109481, jan. 2020.

SAUNDERS, M. N. K.; LEWIS, P.; THORNHILL, A. **Research methods for business students**. New York, USA: Pearson, 2019.

SCHALTEGGER, S.; CSUTORA, M. Carbon accounting for sustainability and management. Status quo and challenges. **Journal of Cleaner Production**, v. 36, p. 1–16, 2012.

SCIPIONI, A.; MANZARDO, A.; MAZZI, A.; MASTROBUONO, M. Monitoring the carbon footprint of products: a methodological proposal. **Journal of Cleaner Production**, v. 36, p. 94–101, nov. 2012a.

SCIPIONI, A.; MANZARDO, A.; MAZZI, A.; MASTROBUONO, M. Monitoring the carbon footprint of products: A methodological proposal. **Journal of Cleaner Production**, v. 36, p. 94–101, nov. 2012b.

SERGEY, K.; EVGENIY, D.; OLEKSANDR, P.; DMITRY, K. Model of forming and analysis of energy saving projects portfolio at metallurgical enterprises. Em: Advances in Intelligent Systems and Computing, 2020, Cham. [...]. Cham: Springer International Publishing, 2020. v. 1080 AISC, p. 304–314.

SEVIGNÉ-ITOIZ, E.; GASOL, C. M.; RIERADEVALL, J.; GABARRELL, X. Environmental consequences of recycling aluminum old scrap in a global market. **Resources, Conservation and Recycling**, v. 89, p. 94–103, ago. 2014.

SHALAPIN, A.; PETERS, M.; RAVIN, A. Local government action towards energy efficiency and sustainability. Em: Proceedings of the Air and Waste Management Association's Annual Conference and Exhibition, A&WMA, 2010, Cargary, Canada. [...]. Cargary, Canada: A&WMA, 2010.

SHAN, Y.; LIU, J.; LIU, Z.; XU, X.; SHAO, S.; WANG, P.; GUAN, D. New provincial CO2 emission inventories in China based on apparent energy consumption data and updated emission factors. **Applied Energy**, v. 184, p. 742–750, 2016. Disponível em: <https://www.sciencedirect.com/science/article/pii/S0306261916303932>.

SHEHZAD, W. Outlining Purposes, Stating the Nature of the Present Research, and Listing Research Questions or Hypotheses in Academic Papers. **Journal of Technical Writing and**

**Communication**, v. 41, n. 2, p. 139–160, 1 abr. 2011. Disponível em: <https://doi.org/10.2190/TW.41.2.c>.

SHERMAN, J.; LE, C.; LAMERS, V.; ECKELMAN, M. Life Cycle Greenhouse Gas Emissions of Anesthetic Drugs. **Anesthesia and Analgesia**, v. 114, n. 5, p. 1086–1090, abr. 2012.

SHI, J.; FAN, S.; WANG, Y.; CHENG, J. A GHG Emissions Analysis Method for Product Remanufacturing: A Case Study on a Diesel Engine. **Journal of Cleaner Production**, v. 206, p. 955–965, jan. 2019.

SHIM, H. S.; LEE, S. J. A study of determination of energy performance indicator for applying energy management system in industrial sector. Em: PICMET 2018 - Portland International Conference on Management of Engineering and Technology: Managing Technological Entrepreneurship: The Engine for Economic Growth, Proceedings, 2018, [...]. IEEE, 2018.

SHUAI, X. G.; LI, H. Q.; TANG, L. Life cycle assessment for the “implicit” environmental impact of construction projects. **Academic Journal of Xi’an Jiaotong University**, v. 21, n. 3, p. 167–171, set. 2009.

SIEBERT, L. C.; YAMAKAWA, E. K.; AOKI, A. R.; FERREIRA, L. R.; SANTOS, P. A.; SILVA, E. J.; KLINGUELFUS, G.; FILIPINI, F. A. Energy efficiency indicators assessment tool for the industry sector. Em: 2014 IEEE PES Transmission & Distribution Conference and Exposition - Latin America (PES T&D-LA), 2014, [...]. IEEE, 2014. p. 1–6.

SIITONEN, S.; RAUHAMÄKI, J. The role of natural gas in energy efficiency improvement. Em: International Gas Union World Gas Conference Papers, 2009, Foz do Iguaçú, Brazil. [...]. Foz do Iguaçú, Brazil: IGU, 2009. v. 5

SIITONEN, S.; TUOMAALA, M.; AHTILA, P. Variables Affecting Energy Efficiency and CO2 Emissions in the Steel Industry. **Energy Policy**, v. 38, n. 5, p. 2477–2485, maio 2010.

SILVA, C. Greenhouse Gas Emission Assessment of Simulated Wastewater Biorefinery. **Resources**, v. 10, n. 8, p. 78, jul. 2021.

SINDEN, G. The contribution of PAS 2050 to the evolution of international greenhouse gas emission standards. **The International Journal of Life Cycle Assessment**, v. 14, n. 3, p. 195–203, 30 maio 2009.

SINGH, A.; GUPTA, A. Best criteria selection based PROMETHEE II to aid decision-making under 2-tuple linguistic framework: case-study of the most energy efficient region worldwide. **International Journal of Management and Decision Making**, v. 19, n. 1, p. 44–65, 2020.

SINGH, N.; JAIN, C. P.; SHARMA, K. K.; JAIN, P. **CO2 Baseline Database for the Indian Power Sector**. [s.l: s.n.].

SINGH, V. K.; SINGH, P.; KARMAKAR, M.; LETA, J.; MAYR, P. The journal coverage of Web of Science, Scopus and Dimensions: A comparative analysis. **Scientometrics**, v. 126, n. 6, p. 5113–5142, 1 jun. 2021.

SJÖRS, C.; RAPOSO, S. E.; SJÖLANDER ARVID AND BÄLTER, O.; HEDENUS, F.; BÄLTER, K. Diet-Related Greenhouse Gas Emissions Assessed by a Food Questionnaire and Validated Using 7-Day Weighed Food. **Environ. Health**, v. 15, n. 1, p. 15, fev. 2016.

SMALL, H. Update on science mapping: Creating large document spaces. **Scientometrics**, v. 38, n. 2, p. 275–293, 1997. Disponível em: <https://app.dimensions.ai/details/publication/pub.1011169667>.

SOGUT, M. Z. Environmental Assessment of Entropy Control in Flight Process. **Aircraft Engineering and Aerospace Technology**, v. 93, n. 8, p. 1358–1366, set. 2021.

SOLOVYEV, I. G.; GOVORKOV, D. A.; KONSTANTINOV, I. v. Resource-energy efficiency of ESP-equipped wells operation management (approaches, models, methods). Em: 2021 IV International Conference on Control in Technical Systems (CTS), 2021, [...]. IEEE, 2021.

SOMMER, S. G.; OLESEN, J. E.; PETERSEN SØREN O AND WEISBJERG, M. R.; VALLI, L.; RODHE, L.; BÉLINE, F. Region-Specific Assessment of Greenhouse Gas Mitigation with different Manure Management Strategies in Four Agroecological. **Glob. Chang. Biol.**, v. 15, n. 12, p. 2825–2837, dez. 2009.

SOTOS, M. **GHG Protocol - Scope 2 Guidance**. [s.l: s.n.].

SOUSA, V.; BOGAS, J. A.; REAL, S.; MEIRELES, I. Industrial Production of Recycled Cement: Energy Consumption and Carbon Dioxide Emission Estimation. **Environmental Science and Pollution Research**, maio 2022.

SPENS, K. M.; KOVÁCS, G. A content analysis of research approaches in logistics research. **International Journal of Physical Distribution & Logistics Management**, v. 36, n. 5, p. 374–390, 1 jan. 2006. Disponível em: <https://doi.org/10.1108/09600030610676259>.

SPORK, C. C.; CHAVEZ, A.; DURANY, X. G.; PATEL, M. K.; MÉNDEZ, G. V. Increasing Precision in Greenhouse Gas Accounting Using Real-Time Emission Factors: A Case Study of Electricity in Spain. **Journal of Industrial Ecology**, v. 19, n. 3, p. 380–390, jun. 2015.

SRIDHAR, A.; PONNUCHAMY, M.; SENTHIL KUMAR, P.; KAPOOR, A.; XIAO, L. Progress in the production of hydrogen energy from food waste: A bibliometric analysis. **International Journal of Hydrogen Energy**, v. 47, n. 62, p. 26326–26354, 2022. Disponível em: <https://www.sciencedirect.com/science/article/pii/S0360319921038805>.

SSEF; CWF; ERNST & YOUNG LLP. **Developing methodology for baseline energy consumption for petroleum refinery subsector**. [s.l: s.n.].

STEPHAN, A.; CRAWFORD, R. H. A Multi-Scale Life-Cycle Energy and Greenhouse-Gas Emissions Analysis Model for Residential Buildings. **Architectural Science Review**, v. 57, n. 1, p. 39–48, jan. 2014.

SU, C.-W.; NAQVI, B.; SHAO, X.-F.; LI, J.-P.; JIAO, Z. Trade and technological innovation: The catalysts for climate change and way forward for COP21. **Journal of Environmental Management**, v. 269, p. 110774, set. 2020.

SUKMAWATI, N. N. Reflective Feedbacks and Project-Based Activities to Improve the Students' Writing Skill: An Exploratory Action Research. **Register Journal**, v. 13, n. 2, p. 315–332, 4 out. 2020.

SUR, R. L.; DAHM, P. History of evidence-based medicine. **Indian journal of urology: IJU: journal of the Urological Society of India**, v. 27, n. 4, p. 487, 2011.

SUTTON, A.; CLOWES, M.; PRESTON, L.; BOOTH, A. Meeting the review family: exploring review types and associated information retrieval requirements. **Health Information & Libraries Journal**, v. 36, n. 3, p. 202–222, 1 set. 2019. Disponível em: <https://doi.org/10.1111/hir.12276>.

TALLINI, A.; CEDOLA, L. Evaluation Methodology for Energy Efficiency Measures in industry and Service Sector. **Energy Procedia**, v. 101, p. 542–549, nov. 2016.

TAN, Z.; LIU, H.; ZELENY, C. Low-carbon design of public buildings based on BIM. **Journal of Mechanical Engineering Research and Developments**, v. 38, n. 1, p. 105–111, 2015.

TANAKA, K. Assessment of Energy Efficiency Performance Measures in Industry and Their Application for Policy. **Energy Policy**, v. 36, n. 8, p. 2887–2902, ago. 2008.

TANDON, A.; KAUR, P.; MÄNTYMÄKI, M.; DHIR, A. Blockchain applications in management: A bibliometric analysis and literature review. **Technological Forecasting and Social Change**, v. 166, p. 120649, 2021. Disponível em: <https://www.sciencedirect.com/science/article/pii/S0040162521000810>.

TAO, G.; JIANPING, W.; WENSHUN, W.; QING, L. Research on carbon footprint of urban settlement in China. Em: Manufacture Engineering and Environment Engineering, 2013, Southampton, UK. [...]. Southampton, UK: WIT Press, 2013.

TATARINOVA, N. v.; SUVOROV, D. M. Comparative and Optimizing Calculations of Energy Efficiency Indicators for Operation of CHP Plants Using the Normative Characteristics and Mathematical Models. Em: Lecture Notes in Electrical Engineering, 22., 2020, Cham. [...]. Cham: 2020. v. 641 LNEE, p. 637–646.

TAVARES, V.; LACERDA, N.; FREIRE, F. Embodied Energy and Greenhouse Gas Emissions Analysis of a prefabricated Modular House: The ``Moby'' Case Study. **J. Clean. Prod.**, v. 212, p. 1044–1053, mar. 2019.

THIELE, G.; JOHANNI, T.; SOMMER, D.; KRÜGER, J. Decomposition of a Cooling Plant for Energy Efficiency Optimization Using OptTopo. **Energies**, v. 15, n. 22, p. 8387, 9 nov. 2022.

TIAN, W.; AN, H.; LI, X.; LI, H.; QUAN, K.; LU, X.; BAI, H. CO2 Accounting Model and Carbon Reduction Analysis of Iron and Steel Plants Based on Intra- and Inter-Process Carbon Metabolism. **Journal of Cleaner Production**, v. 360, n. 132190, p. 132190, ago. 2022.

TIAN, Y.; ZHU, Q. GHG emission assessment of Chinese container terminals: A hybrid approach of IPCC and input-output analysis. **International Journal of Shipping and Transport Logistics**, v. 7, n. 6, p. 758–779, 2015.

TIEDEMANN, K. H. Canada's greenhouse emission policies: Modeling impacts on emissions, costs and benefits. Em: Modelling, Identification, and Control, 2010, Calgary,AB,Canada. [...]. Calgary,AB,Canada: ACTAPRESS, 2010.

TONG, L.-I.; CHANG, C.-W.; JIN, S.-E.; SAMINATHAN, R. Quantifying Uncertainty of Emission Estimates in National Gas Inventories Using Bootstrap Confidence Intervals. **Atmos. Environ. (1994)**, v. 56, p. 80–87, set. 2012.

TORRIE, R. D.; STONE, C.; LAYZELL, D. B. Reconciling Energy Efficiency and Energy Intensity Metrics: An Integrated Decomposition Analysis. **Energy Efficiency**, v. 11, n. 8, p. 1999–2016, dez. 2018.

TRANFIELD, D.; DENYER, D.; SMART, P. Towards a methodology for developing evidence-informed management knowledge by means of systematic review. **British journal of management**, v. 14, n. 3, p. 207–222, 2003.

TRINH, T. M. K. H.; DOH, J.-H. Building's life cycle embodied carbon emissions assessments: A review. Em: Joint Asia-Pacific Network for Housing Research and Australasian Housing Researchers Conference, 2018, Gold Coast, Australia. [...]. Gold Coast, Australia: Griffith University, 2018. p. 248–256.

TRUPIA, L.; PARRY, T.; NEVES, L. C.; LO PRESTI, D. Rolling resistance contribution to a road pavement life cycle carbon footprint analysis. **The International Journal of Life Cycle Assessment**, v. 22, n. 6, p. 972–985, 1 jun. 2017.

TRYBOI, O. v. Efficient biomass value chains for heat production from energy crops in Ukraine. **Energetika/Ehnergetika/Power Eng.**, v. 64, n. 2, set. 2018.

TURNER, D.; WILLIAMS, I.; KEMP, S.; WRIGHT, L.; COELLO, J.; MCMURTRY, E. Towards standardization in GHG quantification and reporting. **Carbon Management**, v. 3, n. 3, p. 223–225, 10 jun. 2012.

TURYAHIKAYO, E. Philosophical paradigms as the bases for knowledge management research and practice. **Knowledge Management & E-Learning: An International Journal**, v. 13, n. 2, p. 209–224, 2021.

UDDIN, N.; HOLTEDAHL, P. **Emission trading schemes - Avenues for unified accounting practicesJournal of Cleaner Production**2013.

UNEP. **Emissions Gap Report 2022: The Closing Window — Climate crisis calls for rapid transformation of societies**. Nairobi, Kenya: UNEP (United Nations Environment Programme), 2022.

USSIRI, D. A. N.; LAL, R. Long-Term Tillage Effects on Soil Carbon Storage and Carbon Dioxide Emissions in Continuous Corn Cropping System from an Alfisol in Ohio. **Soil and Tillage Research**, v. 104, n. 1, p. 39–47, jun. 2009.

VALENCIA-OCHOA, G.; CARDENAS, Y.; RAMOS, E.; MORALES, A.; CAMPO, J. Energy Saving in Industrial Process Based on the Equivalent Production Method to Calculate Energy Performance Indicators. **Chemical Engineering Transactions**, v. 57, p. 709–714, 20 mar. 2017. Disponível em: <https://www.cetjournal.it/index.php/cet/article/view/CET1757119>.

VAN ECK, N. J.; WALTMAN, L. Software survey: VOSviewer, a computer program for bibliometric mapping. **Scientometrics**, v. 84, n. 2, p. 523–538, 2010. Disponível em: <https://doi.org/10.1007/s11192-009-0146-3>.

VAN ECK, N. J.; WALTMAN, L. Visualizing Bibliometric Networks. *Em*: DING, Y.; ROUSSEAU, R.; WOLFRAM, D. **Measuring Scholarly Impact: Methods and Practice**. Cham: Springer International Publishing, 2014. p. 285–320.

VAN ECK, N. J.; WALTMAN, L. Citation-based clustering of publications using CitNetExplorer and VOSviewer. **Scientometrics**, v. 111, n. 2, p. 1053–1070, 2017. Disponível em: <https://doi.org/10.1007/s11192-017-2300-7>.

VIRTANEN, T.; TUOMAALA, M.; PENTTI, E. Energy efficiency complexities: A technical and managerial investigation. **Management Accounting Research**, v. 24, n. 4, p. 401–416, 2013. Disponível em: <https://www.sciencedirect.com/science/article/pii/S1044500513000450>.

VOOS, H. Lotka and information science. **Journal of the American Society for Information Science**, v. 25, n. 4, p. 270–272, 1974.

WALI, S. B.; HANNAN, M. A.; KER, P. J.; RAHMAN, M. S. A.; MANSOR, M.; MUTTAQI, K. M.; MAHLIA, T. M. I.; BEGUM, R. A. Grid-connected lithium-ion battery energy storage system: A bibliometric analysis for emerging future directions. **Journal of Cleaner Production**, v. 334, p. 130272, 2022. Disponível em: <https://www.sciencedirect.com/science/article/pii/S0959652621044371>.

WALTMAN, L.; VAN ECK, N. J. A new methodology for constructing a publication-level classification system of science. **Journal of the American Society for Information Science and Technology**, v. 63, n. 12, p. 2378–2392, 2012.

WALTMAN, L.; VAN ECK, N. J. A smart local moving algorithm for large-scale modularity-based community detection. **The European Physical Journal B**, v. 86, n. 11, p. 471, 2013. Disponível em: <https://doi.org/10.1140/epjb/e2013-40829-0>.

WALTMAN, L.; VAN ECK, N. J.; NOYONS, E. C. M. A unified approach to mapping and clustering of bibliometric networks. **Journal of Informetrics**, v. 4, n. 4, p. 629–635, 2010. Disponível em: <https://www.sciencedirect.com/science/article/pii/S1751157710000660>.

WALTMAN, L.; YAN, E.; VAN ECK, N. J. A recursive field-normalized bibliometric performance indicator: an application to the field of library and information science. **Scientometrics**, v. 89, n. 1, p. 301, 2011. Disponível em: <https://doi.org/10.1007/s11192-011-0449-z>.

WANG, Q.; ZHOU, P.; ZHAO, Z.; SHEN, N. Energy Efficiency and Energy Saving Potential in China: A Directional Meta-Frontier DEA Approach. **Sustainability**, v. 6, n. 8, p. 5476–5492, 2014. Disponível em: <https://www.mdpi.com/2071-1050/6/8/5476>.

WANG, Y.; ZHANG, H.; ZHANG, Z.; WANG, J. Development of an evaluating method for carbon emissions of manufacturing process plans. **Discrete Dynamics in Nature and Society**, v. 2015, p. 1–8, 2015.

WARNER, E.; ZHANG, Y.; INMAN, D.; HEATH, G. Challenges in the Estimation of Greenhouse Gas Emissions from Biofuel-Induced Global Land-Use Change. **Biofuels, Bioproducts and Biorefining**, v. 8, n. 1, p. 114–125, jan. 2014.

WEBER, C. L. Uncertainty and Variability in Product Carbon Footprinting: Case Study of a Server. **Journal of Industrial Ecology**, v. 16, n. 2, p. 203–211, abr. 2012.

WEBER, C. L.; JARAMILLO, P.; MARRIOTT, J.; SAMARAS, C. Uncertainty and variability in accounting for grid electricity in life cycle assessment. Em: 2009 IEEE International Symposium on Sustainable Systems and Technology, ISSST ’09 in Cooperation with 2009 IEEE International Symposium on Technology and Society, ISTAS, 2009, [...]. IEEE, 2009.

WEGENER, M.; LABELLE, R.; JERMAN, L. Unpacking Carbon Accounting Numbers: A Study of the Commensurability and Comparability of Corporate Greenhouse Gas Emission Disclosures. **Journal of Cleaner Production**, v. 211, p. 652–664, fev. 2019.

WEI, L.; FENG, X.; JIA, G. Construction and Application Analysis of Carbon Emission Influence Factor Model of Energy Consumption in Mining Industry. **Advances in Civil Engineering**, v. 2021, p. 1–12, dez. 2021.

WHITE, S. W. Net Energy Payback and CO2 Emissions from Three Midwestern Wind Farms: An Update. **Natural Resources Research**, v. 15, n. 4, p. 271–281, mar. 2006.

WIHERSAARI, M. **Aspects on bioenergy as a technical measure to reduce energy related greenhouse gas emissionsVTT Publications**. Espoo, Finland: VTT Technical Research Centre of Finland, 2005. .

WILLIAMS, V.; NOLAND, R. B. Variability of contrail formation conditions and the implications for policies to reduce the climate impacts of aviation. Em: Proceedings of the 6th USA/Europe Air Traffic Management Research and Development Seminar, ATM 2005, 4., 2005, [...]. Elsevier BV, 2005. v. 10, p. 244–253.

WILSON, J. **Essentials of Business Research: A Guide to Doing Your Research Project**. London, UK: SAGE Publications, 2014.

WINANTI, N.; HERMAWAN, A. D.; SINISUKA, N. I.; DINATA, I. S.; PUTRA SUBAWA, I. G. N.; PRIBADI, A.; WIADNYANA, N. G. R.; MAHENDRA, I. G. N. Greenhouse gas emission analysis of energy efficiency program at gilimanuk gas power plant, bali. Em: International Conference on High Voltage Engineering and Power Systems, ICHVEPS 2017 - Proceeding, 2017, [...]. IEEE, 2017. v. 2017- Janua, p. 219–224.

WORRELL, E.; CORSTEN, M.; GALITSKY, C. **Energy Efficiency Improvement and Cost Saving Opportunities for Petroleum Refineries An ENERGY STAR® Guide for Energy and Plant Managers**. Berkeley, USA: Lawrence Berkeley National Lab.(LBNL), Berkeley, CA (United States), 2015. .

WRI. **Climate Watch Historical GHG Emissions**. [s.l: s.n.]. Disponível em: <https://www.climatewatchdata.org/ghg-emissions>.

WU, L. M.; CHEN, B. S. Modeling of energy efficiency indicator for semiconductor industry. Em: IEEM 2007: 2007 IEEE International Conference on Industrial Engineering and Engineering Management, 2007, [...]. IEEE, 2007. p. 822–826.

WU, L.-M.; CHEN, B.-S.; BOR, Y.-C.; WU, Y.-C. Structure model of energy efficiency indicators and applications. **Energy Policy**, v. 35, n. 7, p. 3768–3777, 2007. Disponível em: <https://www.sciencedirect.com/science/article/pii/S0301421507000158>.

WU, P.; XIA, B.; WANG, X. **The contribution of ISO 14067 to the evolution of global greenhouse gas standards - A reviewRenewable and Sustainable Energy Reviews**Elsevier Ltd, 2015.

XIAO, W.; MIAO, Y.; FORTINO, G.; WU, D.; CHEN, M.; HWANG, K. Collaborative Cloud-Edge Service Cognition Framework for DNN Configuration Toward Smart IIoT. **IEEE Transactions on Industrial Informatics**, v. 18, n. 10, p. 7038–7047, out. 2022.

XU, H.; KONG, Y.; PENG, J.; SONG, X.; LIU, Y.; SU, Z.; LI, B.; GAO, C.; TIAN, W. Comprehensive Analysis of Important Parameters of Choline Chloride-Based Deep Eutectic Solvent Pretreatment of Lignocellulosic Biomass. **Bioresource Technology**, v. 319, n. 124209, p. 124209, jan. 2021a.

XU, K.; KANG, H.; WANG, W.; JIANG, P.; LI, N. Carbon Emission Estimation of Assembled Composite Concrete Beams during Construction. **Energies**, v. 14, n. 7, p. 1810, 24 mar. 2021b.

XU, X.; CHEN, X.; JIA, F.; BROWN, S.; GONG, Y.; XU, Y. Supply chain finance: A systematic literature review and bibliometric analysis. **International Journal of Production**

**Economics**, v. 204, p. 160–173, 2018. Disponível em: <https://www.sciencedirect.com/science/article/pii/S0925527318303098>.

YAN, E.; DING, Y.; JACOB, E. K. Overlaying communities and topics: an analysis on publication networks. **Scientometrics**, v. 90, n. 2, p. 499–513, 2012. Disponível em: <https://doi.org/10.1007/s11192-011-0531-6>.

YAN, W.; MINJUN, S. Co2 Emission Induced by Urban Household Consumption in China. **Chinese Journal of Population Resources and Environment**, v. 7, n. 3, p. 11–19, jan. 2009.

YAN, X.; MENG, Y. Carbon emissions calculation model of building based on PAS2050. **Advanced Materials Research**, v. 255–260, p. 1582–1586, maio 2011.

YAO, L.; LIU, J.; WANG, R. The carbon emissions embodied in Chinese household consumption by the driving factors. **Shengtai Xuebao/Acta Ecologica Sinica**, v. 31, n. 19, p. 5632–5637, 2011.

YIN, R. K. **Case Study Research: Design and Methods**. Thousand Oaks, USA: Sage Publications, Inc., 2014.

YU, Y.; JIN, Z.; QIU, J. Global Isotopic Hydrograph Separation Research History and Trends: A Text Mining and Bibliometric Analysis Study. **Water**, v. 13, n. 18, 2021. Disponível em: <https://www.mdpi.com/2073-4441/13/18/2529>.

YUCEL, R. Scientists' Ontological and Epistemological Views about Science from the Perspective of Critical Realism. **Science & Education**, v. 27, n. 5, p. 407–433, 2018. Disponível em: <https://doi.org/10.1007/s11191-018-9983-x>.

ZAMAN, D.; TIWARI, M. K.; GUPTA, A. K.; SEN, D. Performance Indicators-Based Energy Sustainability in Urban Water Distribution Networks: A State-of-Art Review and Conceptual Framework. **Sustainable Cities and Society**, v. 72, n. 103036, p. 103036, set. 2021.

ZEMANEK, D.; CHAMPAGNE, P.; MABEE, W. Review of Life-Cycle Greenhouse-Gas Emissions Assessments of Hydroprocessed Renewable Fuel (HEFA) from Oilseeds. **Biofuels, Bioproducts and Biorefining**, v. 14, n. 5, p. 935–949, set. 2020.

ZHAO, G.; GAO, X.; WANG, Z.; YANG, S.; DUAN, J.; HU, J.; GUO, X. A mechanism model for accurately estimating carbon emissions on a micro scale of iron-making system. **ISIJ International**, v. 59, n. 2, p. 381–390, maio 2019.

ZHAO, Y.; ZUO, H.; SHE, X.; WANG, G.; WANG, J. Key factors of CO2 emission analysis in iron and steel mill. Em: Proceedings of the 2018 7th International Conference on Energy, Environment and Sustainable Development (ICEESD 2018), 2018, Paris, France. [...]. Paris, France: Atlantis Press, 2018.

ZHAO, Z.; YANG, D.; KANG, T.; YUAN, Z.; ZHENG, H. Carbon emission estimation of a chemical tanker in the life cycle. Em: 2011 International Conference on Electric Information and Control Engineering, 2011, [...]. IEEE, 2011.

ZHOU, J. W.; WANG, Y.; WANG, C. L. A multiple energy complementary strategy considering CCHP and flexible load in active distribution network. Em: China International Conference on Electricity Distribution, CICED, 2018, [...]. IEEE, 2018. p. 1991–1996.

ZIMRING, J. C. Adding More Building Blocks of Human Reasoning to the Knowledge Problem. *Em*: ZIMRING, J. C. **What Science Is and How It Really Works**. Cambridge, UK: Cambridge University Press, 2019. p. 44–65.

ZIPF, G. K. The Unity of Nature, Least-Action, and Natural Social Science. **Sociometry**, v. 5, n. 1, p. 48–62, 1942. Disponível em: <http://www.jstor.org/stable/2784953>.

ZIPF, G. K. **Human behavior and the principle of least effort: An introduction to human ecology**. Cambridge, USA: Addison-Wesley Press, 1949. 573 p.

ŽUKAUSKAS, P.; VVEINHARDT, J.; ANDRIUKAITIENĖ, R. Philosophy and Paradigm of Scientific Research. *Em*: ??UKAUSKAS, P.; VVEINHARDT, J.; ANDRIUKAITIEN?, R. **Management Culture and Corporate Social Responsibility**. Rijeka: IntechOpen, 2018. p. Ch. 6.

# APPENDIX A. COMPLEMENTARY DATA TO ACCOUNTING ENERGY-RELATED GREENHOUSE GAS EMISSIONS

In Chapter 3 – Section 3.3 – Subsection 3.3.2, findings related to network analysis were presented and complementary data related to those findings are presented in the following tables. Bibliographic coupling, co-citation, co-authorship and citation networks were developed using different analysis units as sources, authors, countries and articles. Clusters were investigated according to TLS (Total Link Strength), number of links and/or number of citations. Top 3 vertex with highest TLS (or number of citations) for the five most relevant clusters in the networks presented in Figure 3.9, Figure 3.10 and Figure 3.11, and Figure 3.13 are detailed respectively in Table A.1, Table A.2, and Table A.3.

Table A.1 – Cluster analysis (TLS and Links) in networks from Figure 3.9

| | **Bibliographic coupling** | **Co-citation network** | **Citation network** |
|---|---|---|---|
| **Cluster #1** | Green | Yellow | Green |
| **Source** | Journal of Cleaner Production | Journal of Cleaner Production | Journal of Cleaner Production |
| **TLS** | 3465 | 70576 | 108 |
| **Links** | 58 | 288 | 28 |
| **Source** | Sustainable Cities and Society | Applied Energy | Environmental Science and Pollution Research |
| **TLS** | 340 | 36862 | 28 |
| **Links** | 39 | 259 | 11 |
| **Source** | Journal of Environmental Management | Energy and Buildings | Resources, Conservation, and Recycling |
| **TLS** | 311 | 23860 | 16 |
| **Links** | 49 | 194 | 7 |
| **Cluster #2** | Yellow | Green | Purple |
| **Source** | Sustainability (Switzerland) | Energy Policy | Applied Energy |
| **TLS** | 1501 | 41126 | 54 |
| **Links** | 52 | 279 | 21 |
| **Source** | Energy Policy | Journal of Industrial Ecology | Renewable and Sustainable Energy Reviews |
| **TLS** | 684 | 9248 | 16 |
| **Links** | 49 | 239 | 8 |
| **Source** | Carbon Management | Ecological Economics | Building and Environment |
| **TLS** | 180 | 3659 | 8 |
| **Links** | 35 | 125 | 7 |
| **Cluster #3** | Purple | Orange | Red |
| **Source** | Applied Energy | Renewable and Sustainable Energy Reviews | Energy Policy |
| **TLS** | 1270 | 35066 | 28 |
| **Links** | 48 | 276 | 14 |
| **Source** | Energy and Buildings | Energy | Journal of Industrial Ecology |
| **TLS** | 437 | 30489 | 11 |
| **Links** | 38 | 268 | 6 |

| | Bibliographic coupling | Co-citation network | Citation network |
|---|---|---|---|
| **Source** | IOP Conference Series: Earth and Environmental Science | Renewable Energy | Environmental Research Letters |
| **TLS** | 191 | 10449 | 7 |
| **Links** | 35 | 197 | 6 |
| **Cluster #4** | Blue | Red | Cyan |
| **Source** | Environmental Science and Pollution Research | Science of the Total Environment | Science of the Total Environment |
| **TLS** | 1034 | 19285 | 22 |
| **Links** | 47 | 286 | 9 |
| **Source** | Environmental Research Letters | Nature | International Journal of Environmental Research and Public Health |
| **TLS** | 403 | 12643 | 20 |
| **Links** | 44 | 287 | 12 |
| **Source** | Greenhouse Gases: Science and Technology | Science | Frontiers in Environmental Science |
| **TLS** | 364 | 10993 | 6 |
| **Links** | 45 | 275 | 5 |
| **Cluster #5** | Red | Blue | Yellow |
| **Source** | Renewable and Sustainable Energy Reviews | Environmental Science and Technology | Energies |
| **TLS** | 660 | 13731 | 12 |
| **Links** | 50 | 218 | 8 |
| **Source** | Energies | Bioresource technology | Transportation Research Part D: Transport and Environment |
| **TLS** | 656 | 10491 | 6 |
| **Links** | 53 | 203 | 5 |
| **Source** | Journal of Industrial Ecology | Journal of Environmental Management | Chemical Engineering and Research Design |
| **TLS** | 543 | 8624 | 5 |
| **Links** | 40 | 270 | 4 |

Source: Author's elaboration using VOSviewer (VAN ECK; WALTMAN, 2010)

Table A.2 – Cluster analysis (TLS and Links) in networks from Figure 3.10 and Figure 3.11

| | Citation network | Co-authorship network | | Citation network | Co-authorship network |
|---|---|---|---|---|---|
| **Cluster #1** | Green | Red | **Cluster #1** | Yellow | Green |
| **Author** | Cai B. | Zhang Y. | **Country** | China | China |
| **TLS** | 103 | 57 | **TLS** | 661 | 242 |
| **Links** | 49 | 45 | **Links** | 40 | 31 |
| **Author** | Liu C. | Zhang H. | **Country** | India | Japan |
| **TLS** | 38 | 36 | **TLS** | 45 | 53 |
| **Links** | 24 | 31 | **Links** | 15 | 18 |
| **Author** | Yang J. | Wang J. | **Country** | Singapore | New Zealand |
| **TLS** | 27 | 34 | **TLS** | 45 | 26 |
| **Links** | 21 | 31 | **Links** | 14 | 20 |
| **Cluster #2** | Brown | Blue | **Cluster #2** | Green | Cyan |
| **Author** | Zhang Y. | Liu Y. | **Country** | USA | USA |
| **TLS** | 54 | 46 | **TLS** | 458 | 230 |
| **Links** | 31 | 37 | **Links** | 39 | 41 |
| **Author** | Zhang J. | Li J. | **Country** | Germany | United Kingdom |
| **TLS** | 37 | 49 | **TLS** | 89 | 189 |
| **Links** | 27 | 38 | **Links** | 29 | 40 |
| **Author** | He J. | Zhang C. | **Country** | Japan | Netherlands |
| **TLS** | 31 | 29 | **TLS** | 89 | 91 |
| **Links** | 21 | 21 | **Links** | 29 | 27 |

| | Citation network | Co-authorship network | | Citation network | Co-authorship network |
|---|---|---|---|---|---|
| **Cluster #3** | Blue | Green | **Cluster #3** | Blue | Red |
| **Author** | Wang J. | Zhang X. | **Country** | United Kingdom | Germany |
| **TLS** | 52 | 42 | **TLS** | 286 | 122 |
| **Links** | 37 | 31 | **Links** | 37 | 33 |
| **Author** | Wang Z. | Wang C. | **Country** | Netherlands | France |
| **TLS** | 39 | 27 | **TLS** | 78 | 79 |
| **Links** | 33 | 22 | **Links** | 20 | 27 |
| **Author** | Liu Y. | Li Z. | **Country** | Indonesia | Sweden |
| **TLS** | 34 | 24 | **TLS** | 29 | 71 |
| **Links** | 22 | 23 | **Links** | 13 | 28 |
| **Cluster #4** | Red | Yellow | **Cluster #4** | Purple | Purple |
| **Author** | Wang H. | Zhang J. | **Country** | Canada | Australia |
| **TLS** | 46 | 36 | **TLS** | 95 | 116 |
| **Links** | 34 | 29 | **Links** | 24 | 33 |
| **Author** | Zhang L. | Yang Y. | **Country** | New Zealand | Malaysia |
| **TLS** | 39 | 26 | **TLS** | 42 | 33 |
| **Links** | 31 | 18 | **Links** | 14 | 19 |
| **Author** | Wang B. | Wang Z. | **Country** | Philippines | Pakistan |
| **TLS** | 36 | 24 | **TLS** | 28 | 32 |
| **Links** | 33 | 21 | **Links** | 11 | 14 |
| **Cluster #5** | Yellow | Purple | **Cluster #5** | Red | Blue |
| **Author** | Wang M. | Zhang Z. | **Country** | Norway | Canada |
| **TLS** | 38 | 28 | **TLS** | 85 | 63 |
| **Links** | 21 | 25 | **Links** | 20 | 20 |
| **Author** | Zhou Y. | Sun Y. | **Country** | Austria | Turkey |
| **TLS** | 35 | 27 | **TLS** | 75 | 24 |
| **Links** | 27 | 26 | **Links** | 20 | 12 |
| **Author** | Zhang H. | Wang L. | **Country** | Turkey | Poland |
| **TLS** | 34 | 27 | **TLS** | 58 | 24 |
| **Links** | 25 | 23 | **Links** | 16 | 12 |

Source: Author's elaboration using VOSviewer (VAN ECK; WALTMAN, 2010)

Table A.3 – Cluster analysis (TSL/Citation and Links) in networks from Figure 3.13

| | Bibliographic coupling | | Citation network |
|---|---|---|---|
| **Cluster #1** | Cyan | **Cluster #1** | Brown |
| **Article** | (Chau et al., 2015) | **Article** | (Z. Liu et al., 2015) |
| **TLS** | 157 | **Citations** | 907 |
| **Links** | 43 | **Links** | 18 |
| **Article** | (FENNER et al., 2018) | **Article** | (CHEN et al., 2018) |
| **Citations** | 115 | **Citations** | 86 |
| **TLS** | 48 | **Links** | 1 |
| **Article** | (LU et al., 2019) | **Article** | (PENG et al., 2018) |
| **Citations** | 64 | **Citations** | 86 |
| **TLS** | 23 | **Links** | 1 |
| **Cluster #3** | Brown | **Cluster #2** | Cyan |
| **Article** | (PETERS; DAVIS; ANDREW, 2012) | **Article** | (Chau et al., 2015) |
| **Citations** | 118 | **Citations** | 449 |
| **TLS** | 45 | **Links** | 14 |
| **Article** | (CHEN et al., 2018) | **Article** | (FENNER et al., 2018) |
| **Citations** | 79 | **Citations** | 88 |
| **TLS** | 38 | **Links** | 7 |
| **Article** | (BARRETT et al., 2013) | **Article** | (LU et al., 2019) |
| **Citations** | 75 | **Citations** | 37 |
| **TLS** | 30 | **Links** | 7 |
| **Cluster #4** | Yellow | **Cluster #3** | Green |

| | Bibliographic coupling | | Citation network |
|---|---|---|---|
| **Article** | (BAI et al., 2016) | **Article** | (HONDO, 2005) |
| **Citations** | 93 | **Citations** | 421 |
| **TLS** | 44 | **Links** | 5 |
| **Article** | (MINX *et al.*, 2013) | **Article** | (DOLAN; HEATH, 2012) |
| **Citations** | 77 | **Citations** | 140 |
| **TLS** | 12 | **Links** | 4 |
| **Article** | (CHAVEZ; RAMASWAMI, 2011) | **Article** | (WARNER *et al.*, 2014) |
| **Citations** | 63 | **Citations** | 110 |
| **TLS** | 35 | **Links** | 3 |
| **Cluster #2** | Purple | **Cluster #4** | Yellow |
| **Article** | (LI et al., 2018) | **Article** | (GUAN et al., 2012) |
| **Citations** | 78 | **Citations** | 406 |
| **TLS** | 40 | **Links** | 12 |
| **Article** | (SHAN et al., 2016) | **Article** | (REUTER et al., 2019) |
| **Citations** | 70 | **Citations** | 65 |
| **TLS** | 41 | **Links** | 2 |
| **Article** | (JING et al., 2018) | **Article** | (CAO et al., 2016b) |
| **Citations** | 62 | **Citations** | 45 |
| **TLS** | 33 | **Links** | 3 |
| **Cluster #5** | Pink | **Cluster #5** | Light green |
| **Article** | (CAI; ZHANG, 2014) | **Article** | (KHAN *et al.*, 2020b) |
| **Citations** | 53 | **Citations** | 275 |
| **TLS** | 30 | **Links** | 3 |
| **Article** | (KONOVALOV et al., 2016) | **Article** | (PETERS; DAVIS; ANDREW, 2012) |
| **Citations** | 46 | **Citations** | 235 |
| **TLS** | 26 | **Links** | 4 |
| **Article** | (DAVIS et al., 2017) | **Article** | (KHAN et al., 2020a) |
| **Citations** | 45 | **Citations** | 113 |
| **TLS** | 22 | **Links** | 4 |

Source: Author's elaboration using VOSviewer (VAN ECK; WALTMAN, 2010)

A thematic map was displayed in Figure 3.15 and details of the investigation of its clusters are presented in Table A.4, regarding top keywords associated to each cluster, and in Table A.5, concerning top 3 articles for each cluster.

Table A.4 – Thematic map clusters' top keywords

| Cluster | Keywords | | Occurrences |
|---|---|---|---|
| Cluster #1 (purple) | ghg emissions | | 237 |
| | life cycle assessment (lca) | | 215 |
| | carbon footprint (cf) | | 78 |
| | sustainability | | 44 |
| | energy efficiency | | 30 |
| | | TOTAL | 742 |
| Cluster #2 (blue) | greenhouse gases | | 131 |
| | climate change | | 80 |
| | carbon dioxide (co2) | | 67 |
| | emissions | | 46 |
| | methane (ch4) | | 43 |
| | | TOTAL | 617 |
| Cluster #3 (pink) | carbon emissions | | 217 |
| | co2 emissions | | 146 |
| | energy consumption | | 39 |
| | china | | 29 |
| | input-output analysis | | 17 |
| | | TOTAL | 566 |

| Cluster | Keywords | | Occurrences |
|---|---|---|---|
| Cluster #4 (grey) | lmdi | | 23 |
| | scenario analysis | | 15 |
| | energy savings | | 13 |
| | carbon emission accounting | | 11 |
| | influencing factors | | 9 |
| | | TOTAL | 71 |
| Cluster #5 (brown) | ghg emission accounting | | 13 |
| | ghg emission inventory | | 13 |
| | low carbon | | 13 |
| | cities | | 11 |
| | mitigation | | 9 |
| | | TOTAL | 59 |
| Cluster #6 (orange) | embodied carbon emissions | | 12 |
| | international trade | | 12 |
| | | TOTAL | 24 |
| Cluster #7 (green) | carbon emission reduction | | 10 |
| | carbon emission measurement | | 9 |
| | | TOTAL | 19 |
| Cluster #8 (light pink) | techno-economic analysis | | 11 |
| | | TOTAL | 11 |
| Cluster #9 (light grey) | consumption-based carbon emissions | | 10 |
| | | TOTAL | 10 |

Source: Author's elaboration using data processed in Bibliometrix (ARIA; CUCCURULLO, 2017)

Table A.5 – Top 3 most relevant documents of each thematic map cluster

| Cluster and documents | BP(%) | PR |
|---|---|---|
| **Cluster #1 (purple)** | | |
| Does car sharing reduce greenhouse gas emissions? Assessing the modal shift and lifetime shift rebound effects from a life cycle perspective (AMATUNI et al., 2020) | 100 | 0.175 |
| Do greenhouse gas emission calculations from energy crop cultivation reflect actual agricultural management practices? – a review of carbon footprint calculators (PETER; HELMING; NENDEL, 2017) | 100 | 0.175 |
| Rolling resistance contribution to a road pavement life cycle carbon footprint analysis (TRUPIA et al., 2017) | 100 | 0.175 |
| **Cluster #2 (blue)** | | |
| Legacy effects of individual crops affect $N_2O$ emissions accounting within crop rotations (ADLER et al., 2018) | 94 | 0.190 |
| Mitigation of greenhouse gas emissions from beef production in Western Canada - evaluation using farm-based life cycle assessment (BEAUCHEMIN et al., 2011) | 95 | 0.181 |
| Yields and greenhouse gas emissions of cultivation of red clover-grass leys as assessed by LCA when fertilised with organic or mineral fertilisers (HAKALA et al., 2012) | 89 | 0.185 |
| **Cluster #3 (pink)** | | |
| Energy consumption and energy-related CO2 emissions from China's petrochemical industry based on an environmental input-output life cycle assessment (MENG; SAGER, 2017) | 78 | 0.208 |
| Life cycle energy use and GHG emission assessment of coal based SNG and power cogeneration technology in China (LI; GAO; JIN, 2016) | 93 | 0.154 |
| Comparative life cycle assessment of hydrogen and other selected fuels (HACATOGLU; ROSEN; DINCER, 2012) | 93 | 0.154 |
| **Cluster #4 (grey)** | | |
| How to increase sustainability in the Finnish wine supply chain? Insights from a country of origin-based greenhouse gas emissions analysis (PONSTEIN; GHINOI; STEINER, 2019) | 88 | 0.155 |
| Energy consumption and carbon emission analysis of natural graphite anode material for lithium batteries (GAO et al., 2018) | 89 | 0.135 |

| Cluster and documents | BP(%) | PR |
|---|---|---|
| Life cycle building carbon emissions assessment and driving factors decomposition analysis based on lmdi – A cas(Y. Gong & Song, 2015)in China (GONG; SONG, 2015) | 82 | 0.137 |
| **Cluster #5 (brown)** | | |
| A life cycle assessment of environmental and economic balance of biochar systems in Quebec (DUTTA; RAGHAVAN, 2014) | 84 | 0.184 |
| City level carbon mitigation strategies: What are their true impacts? (HEINONEN; KYRÖ; JUNNILA, 2012) | 84 | 0.184 |
| Carbon metrics for cities: Production and consumption implications for policies (BALOUKTSI, 2020) | 92 | 0.107 |
| **Cluster #6 (orange)** | | |
| Environmental consequences of recycling aluminum old scrap in a global market (SEVIGNÉ-ITOIZ et al., 2014) | 87 | 0.133 |
| Life cycle embodied, operational and mobility-related energy and greenhouse gas emissions analysis of a green development in Melbourne, Australia (LARA ALLENDE; STEPHAN, 2022) | 94 | 0.088 |
| The role of trade in the greenhouse gas footprints of EU diets (SANDSTRÖM et al., 2018) | 51* | 0.043 |
| **Cluster #7 (green)** | | |
| Carbon emission estimation of assembled composite concrete beams during construction (XU et al., 2021b) | 92 | 0.134 |
| Low-carbon design of public buildings based on BIM (TAN; LIU; ZELENY, 2015) | 96 | 0.087 |
| Decomposition analysis of carbon emissions from energy consumption in Beijing-Tianjin-Hebei, China: A weighted-combination model based on logarithmic mean divisia index and shapley value (LIANG et al., 2018) | 72 | 0.010 |
| **Cluster #8 (light pink)** | | |
| Cost-effectiveness of small-scale biomass supply chain and bioenergy production systems in carbon credit markets: a life cycle perspective (AHMADI; KANNANGARA; BENSEBAA, 2020) | 95 | 0.087 |
| Production of marine biofuels from hydrothermal liquefaction of sewage sludge. Preliminary techno-economic analysis and life cycle GHG emissions assessment of Dutch case study (LOZANO et al., 2022) | 95 | 0.087 |
| Modelling, thermodynamic and techno-economic analysis of coke production process with waste heat recovery (QIN; CHANG, 2017) | 93 | 0.030 |
| **Cluster #9 (light grey)** | | |
| Consumption-based carbon emissions and international trade in G7 countries: The role of environmental innovation and renewable energy (Z. Khan et al., 2020) | 55** | 0.009 |
| Trade and technological innovation: The catalysts for climate change and way forward for COP21 (SU et al., 2020) | 55** | 0.009 |
| Environmental R&D and trade-adjusted carbon emissions: Evaluating the role of international trade (JIANG et al., 2022b) | 55** | 0.009 |
| * 49% remaining attributed to Cluster #2 (blue)<br>** 45% remaining attributed to Cluster #6 (orange) | | |

Source: Author’s elaboration using data processed in Bibliometrix (ARIA; CUCCURULLO, 2017)

The thematic evolution with author’s keywords as analysis unit was displayed in Figure 3.16 and for each of its time slices (TS) a thematic map was developed. Details of the investigation of these clusters are presented in the following tables. Top keywords associated to each cluster are presented in Table A.6, Table A.8, Table A.10, Table A.12, and Table A.14. Top 3 articles for each cluster are exhibited in Table A.7, Table A.9, Table A.11, Table A.13, and Table A.15.

Table A.6 – Thematic map clusters' top keywords – 1st time slice (2000 – 2006)

| Cluster | Keywords | Occurrences |
|---|---|---|
| Cluster #1 (green) | greenhouse gases | 4 |
| | bioenergy | 2 |
| | biofuels | 2 |
| | biomass production | 2 |
| | emissions | 2 |
| | TOTAL | 22 |
| Cluster #2 (red) | carbon dioxide (co2) | 3 |
| | ghg emissions | 3 |
| | europe | 2 |
| | TOTAL | 8 |
| Cluster #3 (orange) | co2 emissions | 4 |
| | TOTAL | 4 |
| Cluster #4 (blue) | electricity | 2 |
| | life cycle assessment (lca) | 2 |
| | TOTAL | 4 |
| Cluster #5 (purple) | climate change | 3 |
| | TOTAL | 3 |

Source: Author's elaboration using data processed in Bibliometrix (ARIA; CUCCURULLO, 2017)

Table A.7 – Top 3 most relevant documents of each thematic map cluster – 1st time slice (2000 – 2006)

| Cluster and documents | BP (%) | PR |
|---|---|---|
| **Cluster #1 (green)** | | |
| Methane emissions from enteric fermentation in Alberta's beef cattle population (BASARAB et al., 2005) | 100 | 0.016 |
| $CO_2$ recovery and reuse in the energy sector, energy resource development and others: economic and technical evaluation of large-scale $CO_2$ recycling (KIKUCHI, 2003) | 100 | 0.016 |
| Aspects on bioenergy as a technical measure to reduce energy related greenhouse gas emissions (WIHERSAARI, 2005) | 100 | 0.010 |
| **Cluster #2 (red)** | | |
| Economic and greenhouse gas emission analysis of bioenergy production using multi-product crops - case studies for the Netherlands and Poland (DORNBURG; TERMEER; FAAIJ, 2005) | 100 | 0.034 |
| Impacts of urbanization on land-atmosphere carbon exchange within a metropolitan area in the USA (DIEM; RICKETTS; DEAN, 2006) | 100 | 0.028 |
| A dense and sickly mist from thousands of bog fires: An attempt to compare the energy consumption in slash-and-burn cultivation and burning cultivation of peatlands in Finland in 1820-1920 (KUNNAS, 2005) | 100 | 0.028 |
| **Cluster #3 (orange)** | | |
| Boundary problem in carbon emission decomposition (ANG; CHOI, 2002) | 100 | 0.018 |
| Measures for climate protection in Mediterranean cities: The implementation of Medclima project by municipality of Palermo (KARNIADAKI et al., 2005) | 100 | 0.018 |
| GIS-based assessment of $CO_2$ emission caused by automobile trips for shopping, case study in Muko river basin region (KHALED; FUJITA; MORIOKA, 2004) | 100 | 0.018 |
| **Cluster #4 (blue)** | | |
| Net energy payback and $CO_2$ emissions from three midwestern wind farms: An update (WHITE, 2006) | 100 | 0.023 |
| Environmental aspects of ethanol derived from no-tilled corn grain: Non-renewable energy consumption and greenhouse gas emissions (KIM; DALE, 2005) | 100 | 0.013 |
| The differences that methods make: Cross-border power flows and accounting for carbon emissions from electricity use (JIUSTO, 2006) | 100 | 0.011 |
| **Cluster #5 (purple)** | | |
| Federal fossil fuel subsidies and greenhouse gas emissions: A case study of increasing transparency for fiscal policy (KOPLOW; DERNBACH, 2001) | 100 | 0.017 |

| Cluster and documents | BP (%) | PR |
|---|---|---|
| Variability of contrail formation conditions and the implications for policies to reduce the climate impacts of aviation (WILLIAMS; NOLAND, 2005) | 100 | 0.017 |
| Stabilizing greenhouse gas emissions: assessing the intergenerational costs and benefits of the Kyoto protocol (KAVUNCU; KNABB, 2005) | 100 | 0.017 |

Source: Author's elaboration using data processed in Bibliometrix (ARIA; CUCCURULLO, 2017)

Table A.8 – Thematic map clusters' top keywords – 2nd time slice (2007 – 2010)

| Cluster | Keywords | Occurrences |
|---|---|---|
| Cluster #1 (blue) | greenhouse gases | 18 |
| | climate change | 8 |
| | life cycle assessment (lca) | 7 |
| | methane (ch4) | 7 |
| | carbon dioxide (co2) | 6 |
| | TOTAL | 69 |
| Cluster #2 (brown) | ghg emissions | 14 |
| | carbon emissions | 5 |
| | emission inventories | 2 |
| | energy efficiency | 2 |
| | industrial ecology | 2 |
| | TOTAL | 27 |
| Cluster #3 (orange) | emissions | 7 |
| | energy sources | 3 |
| | costs | 2 |
| | infrastructure | 2 |
| | performance | 2 |
| | TOTAL | 16 |
| Cluster #4 (mint) | co2 emissions | 9 |
| | input-output model | 2 |
| | TOTAL | 11 |
| Cluster #5 (lavander) | biomass | 4 |
| | anaerobic digestion | 2 |
| | gasification | 2 |
| | waste | 2 |
| | TOTAL | 10 |
| Cluster #6 (rose/orange) | carbon sequestration | 2 |
| | transportation | 2 |
| | TOTAL | 4 |

Source: Author's elaboration using data processed in Bibliometrix (ARIA; CUCCURULLO, 2017)

Table A.9 – Top 3 most relevant documents of each thematic map cluster – 2nd time slice (2007 – 2010)

| Cluster and documents | BP (%) | PR |
|---|---|---|
| **Cluster #1 (blue)** | | |
| Canada's greenhouse emission policies: Modeling impacts on emissions, costs and benefits (TIEDEMANN, 2010) | 89 | 0.105 |
| Greenhouse gas (GHG) emissions from broiler houses in the South-eastern United States (BURNS et al., 2008) | 100 | 0.086 |
| Greenhouse gas emissions from heavy-duty vehicles (GRAHAM et al., 2008) | 100 | 0.073 |
| **Cluster #2 (brown)** | | |
| Local government action towards energy efficiency and sustainability (SHALAPIN; PETERS; RAVIN, 2010) | 72 | 0.079 |
| Impact of power generation mix on life cycle assessment and carbon footprint greenhouse gas results (MARRIOTT; MATTHEWS; HENDRICKSON, 2010) | 100 | 0.052 |
| Uncertainty analysis in biofuel systems (MALÇA; FREIRE, 2010) | 100 | 0.048 |
| **Cluster #3 (orange)** | | |

| Cluster and documents | BP (%) | PR |
|---|---|---|
| Production and use of hydrogen-regional energy systems analysis of Oslo, Telemark and Rogaland (ESPEGREN et al., 2009) | 90 | 0.048 |
| Greenhouse gas emissions assessment of hydrogen and kerosene-fueled aircraft propulsion (NOJOUMI; DINCER; NATERER, 2009) | 69 | 0.061 |
| Turkey's energy policy and investment plans (ONAT; BAYAR. H., 2010) | 82 | 0.041 |
| **Cluster #4 (mint)** | | |
| A model for China's energy requirements and co2 emissions analysis (FAN et al., 2007) | 100 | 0.022 |
| $CO_2$ emission induced by urban household consumption in China (YAN; MINJUN, 2009) | 100 | 0.022 |
| $CO_2$ emissions of international freight transport and offshoring: measurement and allocation (CADARSO et al., 2010) | 100 | 0.017 |
| **Cluster #5 (lavander)** | | |
| Economic assessment of regional bioenergy systems in Australia: a flow analysis application (JAKRAWATANA; MOORE; MACGILL, 2009) | 94 | 0.114 |
| Greenhouse gas emission reductions for seven on-farm dairy manure-based anaerobic digestion systems - final results (PRONTO; GOOCH, 2010) | 90 | 0.048 |
| Comparative analysis of large biomass & coal co-utilization units (LISZKA; NOWAK; PTASINSKI, 2010) | 100 | 0.020 |
| **Cluster #6 (pink/orange)** | | |
| Greenhouse gas and climate change assessment: Framing a transportation research agenda (MEYER, 2010) | 72 | 0.064 |
| Region-specific assessment of greenhouse gas mitigation with different manure management strategies in four agroecological zones (SOMMER et al., 2009) | 62 | 0.038 |
| Long-term tillage effects on soil carbon storage and carbon dioxide emissions in continuous corn cropping system from an alfisol in Ohio (USSIRI; LAL, 2009) | 100 | 0.006 |

Source: Author's elaboration using Biblioshiny (ARIA; CUCCURULLO, 2017)

Table A.10 – Thematic map clusters' top keywords – 3rd time slice (2011 – 2014)

| Cluster | Keywords | Occurrences |
|---|---|---|
| Cluster #1 (orange) | ghg emissions | 49 |
| | life cycle assessment (lca) | 45 |
| | greenhouse gases | 33 |
| | climate change | 13 |
| | methane (ch4) | 7 |
| | TOTAL | 220 |
| Cluster #2 (mint) | carbon emissions | 38 |
| | energy consumption | 12 |
| | China | 7 |
| | low carbon | 6 |
| | low-carbon economy | 5 |
| | TOTAL | 84 |
| Cluster #3 (lavander) | carbon footprint (cf) | 19 |
| | carbon dioxide (co2) | 16 |
| | emissions | 14 |
| | energy | 6 |
| | logistics | 3 |
| | TOTAL | 58 |
| Cluster #4 (purple) | co2 emissions | 18 |
| | scenario analysis | 4 |
| | TOTAL | 22 |
| Cluster #5 (rose) | sustainability | 12 |
| | energy efficiency | 7 |
| | TOTAL | 19 |
| Cluster #6 (light grey) | emission factors | 3 |
| | emission inventories | 3 |
| | TOTAL | 6 |
| Cluster #7 | uncertainties | 4 |

| Cluster | Keywords | Occurrences |
|---|---|---|
| (blue) | TOTAL | 4 |

Source: Author's elaboration using data processed in Bibliometrix (ARIA; CUCCURULLO, 2017)

Table A.11 – Top 3 most relevant documents of each thematic map cluster – 3rd time slice (2011 – 2014)

| Cluster and documents | BP (%) | PR |
|---|---|---|
| **Cluster #1 (orange)** | | |
| Life cycle greenhouse gas emissions of utility-scale wind power: systematic review and harmonization (SHERMAN et al., 2012) | 100 | 0.145 |
| A life cycle assessment of environmental and economic balance of biochar systems in Quebec (DUTTA; RAGHAVAN, 2014) | 100 | 0.141 |
| City level carbon mitigation strategies: what are their true impacts? (HEINONEN; KYRÖ; JUNNILA, 2012) | 100 | 0.141 |
| **Cluster #2 (mint)** | | |
| LCA energy consumption and carbon emission analysis for residential partition in hot summer and cold winter zone (JIANG; SU, 2011) | 83 | 0.117 |
| Low-carbon building assessment and multi-scale input-output analysis (CHEN et al., 2011) | 94 | 0.105 |
| Quantification of carbon emission reduction by U-transportation service effect: A case study of Dongtan U-city (JUNG; PYEON; KOO, 2012) | 92 | 0.090 |
| **Cluster #3 (lavander)** | | |
| Research on carbon footprint of urban settlement in China (TAO et al., 2013) | 52* | 0.122 |
| Life cycle energy use and greenhouse gas emission analysis for a water resource recovery facility in India (MILLER-ROBBIE; RAMASWAMI; KUMAR, 2013) | 76 | 0.115 |
| The study of urban metabolism and its applications to urban planning and design (KENNEDY; PINCETL; BUNJE, 2011) | 89 | 0.065 |
| **Cluster #4 (purple)** | | |
| The carbon emissions embodied in Chinese household consumption by the driving factors (YAO; LIU; WANG, 2011) | 71 | 0.075 |
| Carbon emission estimation of a chemical tanker in the life cycle (ZHAO et al., 2011) | 71 | 0.075 |
| Development of assessment index and assessment technique using a case analysis for carbon emissions in apartment buildings in Korea (CHOI et al., 2014) | 71 | 0.075 |
| **Cluster #5 (rose)** | | |
| Brownfields regeneration as a smart growth option and building technologies: the case study of "La Goccia di Bovisa" in Milano (PITTAU et al., 2014) | 91 | 0.086 |
| The impact of reducing greenhouse gas emissions in crop agriculture: a spatial- and production-level analysis (NALLEY; POPP; FORTIN, 2011) | 80 | 0.072 |
| Lessons learned from IRWD - Setting boundary conditions at their WWTP when estimating GHG emissions for their sustainability evaluation (FALK et al., 2013) | 80 | 0.072 |
| **Cluster #6 (light grey)** | | |
| A multitower measurement network estimate of California's methane emissions (JEONG et al., 2013) | 66 | 0.062 |
| Comprehensive greenhouse gases inventory for the state of Ohio (GHOSH; KIM; CRIST, 2012) | 96 | 0.056 |
| A review of system boundaries of GHG emission inventories in waste management (BRASCHEL; POSCH, 2013) | 92 | 0.051 |
| **Cluster #7 (blue)** | | |
| Perspectives on greenhouse gas emission estimates based on Australian wastewater treatment plant operating data (DE HAAS; PEPPERELL; FOLEY, 2014) | 93 | 0.062 |
| Quantifying uncertainty of emission estimates in National Greenhouse Gas Inventories using bootstrap confidence intervals (TONG et al., 2012) | 93 | 0.062 |
| Manufacturing-focused emissions reductions in footwear production (CHEAH et al., 2013) | 83 | 0.025 |
| * 48% remaining attributed to Cluster #1 (orange), 22%, and Cluster #2 (mint), 26%. | | |

Source: Author's elaboration using data processed in Bibliometrix (ARIA; CUCCURULLO, 2017)

Table A.12 – Thematic map clusters' top keywords – 4th time slice (2015 – 2018)

| Cluster | Keywords | Occurrences |
|---|---|---|
| Cluster #1 (green) | ghg emissions | 85 |
| | life cycle assessment (lca) | 66 |
| | carbon footprint (cf) | 21 |
| | sustainability | 13 |
| | energy consumption | 9 |
| | TOTAL | 242 |
| Cluster #2 (light pink) | greenhouse gases | 32 |
| | climate change | 23 |
| | carbon dioxide (co2) | 21 |
| | methane (ch4) | 17 |
| | energy efficiency | 11 |
| | TOTAL | 133 |
| Cluster #3 (red) | carbon emissions | 60 |
| | china | 10 |
| | emission factors | 9 |
| | buildings | 6 |
| | land use change (luc) | 5 |
| | TOTAL | 90 |
| Cluster #4 (pink) | co2 emissions | 42 |
| | input-output analysis | 9 |
| | biomass | 5 |
| | low carbon | 5 |
| | simulation | 5 |
| | TOTAL | 66 |
| Cluster #5 (orange) | lmdi | 9 |
| | TOTAL | 9 |

Source: Author's elaboration using data processed in Bibliometrix (ARIA; CUCCURULLO, 2017)

Table A.13 – Top 3 most relevant documents of each thematic map cluster – 4th time slice (2015 – 2018)

| Cluster and documents | BP (%) | PR |
|---|---|---|
| **Cluster #1 (green)** | | |
| Energy consumption and energy-related $CO_2$ emissions from China's petrochemical industry based on an environmental input-output life cycle assessment (MENG; SAGER, 2017) | 86 | 0.180 |
| Do greenhouse gas emission calculations from energy crop cultivation reflect actual agricultural management practices? – A review of carbon footprint calculators (PETER; HELMING; NENDEL, 2017) | 100 | 0.153 |
| Rolling resistance contribution to a road pavement life cycle carbon footprint analysis (TRUPIA et al., 2017) | 100 | 0.153 |
| **Cluster #2 (light pink)** | | |
| Field investigation and parametric study of greenhouse gas emissions from railway plain-line renewals (KREZO et al., 2016) | 86 | 0.137 |
| Legacy effects of individual crops affect $N_2O$ emissions accounting within crop rotations (ADLER et al., 2018) | 77 | 0.153 |
| Diet-related greenhouse gas emissions assessed by a food frequency questionnaire and validated using 7-day weighed food records (SJÖRS et al., 2016) | 62 | 0.151 |
| **Cluster #3 (red)** | | |
| A tool for assessing life cycle co2 emissions of buildings in Sri Lanka (KUMANAYAKE; LUO, 2018) | 92 | 0.121 |
| Influence of spatially dependent, modeled soil carbon emission factors on life-cycle greenhouse gas emissions of corn and cellulosic ethanol (QIN et al., 2016) | 93 | 0.077 |
| A review on life cycle assessment, life cycle energy assessment and life cycle carbon emissions assessment on buildings (Chau et al., 2015) | 92 | 0.077 |
| **Cluster #4 (pink)** | | |
| A global meta-analysis of forest bioenergy greenhouse gas emission accounting studies (BUCHHOLZ et al., 2016) | 77 | 0.097 |

| Cluster and documents | BP (%) | PR |
|---|---|---|
| Life cycle carbon dioxide emissions simulation and environmental cost analysis for building construction (CHOU; YEH, 2015) | 61 | 0.101 |
| Simulation and optimization model for energy efficient building and environmental assessment (GUL; WANG; ZHANG, 2018) | 61 | 0.101 |
| **Cluster #5 (orange)** | | |
| Life cycle building carbon emissions assessment and driving factors decomposition analysis based on lmdi – A case study of Wuhan city in China (GONG; SONG, 2015) | 78 | 0.124 |
| Analysis on influence factors of greenhouse gas emissions of magnesium production process (CAO et al., 2016a) | 90 | 0.070 |
| Decomposing the decoupling relationship between energy-related $CO_2$ emissions and economic growth in China (LI; SUN; LI, 2015) | 87 | 0.053 |

Source: Author's elaboration using data processed in Bibliometrix (ARIA; CUCCURULLO, 2017)

Table A.14 – Thematic map clusters' top keywords – 5th time slice (2019 – 2022)

| Cluster | Keywords | Occurrences |
|---|---|---|
| Cluster #1 (pink) | life cycle assessment (lca) | 95 |
| | ghg emissions | 86 |
| | greenhouse gases | 44 |
| | carbon footprint (cf) | 37 |
| | carbon dioxide (co2) | 21 |
| | TOTAL | 335 |
| Cluster #2 (green) | carbon emissions | 114 |
| | co2 emissions | 73 |
| | energy consumption | 17 |
| | china | 12 |
| | energy efficiency | 10 |
| | TOTAL | 243 |
| Cluster #3 (rose) | climate change | 33 |
| | cities | 8 |
| | TOTAL | 41 |
| Cluster #4 (lemon) | climate change mitigation | 11 |
| | carbon neutrality | 9 |
| | TOTAL | 20 |
| Cluster #5 (red) | lmdi | 10 |
| | carbon emission accounting | 8 |
| | TOTAL | 18 |
| Cluster #6 (light grey) | methane (ch4) | 11 |
| | TOTAL | 11 |
| Cluster #7 (grey) | consumption-based carbon emissions | 9 |
| | TOTAL | 9 |

Source: Author's elaboration using data processed in Bibliometrix (ARIA; CUCCURULLO, 2017)

Table A.15 – Top 3 most relevant documents of each thematic map cluster – 5th time slice (2019 – 2022)

| Cluster and documents | BP (%) | PR |
|---|---|---|
| **Cluster #1 (pink)** | | |
| Emission assessment of alternative dam structure types, a novel approach to consider in new dam projects (ALVANCHI; BAJALAN; IRAVANI, 2021) | 71 | 0.219 |
| Review of life-cycle greenhouse-gas emissions assessments of hydroprocessed renewable fuel (HEFA) from oilseeds (ZEMANEK; CHAMPAGNE; MABEE, 2020) | 100 | 0.154 |
| Eco-efficiency of the differential ratio change in a heavy-duty vehicle and implications for the automotive industry (FERREIRA et al., 2020) | 100 | 0.154 |
| **Cluster #2 (green)** | | |
| Energy consumption and greenhouse gas emission assessment in the Algerian sector of fertilisers production with life cycle assessment (MAKHLOUF; QUARANTA; KARDACHE, 2019) | 73 | 0.141 |

| Cluster and documents | BP (%) | PR |
|---|---|---|
| Life cycle energy consumption and greenhouse gas emissions analysis of primary and recycled aluminum in China (PENG et al., 2022) | 73 | 0.141 |
| Greenhouse gas emissions of stationary battery installations in two renewable energy projects (PUCKER-SINGER et al., 2021) | 91 | 0.085 |
| **Cluster #3 (rose)** | | |
| Carbon metrics for cities: Production and consumption implications for policies (BALOUKTSI, 2020) | 93 | 0.085 |
| Embodied energy and greenhouse gas emissions analysis of a prefabricated modular house: The "moby" case study (TAVARES; LACERDA; FREIRE, 2019) | 74 | 0.104 |
| Coupling economic and GHG emission accounting models to evaluate the sustainability of biogas policies (BARTOLI et al., 2019) | 74 | 0.104 |
| **Cluster #4 (lemon)** | | |
| Renewable energy generation from livestock waste for a sustainable circular economy in Bangladesh (ISLAM et al., 2021) | 90 | 0.085 |
| Integrating climate change impact in new building design process: A review of building life cycle carbon emission assessment methodologies (LI, 2021) | 90 | 0.085 |
| Optimal scheduling of integrated energy system under the background of carbon neutrality (LV *et al.*, 2022) | 93 | 0.067 |
| **Cluster #5 (red)** | | |
| Coupling coordination between carbon emissions and the eco-environment in China (JIANG et al., 2022a) | 92 | 0.070 |
| Driving factors of direct greenhouse gas emissions from China's pig industry from 1976 to 2016 (DAI; SUN; MÜLLER, 2021) | 92 | 0.070 |
| Research on measurement of regional differences and decomposition of influencing factors of carbon emissions of China's logistics industry (LI; SUN, 2021) | 92 | 0.070 |
| **Cluster #6 (light grey)** | | |
| LNG supply chains: A supplier-specific life-cycle assessment for improved emission accounting (DONAGHY; STOCKMAN, 2022) | 73 | 0.115 |
| New York City greenhouse gas emissions estimated with inverse modeling of aircraft measurements (PITT et al., 2022) | 61 | 0.076 |
| A modeling approach for addressing sensitivity and uncertainty of estuarine greenhouse gas ($CO_2$ and $CH_4$) dynamics (HUANG et al., 2022) | 61 | 0.076 |
| **Cluster #7 (grey)** | | |
| Consumption-based carbon emissions and international trade in G7 countries: the role of environmental innovation and renewable energy (Z. Khan et al., 2020) | 100 | 0.004 |
| The impact of technological innovation and public-private partnership investment on sustainable environment in China: Consumption-based carbon emissions analysis (KHAN et al., 2020a) | 100 | 0.004 |
| Asymmetric inter-linkages between green technology innovation and consumption-based carbon emissions in BRICS countries using quantile-on-quantile framework (RAZZAQ et al., 2021) | 100 | 0.004 |

Source: Author's elaboration using data processed in Bibliometrix (ARIA; CUCCURULLO, 2017)

In Chapter 3 – Section 3.3 – Subsection 3.3.3, findings related to content analysis were presented and complementary data related to those findings are presented in the following tables. The final selected articles references and titles are exhibited in Table A.16. Main approach, from Figure 3.26, and sector coverage of final selected articles are detailed in Table A.17.

Table A.16 – Final list of articles selected during content analysis

| Article | Title |
|---|---|
| (ÅDAHL; HARVEY; BERNTSSON, 2004) | Process industry energy retrofits: The importance of emission baselines for greenhouse gas reductions |
| (ABELLA; BERGERSON, 2012) | Model to investigate energy and greenhouse gas emissions implications of refining petroleum: Impacts of crude quality and refinery configuration |
| (ANG; CHOI, 2002) | Boundary problem in carbon emission decomposition |
| (BASTIANONI et al., 2014a) | The effect of a consumption-based accounting method in national GHG inventories: A trilateral trade system application |
| (BASTIANONI et al., 2014b) | The connection between 2006 IPCC GHG inventory methodology and ISO 14064-1 certification standard - A reference point for the environmental policies at sub-national scale |
| (BRANDER, 2022) | The most important GHG accounting concept you may not have heard of: the attributional-consequential distinction |
| (BRANDER, 2016) | Transposing lessons between different forms of consequential greenhouse gas accounting: Lessons for consequential life cycle assessment, project-level accounting, and policy-level accounting |
| (BRANDER, 2017) | Comparative analysis of attributional corporate greenhouse gas accounting, consequential life cycle assessment, and project/policy level accounting: A bioenergy case study |
| (BRANDER et al., 2021) | Carbon accounting for negative emissions technologies |
| (BRANDER; GILLENWATER; ASCUI, 2018) | Creative accounting: A critical perspective on the market-based method for reporting purchased electricity (scope 2) emissions |
| (BRASCHEL; POSCH, 2013) | A review of system boundaries of GHG emission inventories in waste management |
| (CAO et al., 2016a) | Analysis on influence factors of greenhouse gas emissions of magnesium production process |
| (CHOUDHARY; SRIVASTAVA; DE, 2018) | Integrating Greenhouse gases (GHG) assessment for low carbon economy path: Live case study of Indian national oil company |
| (DAVYDENKO et al., 2014) | Towards a global CO2 calculation standard for supply chains: Suggestions for methodological improvements |
| (EL-HOUJEIRI; BRANDT; DUFFY, 2013) | Open-source LCA tool for estimating greenhouse gas emissions from crude oil production using field characteristics |
| (FENG et al., 2022) | Typical case of carbon capture and utilization in Chinese iron and steel enterprises: CO2 emission analysis |
| (FENNER et al., 2018) | The carbon footprint of buildings: A review of methodologies and applications |
| (GAO et al., 2012) | Comparison of greenhouse gas emission accounting for a constructed wetland wastewater treatment system |
| (GAO et al., 2018) | Energy consumption and carbon emission analysis of natural graphite anode material for lithium batteries |
| (GARCIA; FREIRE, 2014) | Carbon footprint of particleboard: a comparison between ISO/TS 14067, GHG Protocol, PAS 2050 and Climate Declaration |
| (GIBASSIER; SCHALTEGGER, 2015) | Carbon management accounting and reporting in practice: A case study on converging emergent approaches |
| (HÄKKINEN; HAAPIO, 2013) | Principles of GHG emissions assessment of wooden building products |
| (HACATOGLU; ROSEN; DINCER, 2012) | Comparative life cycle assessment of hydrogen and other selected fuels |
| (HONDO, 2005) | Life cycle GHG emission analysis of power generation systems: Japanese case |
| (JIA et al., 2020) | Paraffin-based crude oil refining process unit-level energy consumption and CO2 emissions in China |
| (JUSOH; HASHIM, 2018) | Development of a framework for greenhouse gas emissions accounting for industry reporting |
| (KHAN, 2019) | Greenhouse gas emission accounting approaches in electricity generation systems: A review |

| Article | Title |
|---|---|
| (KHAN, 2018) | Importance of GHG emissions assessment in the electricity grid expansion towards a low-carbon future: A time-varying carbon intensity approach |
| (KWOK et al., 2013) | Carbon emissions modeling for green buildings: A comprehensive study of calculations |
| (LARSEN; MERRILD; CHRISTENSEN, 2009) | Recycling of glass: Accounting of greenhouse gases and global warming contributions |
| (LI et al., 2021) | CO2 Emission Calculation Model of Integrated Steel Works Based on Process Analysis |
| (LI; GAO; JIN, 2016) | Life cycle energy use and GHG emission assessment of coal-based SNG and power cogeneration technology in China |
| (LIMSAWASD, 2017) | GHG emission quantification for pavement construction projects using a process-based approach |
| (LIU et al., 2022) | Near-Real-Time Carbon Emission Accounting Technology Toward Carbon Neutrality |
| (MAKHLOUF; QUARANTA; KARDACHE, 2019) | Energy consumption and greenhouse gas emission assessment in the Algerian sector of fertilisers production with life cycle assessment |
| (MENG; SAGER, 2017) | Energy consumption and energy-related CO2 emissions from China's petrochemical industry based on an environmental input-output life cycle assessment |
| (NUTTER et al., 2013) | Greenhouse gas emission analysis for USA fluid milk processing plants: Processing, packaging, and distribution |
| (PAN; QIN; ZHAO, 2017) | Challenges for energy and carbon modeling of high-rise buildings: The case of public housing in Hong Kong |
| (PENG et al., 2022) | Life Cycle Energy Consumption and Greenhouse Gas Emissions Analysis of Primary and Recycled Aluminum in China |
| (PETER; HELMING; NENDEL, 2017) | Do greenhouse gas emission calculations from energy crop cultivation reflect actual agricultural management practices? A review of carbon footprint calculators |
| (PINEM; KARUNIASA; ABDINI, 2020) | Estimating GHG Emission Level from Oil and Gas Offshore Production Facility |
| (PRAPASPONGSA; GHEEWALA, 2017) | Consequential and attributional environmental assessment of biofuels: implications of modelling choices on climate change mitigation strategies |
| (SCHALTEGGER; CSUTORA, 2012) | Carbon accounting for sustainability and management. Status quo and challenges |
| (SHI et al., 2019) | A GHG emissions analysis method for product remanufacturing: A case study on a diesel engine |
| (SILVA, 2021) | Greenhouse gas emission assessment of simulated wastewater biorefinery |
| (SOUSA et al., 2022) | Industrial production of recycled cement: energy consumption and carbon dioxide emission estimation |
| (SPORK et al., 2015) | Increasing Precision in Greenhouse Gas Accounting Using Real-Time Emission Factors: A Case Study of Electricity in Spain |
| (STEPHAN; CRAWFORD, 2014) | A multi-scale life-cycle energy and greenhouse-gas emissions analysis model for residential buildings |
| (TIAN et al., 2022) | CO2 accounting model and carbon reduction analysis of iron and steel plants based on intra- and inter-process carbon metabolism |
| (TIAN; ZHU, 2015) | GHG emission assessment of Chinese container terminals: A hybrid approach of IPCC and input-output analysis |
| (TRINH; DOH, 2018) | Building's life cycle embodied carbon emissions assessments: A review |
| (WANG et al., 2015) | Development of an evaluating method for carbon emissions of manufacturing process plans |
| (Warner et al., 2014) | Challenges in the estimation of greenhouse gas emissions from biofuel-induced global land-use change |
| (WEBER, 2012) | Uncertainty and Variability in Product Carbon Footprinting: Case Study of a Server |
| (WEBER et al., 2009) | Uncertainty and variability in accounting for grid electricity in life cycle assessment |

| Article | Title |
|---|---|
| (WEGENER; LABELLE; JERMAN, 2019) | Unpacking carbon accounting numbers: A study of the commensurability and comparability of corporate greenhouse gas emission disclosures |
| (WEI; FENG; JIA, 2021) | Construction and Application Analysis of Carbon Emission Influence Factor Model of Energy Consumption in Mining Industry |
| (WINANTI et al., 2017) | Greenhouse gas emission analysis of energy efficiency program at gilimanuk gas power plant, bali |
| (WU; XIA; WANG, 2015) | The contribution of ISO 14067 to the evolution of global greenhouse gas standards - A review |
| (YAN; MENG, 2011) | Carbon emissions calculation model of building based on PAS2050 |
| (ZEMANEK; CHAMPAGNE; MABEE, 2020) | Review of life-cycle greenhouse-gas emissions assessments of hydroprocessed renewable fuel (HEFA) from oilseeds |
| (RONG-RONG; YANG; LI-QIANG, 2008) | Greenhouse gas emission analysis for distributed energy system |
| (ZHAO et al., 2019) | A mechanism model for accurately estimating carbon emissions on a micro scale of iron-making system |
| (ZHAO et al., 2018) | Key factors of CO2 emission analysis in iron and steel mill |

Source: Author’s elaboration using data processed in StArt (FABBRI et al., 2016)

Table A.17 – Final list of articles selected during content analysis – Main approaches and sectoral coverage

| | Main approaches | | Sectoral coverage | |
|---|---|---|---|---|
| **Article** | **Energy-related emissions** | **Accounting discussion** | **Main sector** | **Subsector** |
| (ÅDAHL; HARVEY; BERNTSSON, 2004) | X | X | Industry | Energy process |
| (ABELLA; BERGERSON, 2012) | X | - | Industry | Oil and Gas |
| (ANG; CHOI, 2002) | - | X | Energy | Power and heat |
| (BASTIANONI et al., 2014a) | - | X | Transportation | Supply chain |
| (BASTIANONI et al., 2014b) | - | X | City/Region /National | Regional |
| (BRANDER, 2022) | - | X | General | |
| (BRANDER, 2016) | - | X | General | |
| (BRANDER, 2017) | - | X | Energy | Bioenergy |
| (BRANDER et al., 2021) | - | X | General | |
| (BRANDER; GILLENWATER; ASCUI, 2018) | - | X | General | |
| (BRASCHEL; POSCH, 2013) | X | X | Industry | W&WW |
| (CAO et al., 2016a) | X | - | Industry | Other metals |
| (CHOUDHARY; SRIVASTAVA; DE, 2018) | X | No | Industry | Oil and Gas |
| (DAVYDENKO et al., 2014) | - | X | Transportation | Supply chain |
| (EL-HOUJEIRI; BRANDT; DUFFY, 2013) | X | X | Industry | Oil and Gas |
| (FENG et al., 2022) | X | - | Industry | Iron and Steel |
| (FENNER et al., 2018) | - | X | Buildings | General |
| (GAO et al., 2012) | X | X | Industry | W&WW |
| (GAO et al., 2018) | X | - | Industry | Other metals |
| (GARCIA; FREIRE, 2014) | - | X | Industry | Pulp and Paper |
| (GIBASSIER; SCHALTEGGER, 2015) | - | X | General | |
| (HÄKKINEN; HAAPIO, 2013) | - | X | Industry | Forestry and forestry products |
| (HACATOGLU; ROSEN; DINCER, 2012) | X | - | Energy | Fuel |
| (HONDO, 2005) | X | - | Energy | Power and heat |
| (JIA et al., 2020) | X | - | Industry | Oil and Gas |
| (JUSOH; HASHIM, 2018) | X | X | Industry | Manufacturing |
| (KHAN, 2019) | X | X | Energy | Power and heat |
| (KHAN, 2018) | X | X | Energy | Power and heat |

| Article | Main approaches | | Sectoral coverage | |
|---|---|---|---|---|
| | Energy-related emissions | Accounting discussion | Main sector | Subsector |
| (KWOK et al., 2013) | X | - | Buildings | General |
| (LARSEN; MERRILD; CHRISTENSEN, 2009) | X | X | Industry | Glass |
| (LI et al., 2021) | X | - | Industry | Iron and Steel |
| (LI; GAO; JIN, 2016) | X | - | Energy | Fuel |
| (LIMSAWASD, 2017) | X | - | Industry | Construction |
| (LIU et al., 2022) | X | X | General | |
| (MAKHLOUF; QUARANTA; KARDACHE, 2019) | X | - | Industry | Chemical and petrochemical |
| (MENG; SAGER, 2017) | X | - | Industry | Chemical and petrochemical |
| (NUTTER et al., 2013) | X | - | Industry | Food |
| (PAN; QIN; ZHAO, 2017) | X | - | Buildings | Residential |
| (PENG et al., 2022) | X | - | Industry | Other metals |
| (PETER; HELMING; NENDEL, 2017) | - | X | Energy | Bioenergy |
| (PINEM; KARUNIASA; ABDINI, 2020) | X | X | Industry | Oil and Gas |
| (PRAPASPONGSA; GHEEWALA, 2017) | - | X | Energy | Bioenergy |
| (SCHALTEGGER; CSUTORA, 2012) | - | X | General | |
| (SHI et al., 2019) | X | - | Industry | Manufacturing |
| (SILVA, 2021) | X | X | Industry | W&WW |
| (SOUSA et al., 2022) | X | - | Industry | Cement |
| (SPORK et al., 2015) | X | X | Energy | Power and heat |
| (STEPHAN; CRAWFORD, 2014) | X | - | Buildings | Residential |
| (TIAN et al., 2022) | X | - | Industry | Iron and Steel |
| (TIAN; ZHU, 2015) | X | X | Transportation | Maritime |
| (TRINH; DOH, 2018) | - | X | Buildings | General |
| (WANG et al., 2015) | X | X | Industry | Manufacturing |
| (Warner et al., 2014) | X | X | Energy | Bioenergy |
| (WEBER, 2012) | - | X | Industry | Manufacturing |
| (WEBER et al., 2009) | X | X | Energy | Power and heat |
| (WEGENER; LABELLE; JERMAN, 2019) | - | X | General | |
| (WEI; FENG; JIA, 2021) | X | - | Industry | Other metals |
| (WINANTI et al., 2017) | X | - | Energy | Power and heat |
| (WU; XIA; WANG, 2015) | - | X | General | |
| (YAN; MENG, 2011) | - | X | Buildings | General |
| (ZEMANEK; CHAMPAGNE; MABEE, 2020) | - | X | Energy | Bioenergy |
| (RONG-RONG; YANG; LI-QIANG, 2008) | X | - | Energy | Power and heat |
| (ZHAO et al., 2019) | X | X | Industry | Iron and Steel |
| (ZHAO et al., 2018) | X | - | Industry | Iron and Steel |

Source: Author’s elaboration using data processed in StArt (FABBRI et al., 2016)

Consolidated findings presented in Figure 3.27 are detailed by article in Table A.18, Table A.19, and Table A.20. While the previous tables contained the full list of final selected articles, the following tables contain only the articles that fulfill at least one column criterion.

Table A.18 – Final list of articles selected during content analysis – GHG accounting method mentioned

| Article | GHG accounting method mentioned | | | | | |
|---|---|---|---|---|---|---|
| | GHG Protocol Standards and guidance | IPCC Guidelines | ISO 14060 family | PAS 2050 | ISO 14040 family | API Guidelines |
| (BASTIANONI et al., 2014a) | - | X | - | - | - | - |
| (BASTIANONI et al., 2014b) | - | X | X | - | - | - |
| (BRANDER, 2016) | X | X | X | - | - | - |
| (BRANDER, 2017) | X | X | X | - | - | - |
| (BRANDER et al., 2021) | X | - | - | - | - | - |
| (BRANDER; GILLENWATER; ASCUI, 2018) | X | - | X | - | - | - |
| (BRASCHEL; POSCH, 2013) | X | X | X | - | - | - |
| (CAO et al., 2016a) | - | X | - | - | - | - |
| (CHOUDHARY; SRIVASTAVA; DE, 2018) | X | - | X | - | - | X |
| (DAVYDENKO et al., 2014) | X | - | X | - | - | - |
| (FENG et al., 2022) | X | X | - | - | - | - |
| (FENNER et al., 2018) | - | X | - | X | X | - |
| (GAO et al., 2018) | - | - | - | - | X | - |
| (GARCIA; FREIRE, 2014) | X | - | X | X | - | - |
| (GIBASSIER; SCHALTEGGER, 2015) | X | - | - | X | - | - |
| (JUSOH; HASHIM, 2018) | X | - | - | - | - | - |
| (KHAN, 2019) | X | - | - | - | - | - |
| (KHAN, 2018) | - | X | - | - | - | - |
| (LIU et al., 2022) | X | X | X | X | - | - |
| (NUTTER et al., 2013) | - | - | - | - | X | - |
| (PETER; HELMING; NENDEL, 2017) | - | - | X | - | - | - |
| (PINEM; KARUNIASA; ABDINI, 2020) | - | X | - | - | - | X |
| (SCHALTEGGER; CSUTORA, 2012) | X | - | X | X | - | - |
| (SILVA, 2021) | - | - | - | - | X | - |
| (SPORK et al., 2015) | X | - | - | - | - | - |
| (TIAN; ZHU, 2015) | - | X | - | - | - | - |
| (TRINH; DOH, 2018) | - | - | - | - | X | - |
| (WANG et al., 2015) | - | - | X | - | - | - |
| (Warner et al., 2014) | - | X | - | - | - | - |
| (WEBER, 2012) | X | - | - | X | X | - |
| (WEBER et al., 2009) | X | - | - | X | X | - |
| (WEGENER; LABELLE; JERMAN, 2019) | X | - | - | - | - | - |
| (WEI; FENG; JIA, 2021) | - | X | - | - | - | - |
| (WU; XIA; WANG, 2015) | X | - | X | X | X | - |
| (YAN; MENG, 2011) | - | - | - | X | - | - |
| (ZHAO et al., 2019) | - | X | - | - | X | - |
| (ZHAO et al., 2018) | X | X | - | X | - | - |

Source: Author's elaboration using data processed in StArt (FABBRI et al., 2016)

Table A.19 – Final list of articles selected during content analysis – GHG accounting element discussed

| Article | GHG accounting element discussed | | | | |
|---|---|---|---|---|---|
| | Boundary | EF | Scope | Method | AF |
| (ANG; CHOI, 2002) | X | X | - | - | - |
| (BASTIANONI et al., 2014a) | X | - | X | X | - |

| Article | GHG accounting element discussed<br>Boundary | EF | Scope | Method | AF |
|---|---|---|---|---|---|
| (BASTIANONI et al., 2014b) | - | - | X | - | - |
| (BRANDER, 2022) | - | - | - | X | - |
| (BRANDER, 2016) | - | - | - | X | - |
| (BRANDER, 2017) | - | - | - | X | - |
| (BRANDER et al., 2021) | X | - | - | - | - |
| (BRANDER; GILLENWATER; ASCUI, 2018) | - | X | X | - | - |
| (BRASCHEL; POSCH, 2013) | X | - | - | - | - |
| (DAVYDENKO et al., 2014) | X | - | - | X | - |
| (EL-HOUJEIRI; BRANDT; DUFFY, 2013) | X | X | X | - | X |
| (FENNER et al., 2018) | X | - | - | - | - |
| (GAO et al., 2012) | - | - | X | - | - |
| (GARCIA; FREIRE, 2014) | X | X | - | - | - |
| (GIBASSIER; SCHALTEGGER, 2015) | - | - | X | X | - |
| (HÄKKINEN; HAAPIO, 2013) | X | X | - | X | - |
| (JUSOH; HASHIM, 2018) | X | - | X | - | - |
| (KHAN, 2019) | - | - | X | X | - |
| (KHAN, 2018) | - | X | - | - | - |
| (LARSEN; MERRILD; CHRISTENSEN, 2009) | X | - | X | - | - |
| (LIU et al., 2022) | - | X | - | - | X |
| (PETER; HELMING; NENDEL, 2017) | X | - | - | - | - |
| (PINEM; KARUNIASA; ABDINI, 2020) | - | X | - | - | X |
| (PRAPASPONGSA; GHEEWALA, 2017) | - | - | - | X | - |
| (SCHALTEGGER; CSUTORA, 2012) | X | - | X | - | - |
| (SILVA, 2021) | X | - | - | - | - |
| (SPORK et al., 2015) | - | X | X | - | - |
| (WANG et al., 2015) | X | X | X | - | X |
| (Warner et al., 2014) | - | - | X | - | - |
| (WEBER et al., 2009) | - | X | - | X | - |
| (WEGENER; LABELLE; JERMAN, 2019) | X | X | - | X | X |
| (WU; XIA; WANG, 2015) | X | - | - | - | - |
| (YAN; MENG, 2011) | X | X | - | - | - |
| (ZEMANEK; CHAMPAGNE; MABEE, 2020) | X | X | - | - | - |
| (ZHAO et al., 2019) | - | X | - | - | X |

Source: Author's elaboration using data processed in StArt (FABBRI et al., 2016)

Table A.20 – Final list of articles selected during content analysis – Energy-related emission indicator and activity data

| Article | Energy-related emission indicator<br>Simple metric | Ratio or Specific emission | Life cycle emission | Energy-related activity data<br>Simple metric | Ratio or SEC | Input-Output Model | Reg. Model | Eng. Model |
|---|---|---|---|---|---|---|---|---|
| (ÅDAHL; HARVEY; BERNTSSON, 2004) | X | X | - | X | X | - | - | - |
| (ABELLA; BERGERSON, 2012) | - | X | - | X | X | - | - | - |
| (ANG; CHOI, 2002) | - | X | - | X | - | - | - | - |
| (CAO et al., 2016a) | X | - | - | X | X | - | - | - |
| (CHOUDHARY; SRIVASTAVA; DE, 2018) | X | X | - | X | - | - | - | - |
| (EL-HOUJEIRI; BRANDT; DUFFY, 2013) | - | X | - | X | - | - | - | X |
| (FENG et al., 2022) | - | X | - | X | - | - | - | - |
| (GAO et al., 2012) | X | - | - | X | - | X | - | - |

| Article | Energy-related emission indicator | | | Energy-related activity data | | | | |
|---|---|---|---|---|---|---|---|---|
| | Simple metric | Ratio or Specific emission | Life cycle emission | Simple metric | Ratio or SEC | Input-Output Model | Reg. Model | Eng. Model |
| (GAO et al., 2018) | - | X | - | - | X | - | - | - |
| (HACATOGLU; ROSEN; DINCER, 2012) | - | X | X | X | - | - | - | - |
| (HONDO, 2005) | - | - | X | X | - | - | - | - |
| (JIA et al., 2020) | X | - | - | X | - | - | - | - |
| (JUSOH; HASHIM, 2018) | X | X | - | X | - | - | - | - |
| (KHAN, 2019) | X | X | - | - | - | - | - | - |
| (KHAN, 2018) | - | X | X | X | - | - | - | - |
| (KWOK et al., 2013) | X | - | - | X | - | - | - | - |
| (LARSEN; MERRILD; CHRISTENSEN, 2009) | - | X | - | - | X | - | - | - |
| (LI et al., 2021) | - | X | - | X | - | - | - | - |
| (LI; GAO; JIN, 2016) | - | - | X | X | - | - | - | - |
| (LIMSAWASD, 2017) | X | - | - | X | - | - | - | - |
| (LIU et al., 2022) | X | - | - | X | X | X | X | - |
| (MAKHLOUF; QUARANTA; KARDACHE, 2019) | - | - | X | X | - | - | - | - |
| (MENG; SAGER, 2017) | X | - | - | X | - | X | - | - |
| (NUTTER et al., 2013) | - | - | X | X | X | - | - | - |
| (PAN; QIN; ZHAO, 2017) | X | - | - | X | - | - | - | X |
| (PENG et al., 2022) | - | X | - | - | X | - | - | - |
| (PINEM; KARUNIASA; ABDINI, 2020) | X | - | - | X | - | - | - | - |
| (SHI et al., 2019) | X | - | - | X | - | - | - | - |
| (SILVA, 2021) | X | - | - | X | - | - | - | - |
| (SOUSA et al., 2022) | - | X | - | - | X | - | - | - |
| (SPORK et al., 2015) | - | X | X | X | - | - | - | - |
| (STEPHAN; CRAWFORD, 2014) | - | - | X | X | X | - | - | - |
| (TIAN et al., 2022) | X | X | - | X | - | - | - | - |
| (TIAN; ZHU, 2015) | X | - | - | X | - | - | - | - |
| (WANG et al., 2015) | X | X | - | X | - | - | X | - |
| (Warner et al., 2014) | - | X | - | X | - | - | - | - |
| (WEBER et al., 2009) | - | X | - | X | - | - | - | - |
| (WEGENER; LABELLE; JERMAN, 2019) | X | - | - | X | - | - | X | - |
| (WEI; FENG; JIA, 2021) | X | - | - | X | - | - | - | - |
| (WINANTI et al., 2017) | X | - | - | X | - | - | - | - |
| (RONG-RONG; YANG; LI-QIANG, 2008) | X | - | - | X | - | - | - | - |
| (ZHAO et al., 2019) | X | X | - | X | - | - | - | X |
| (ZHAO et al., 2018) | - | X | - | X | - | - | - | - |

Source: Author’s elaboration using data processed in StArt (FABBRI et al., 2016)

# APPENDIX B. COMPLEMENTARY DATA TO EVALUATING ENERGY PERFORMANCE WITH INDICATORS

In Chapter 4 – Section 4.3 – Subsection 4.3.2, findings related to network analysis were presented and complementary data related to these findings are presented in this appendix. Bibliographic coupling, co-citation, co-authorship and citation networks were developed using different analysis units as sources, authors, countries and articles. Clusters were investigated according to TLS (Total Link Strength), number of links and/or number of citations. Top 3 vertex with highest TLS (or number of citations) for the five most relevant clusters in the networks presented in Figure 4.9, Figure 4.10 and Figure 4.11, and Figure 4.13 are detailed respectively in Table B.1. Table B.2, and Table B.3.

Table B.1 – Cluster analysis (TLS and Links) in networks from Figure 4.9

| | Bibliographic coupling | Co-citation | Citation |
|---|---|---|---|
| **Cluster #1** | Yellow | Red | Yellow |
| **Source** | Energy | Energy | Energy Policy |
| **TLS** | 512 | 12885 | 64 |
| **Links** | 34 | 40 | 18 |
| **Source** | Energy Conversion and Management | Journal of Cleaner Production | IOP Conference Series: Earth and Environmental Science |
| **TLS** | 129 | 9416 | 1 |
| **Links** | 24 | 40 | 1 |
| **Source** | Science of the Total Environment | Applied Thermal Engineering | IOP Conference Series: Materials Science and Engineering |
| **TLS** | 54 | 1931 | 1 |
| **Links** | 9 | 110 | 1 |
| **Cluster #2** | Blue | Green | Purple |
| **Source** | Energy Policy | Energy and Buildings | Journal of Cleaner Production |
| **TLS** | 489 | 11649 | 31 |
| **Links** | 22 | 35 | 8 |
| **Source** | Energy Efficiency | Applied Energy | Energy Efficiency |
| **TLS** | 425 | 10864 | 17 |
| **Links** | 29 | 40 | 8 |
| **Source** | Energy Economics | Energy Conversion and Management | Energy Economics |
| **TLS** | 199 | 4581 | 10 |
| **Links** | 20 | 40 | 4 |
| **Cluster #3** | Red | Blue | Blue |
| **Source** | Applied Energy | Energy Policy | Applied Energy |
| **TLS** | 461 | 10032 | 28 |
| **Links** | 36 | 40 | 9 |
| **Source** | Energies | Energy Economics | International Journal of Energy Economics and Policy |
| **TLS** | 413 | 3575 | 4 |
| **Links** | 37 | 33 | 3 |
| **Source** | Sustainability (Switzerland) | Energy Efficiency | Chemical Engineering Transactions |

| | Bibliographic coupling | Co-citation | Citation |
|---|---|---|---|
| **TLS** | 283 | 2029 | 2 |
| **Links** | 35 | 34 | 2 |
| **Cluster #4** | Green | Yellow | Red |
| **Source** | Journal of Cleaner Production | Renewable and Sustainable Energy Reviews | Energies |
| **TLS** | 461 | 9009 | 27 |
| **Links** | 33 | 40 | 10 |
| **Source** | International Journal of Energy Economics and Policy | Sustainable Cities and Society | Energy |
| **TLS** | 200 | 1825 | 22 |
| **Links** | 30 | 31 | 8 |
| **Source** | Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture | Journal of Water Resources Planning and Management | Energy and Buildings |
| **TLS** | 124 | 730 | 19 |
| **Links** | 17 | 12 | 9 |
| **Cluster #5** | Purple | Purple | Green |
| **Source** | IOP Conference Series: Earth and Environmental Science | Energies | Energy Conversion and Management |
| **TLS** | 66 | 4568 | 9 |
| **Links** | 21 | 35 | 7 |
| **Source** | IOP Conference Series: Materials Science and Engineering | Sustainability | Science of the Total Environment |
| **TLS** | 55 | 2905 | 7 |
| **Links** | 17 | 37 | 5 |
| **Source** | E3S Web of Conferences | Applied Sciences | Water Science and Technology |
| **TLS** | 14 | 593 | 3 |
| **Links** | 4 | 21 | 2 |

Source: Author's elaboration using VOSviewer (VAN ECK; WALTMAN, 2010)

Table B.2 – Cluster analysis (TLS and Links) in networks from Figure 4.10 and Figure 4.11

| | Citation | Co-authorship | | Citation | Co-authorship |
|---|---|---|---|---|---|
| **Cluster #1** | Blue | Cyan | **Cluster #1** | Purple | Red |
| **Author** | Thollander P. | Zhang J. | **Country** | Spain | Italy |
| **TLS** | 52 | 12 | **TLS** | 21 | 55 |
| **Links** | 20 | 6 | **Links** | 14 | 24 |
| **Author** | Andersson E. | Gong. L. | **Country** | United Kingdom | China |
| **TLS** | 30 | 10 | **TLS** | 19 | 39 |
| **Links** | 17 | 4 | **Links** | 13 | 20 |
| **Author** | Beisheim B. | Hou G. | **Country** | Pakistan | Spain |
| **TLS** | 24 | 10 | **TLS** | 4 | 17 |
| **Links** | 18 | 4 | **Links** | 3 | 12 |
| **Cluster #2** | Yellow | Yellow | **Cluster #2** | Blue | Purple |
| **Author** | Introna V. | Hao X. | **Country** | Germany | USA |
| **TLS** | 28 | 9 | **TLS** | 21 | 37 |
| **Links** | 21 | 5 | **Links** | 15 | 18 |
| **Author** | Cesarotti V. | Li Z. | **Country** | USA | Ireland |
| **TLS** | 27 | 9 | **TLS** | 17 | 18 |
| **Links** | 20 | 5 | **Links** | 9 | 11 |
| **Author** | Benedetti M. | Huang G. | **Country** | Netherlands | Brazil |
| **TLS** | 25 | 8 | **TLS** | 6 | 17 |
| **Links** | 21 | 4 | **Links** | 4 | 9 |

| | Citation | Co-authorship | | Citation | Co-authorship |
|---|---|---|---|---|---|
| **Cluster #3** | Purple | Green | **Cluster #3** | Brown | Green |
| **Author** | Tanaka K. | Li Y. | **Country** | Italy | Germany |
| **TLS** | 20 | 7 | **TLS** | 17 | 27 |
| **Links** | 14 | 7 | **Links** | 14 | 14 |
| **Author** | Do P. | He Y.-L. | **Country** | France | France |
| **TLS** | 19 | 3 | **TLS** | 11 | 26 |
| **Links** | 10 | 2 | **Links** | 9 | 12 |
| **Author** | Chiu T. Y. | Tao W.-Q. | **Country** | Greece | Sweden |
| **TLS** | 11 | 3 | **TLS** | 3 | 26 |
| **Links** | 7 | 2 | **Links** | 2 | 11 |
| **Cluster #4** | Red | Purple | **Cluster #4** | Green | Blue |
| **Author** | Boyd G. A. | Gao C. | **Country** | Colombia | Netherlands |
| **TLS** | 20 | 5 | **TLS** | 17 | 19 |
| **Links** | 15 | 5 | **Links** | 8 | 14 |
| **Author** | Ang B. W. | Liu Y. | **Country** | Belgium | United Kingdom |
| **TLS** | 19 | 5 | **TLS** | 10 | 11 |
| **Links** | 16 | 5 | **Links** | 6 | 9 |
| **Author** | Blok K. | Li B. | **Country** | Cuba | Poland |
| **TLS** | 17 | 4 | **TLS** | 8 | 11 |
| **Links** | 14 | 4 | **Links** | 3 | 9 |
| **Cluster #5** | Green | Purple | **Cluster #5** | Cyan | Yellow |
| **Author** | Morfeld J. | Liu H. | **Country** | China | Singapore |
| **TLS** | 15 | 5 | **TLS** | 21 | 15 |
| **Links** | 11 | 5 | **Links** | 15 | 10 |
| **Author** | Silveira S. | Zhang Y. | **Country** | Saudi Arabia | Russian Federation |
| **TLS** | 15 | 4 | **TLS** | 5 | 12 |
| **Links** | 11 | 4 | **Links** | 3 | 10 |
| **Author** | Tao W.-Q. | Liu G. | **Country** | Egypt | Austria |
| **TLS** | 13 | 4 | **TLS** | 3 | 8 |
| **Links** | 11 | 4 | **Links** | 1 | 6 |

Source: Author's elaboration using VOSviewer (VAN ECK; WALTMAN, 2010)

Table B.3 – Cluster analysis (TLS/Citation and Links) in networks from Figure 4.13

| | Bibliographic coupling | | Citation |
|---|---|---|---|
| **Cluster #1** | Green | **Cluster #1** | Purple |
| **Article** | (PERRONI et al., 2018) | **Article** | (ANG, 2006) |
| **TLS** | 133 | **Citation** | 223 |
| **Links** | 64 | **Links** | 11 |
| **Article** | (LAWRENCE et al., 2019) | **Article** | (WANG et al., 2014) |
| **TLS** | 83 | **Citation** | 47 |
| **Links** | 47 | **Links** | 2 |
| **Article** | (ANDERSSON et al., 2021) | **Article** | (DENISOVA, 2019) |
| **TLS** | 77 | **Citation** | 38 |
| **Links** | 29 | **Links** | 2 |
| **Cluster #2** | Purple | **Cluster #2** | Yellow |
| **Article** | (SALTA; POLATIDIS; HARALAMBOPOULOS, 2009) | **Article** | (AZADEH et al., 2007) |
| **TLS** | 97 | **Citation** | 147 |
| **Links** | 44 | **Links** | 5 |
| **Article** | (BOR, 2008) | **Article** | (Ó GALLACHÓIR et al., 2007) |
| **TLS** | 72 | **Citation** | 40 |
| **Links** | 40 | **Links** | 1 |
| **Article** | (ANG, 2006) | **Article** | (BOYD, 2014) |
| **TLS** | 71 | **Citation** | 27 |

| | Bibliographic coupling | | Citation |
|---|---|---|---|
| **Links** | 40 | **Links** | 4 |
| **Cluster #3** | Cyan | **Cluster #3** | Rose |
| **Article** | (HOANG; DO; IUNG, 2017) | **Article** | (BOYD; DUTROW; TUNNESSEN, 2008) |
| **TLS** | 86 | **Citation** | 111 |
| **Links** | 55 | **Links** | 9 |
| **Article** | (MORFELDT et al., 2015) | **Article** | (LI; HE; TAO, 2017) |
| **TLS** | 65 | **Citation** | 60 |
| **Links** | 42 | **Links** | 1 |
| **Article** | (SIEBERT et al., 2014) | **Article** | (FINNERTY et al., 2017) |
| **TLS** | 47 | **Citation** | 25 |
| **Links** | 40 | **Links** | 1 |
| **Cluster #4** | Light green | **Cluster #4** | Blue |
| **Article** | (CHAN et al., 2014) | **Article** | (TANAKA, 2008) |
| **TLS** | 65 | **Citation** | 99 |
| **Links** | 37 | **Links** | 2 |
| **Article** | (PÉREZ-LOMBARD; ORTIZ; VELÁZQUEZ, 2013) | **Article** | (VIRTANEN; TUOMAALA; PENTTI, 2013) |
| **TLS** | 61 | **Citation** | 63 |
| **Links** | 44 | **Links** | 2 |
| **Article** | (AZADEH et al., 2007) | **Article** | (HOANG; DO; IUNG, 2017) |
| **TLS** | 38 | **Citation** | 36 |
| **Links** | 24 | **Links** | 8 |
| **Cluster #5** | Red | **Cluster #5** | Red |
| **Article** | (PÉREZ-LOMBARD et al., 2012) | **Article** | (SIITONEN; TUOMAALA; AHTILA, 2010) |
| **TLS** | 51 | **Citation** | 71 |
| **Links** | 41 | **Links** | 4 |
| **Article** | (KIM; KIM; LEE, 2019) | **Article** | (BENEDETTI; CESAROTTI; INTRONA, 2017) |
| **TLS** | 34 | **Citation** | 30 |
| **Links** | 23 | **Links** | 12 |
| **Article** | (ALONSO et al., 2019) | **Article** | (WU et al., 2007) |
| **TLS** | 21 | **Citation** | 23 |
| **Links** | 15 | **Links** | 2 |

Source: Author's elaboration using VOSviewer (VAN ECK; WALTMAN, 2010)

A thematic map was displayed in Figure 4.15 and details of the investigation of its clusters are presented in Table B.4, regarding top keywords associated to each cluster, and in Table B.5, concerning top 3 articles for each cluster.

Table B.4 – Thematic map clusters' top keywords

| Cluster | Keywords | Occurrences |
|---|---|---|
| Cluster #1 (red) | energy efficiency | 216 |
| | energy consumption | 81 |
| | energy performance | 31 |
| | buildings | 29 |
| | renewable energy sources | 25 |
| | TOTAL | 450 |
| Cluster #2 (brown) | energy performance indicator (enpi) | 107 |
| | energy management | 31 |
| | energy management system (enms) | 27 |
| | iso 50001 standard | 21 |
| | specific energy consumption (sec) | 11 |

| Cluster | Keywords | Occurrences |
|---|---|---|
| | TOTAL | 197 |
| Cluster #3 (green) | energy efficiency indicator | 65 |
| | energy audit | 18 |
| | energy intensity | 13 |
| | TOTAL | 96 |
| Cluster #4 (blue) | industry | 27 |
| | co2 emissions | 23 |
| | TOTAL | 50 |
| Cluster #5 (purple) | energy benchmarking | 21 |
| | linear regression | 12 |
| | monitoring | 7 |
| | TOTAL | 40 |
| Cluster #6 (orange) | energy savings | 23 |
| | energy policy | 13 |
| | TOTAL | 36 |
| Cluster #7 (rose) | optimization | 19 |
| | TOTAL | 19 |
| Cluster #8 (mint) | smart metering | 14 |
| | TOTAL | 14 |
| Cluster #9 (light pink) | nearly zero energy building (nzeb) | 11 |
| | TOTAL | 11 |
| Cluster #10 (lavender) | life cycle assessment (lca) | 10 |
| | TOTAL | 10 |

Source: Author's elaboration using data processed in Bibliometrix (ARIA; CUCCURULLO, 2017)

Table B.5 – Top 3 most relevant documents of each thematic map cluster

| Cluster and documents | BP(%) | PR |
|---|---|---|
| **Cluster #1 (red)** | | |
| Modeling the performance of residential building envelope: the role of sustainable energy performance indicators (MWASHA; WILLIAMS; IWARO, 2011) | 100 | 0.274 |
| Significance of sub-criteria in measuring sustainable performance of building envelope development (MWASHA; WILLIAMS; IWARO, 2013) | 100 | 0.266 |
| Energy and the US hardwood industry - Part II: responses to increasing prices (ESPINOZA; BUEHLMANN; BOND, 2011) | 100 | 0.239 |
| **Cluster #2 (brown)** | | |
| Specific energy consumption/use (SEC) in energy management for improving energy efficiency in industry: meaning, usage and differences (LAWRENCE et al., 2019) | 88 | 0.272 |
| Future key energy monitoring (JUNG, 2012) | 97 | 0.232 |
| From energy targets setting to energy-aware operations control and back: an advanced methodology for energy efficient manufacturing (BENEDETTI; CESAROTTI; INTRONA, 2017) | 90 | 0.221 |
| **Cluster #3 (green)** | | |
| Private hospital energy performance benchmarking using energy audit data: an Italian case study (DADI et al., 2022) | 80 | 0.212 |
| A method for measuring the efficiency gap between average and best practice energy use: the ENERGY STAR industrial energy performance indicator (BOYD, 2005) | 94 | 0.140 |
| Reconciling energy efficiency and energy intensity metrics: an integrated decomposition analysis (TORRIE; STONE; LAYZELL, 2018) | 94 | 0.140 |
| **Cluster #4 (blue)** | | |
| Key performance indicators for energy management in the Swedish pulp and paper industry (ANDERSSON; THOLLANDER, 2019) | 62 | 0.262 |
| Evaluation methodology for energy efficiency measures in industry and service sector (TALLINI; CEDOLA, 2016) | 73 | 0.218 |
| An energy consumption analysis on public applications in the city of Novi Sad (AŠONJA; RAJKOVIĆ, 2017) | 72 | 0.198 |
| **Cluster #5 (purple)** | | |

| Cluster and documents | BP(%) | PR |
|---|---|---|
| Communicating a model-based energy performance indicator (HILLIARD; JAMIESON; JORJANI, 2014) | 89 | 0.191 |
| Performance indicators-based energy sustainability in urban water distribution networks: a state-of-art review and conceptual framework (ZAMAN et al., 2021) | 77 | 0.216 |
| Identifying potential gas consumption reductions from municipal buildings through the analysis of half-hourly primary gas meter data (FERREIRA; FLEMING; STUART, 2015) | 98 | 0.155 |
| **Cluster #6 (orange)** | | |
| Best criteria selection based PROMETHEE II to aid decision-making under 2-tuple linguistic framework: Case-study of the most energy efficient region worldwide (SINGH; GUPTA, 2020) | 97 | 0.149 |
| A harmonized calculation model for transforming EU bottom-up energy efficiency indicators into empirical estimates of policy impacts (HOROWITZ; BERTOLDI, 2015) | 90 | 0.148 |
| New method to assess the energy efficiency and energy effectiveness to the industrial end-users (IONESCU; DARIE, 2018) | 90 | 0.148 |
| **Cluster #7 (rose)** | | |
| An integrated DEA PCA numerical taxonomy approach for energy efficiency assessment and consumption optimization in energy intensive manufacturing sectors (AZADEH et al., 2008) | 92 | 0.138 |
| Robust optimization of the energy efficiency of the cold roll forming process (PARALIKAS; SALONITIS; CHRYSSOLOURIS, 2013) | 92 | 0.138 |
| Energy efficiency optimization of ethylene production process with respect to a novel FLPEM-based material-product nexus (GONG; SHAO; ZHU, 2019) | 92 | 0.138 |
| **Cluster #8 (mint)** | | |
| Rule-based system to detect energy efficiency anomalies in smart buildings, a data mining approach (PEÑA et al., 2016) | 78 | 0.178 |
| A comprehensive review of maritime microgrids: system architectures, energy efficiency, power quality, and regulations (KUMAR; ZARE, 2019) | 94 | 0.144 |
| Decision support system to classify and optimize the energy efficiency in smart buildings: a data analytics approach (PEÑA; BISCARRI; PERSONAL ENRIQUE AND LEÓN, 2022) | 94 | 0.144 |
| **Cluster #9 (light pink)** | | |
| Heating demand as an energy performance indicator: a case study of buildings built under the passive house standard in Spain (MARTÍNEZ-DE-ALEGRÍA et al., 2021) | 87 | 0.208 |
| Multi-criteria optimisation of an experimental complex of single-family nearly zero-energy buildings (FEDORCZAK-CISAK et al., 2020) | 78 | 0.166 |
| Thermo-energy performance of lightweight steel framed constructions: a case study (MENGUAL TORRES et al., 2022) | 74 | 0.033 |
| **Cluster #10 (lavander)** | | |
| Energy efficiency evaluation of coal production (PIKOŃ et al., 2015) | 96 | 0.137 |
| Efficient biomass value chains for heat production from energy crops in Ukraine (TRYBOI, 2018) | 68 | 0.150 |
| A review of key environmental and energy performance indicators for the case of renewable energy systems when integrated with storage solutions (KOURKOUMPAS et al., 2018) | 67 | 0.095 |

Source: Author's elaboration using data processed in Bibliometrix (ARIA; CUCCURULLO, 2017)

The thematic evolution with author's keywords as analysis unit was displayed in Figure 4.16 and for each of its time slices (TS) a thematic map was developed. Details of the investigation of these clusters are presented in the following tables. Top keywords associated to each cluster are presented in Table B.6, Table B.8, Table B.10, Table B.12, and Table B.14. Top 3 articles for each cluster are exhibited in Table B.7, Table B.9, Table B.11, Table B.13, and Table B.15.

Table B.6 – Thematic map clusters' top keywords – 1st time slice (2000 – 2006)

| Cluster | Keywords | Occurrences |
|---|---|---|
| Cluster #1 (red) | energy efficiency | 5 |
| | specific energy consumption (sec) | 3 |
| | TOTAL | 8 |
| Cluster #2 (blue) | energy efficiency indicator | 2 |
| | TOTAL | 2 |
| Cluster #3 (green) | energy consumption | 2 |
| | TOTAL | 2 |

Source: Author's elaboration using data processed in Bibliometrix (ARIA; CUCCURULLO, 2017)

Table B.7 – Top 3 most relevant documents of each thematic map cluster – 1st time slice (2000 – 2006)

| | BP (%) | PR |
|---|---|---|
| **Cluster #1 (red)** | | |
| From fluid milk to milk powder: energy use and energy efficiency in the European dairy industry (RAMÍREZ; PATEL; BLOK, 2006b) | 100 | 0.083 |
| Adding apples and oranges: the monitoring of energy efficiency in the Dutch food industry (RAMÍREZ et al., 2006) | 100 | 0.083 |
| How much energy to process one pound of meat? A comparison of energy use and specific energy consumption in the meat industry of four European countries (RAMÍREZ; PATEL; BLOK, 2006a) | 100 | 0.083 |
| **Cluster #2 (blue)** | | |
| Monitoring changes in economy-wide energy efficiency: from energy-GDP ratio to composite efficiency index (ANG, 2006) | 100 | 0.030 |
| Indicators for energy performance efficiency certification in the Lithuanian residential buildings (JUODIS et al., 2003) | 100 | 0.030 |
| **Cluster #3 (green)** | | |
| An econometric analysis of energy input-output in Turkish agriculture (HATIRLI; OZKAN; FERT, 2005) | 100 | 0.032 |
| Energy consumption indicators and CHP technical potential in the Brazilian hospital sector (SALEM SZKLO; SOARES; TOLMASQUIM, 2004) | 100 | 0.032 |

Source: Author's elaboration using data processed in Bibliometrix (ARIA; CUCCURULLO, 2017)

Table B.8 – Thematic map clusters' top keywords – 2nd time slice (2007 – 2010)

| Cluster | Keywords | Occurrences |
|---|---|---|
| Cluster #1 (green) | energy efficiency indicator | 7 |
| | industry | 3 |
| | boundary definitions | 2 |
| | TOTAL | 12 |
| Cluster #2 (red) | energy efficiency | 6 |
| | co2 emissions | 3 |
| | energy benchmarking | 2 |
| | TOTAL | 11 |
| Cluster #3 (blue) | energy performance indicator (enpi) | 5 |
| | energy consumption | 4 |
| | buildings | 2 |
| | TOTAL | 11 |
| Cluster #4 (purple) | life cycle assessment (lca) | 3 |
| | TOTAL | 3 |
| Cluster #5 (orange) | energy savings | 2 |
| | TOTAL | 2 |

Source: Author's elaboration using data processed in Bibliometrix (ARIA; CUCCURULLO, 2017)

Table B.9 – Top 3 most relevant documents of each thematic map cluster – 2nd time slice (2007 – 2010)

| Cluster and documents | BP (%) | PR |
|---|---|---|
| **Cluster #1 (green)** | | |
| Energy use and energy efficiency development in the German and Colombian textile industries (PARDO MARTÍNEZ, 2010) | 74 | 0.086 |
| Assessment of energy efficiency performance measures in industry and their application for policy (TANAKA, 2008) | 100 | 0.058 |
| Consistent multi-level energy efficiency indicators and their policy implications (BOR, 2008) | 100 | 0.037 |
| **Cluster #2 (red)** | | |
| Variables affecting energy efficiency and $CO_2$ emissions in the steel industry (SIITONEN; TUOMAALA; AHTILA, 2010) | 100 | 0.049 |
| The role of natural gas in energy efficiency improvement (SIITONEN; RAUHAMÄKI, 2009) | 100 | 0.049 |
| Monitoring and modelling energy efficiency of municipal public buildings: Case study in Catalonia region (CIPRIANO; CARBONELL; CIPRIANO, 2009) | 57* | 0.065 |
| **Cluster #3 (blue)** | | |
| A method for heating consumption assessment in existing buildings: A field survey concerning 120 Italian schools (CORGNATI; CORRADO; FILIPPI, 2008) | 100 | 0.070 |
| Energy performance index based on LMDI technique and decomposition analysis of Beijing's energy consumption (JUN; MING, 2010) | 100 | 0.055 |
| Modeling of energy efficiency indicator for semiconductor industry (WU; CHEN, 2007) | 64 | 0.059 |
| **Cluster #4 (purple)** | | |
| Life cycle assessment and energy pay-back time of advanced photovoltaic modules: CdTe and CIS compared to Poly-Si (RAUGEI; BARGIGLI; ULGIATI, 2007) | 100 | 0.024 |
| Environmental performance evaluation of thermal insulation materials and its impact on the building (PAPADOPOULOS; GIAMA, 2007) | 100 | 0.024 |
| Life cycle assessment for the "implicit" environmental impact of construction projects (SHUAI; LI; TANG, 2009) | 100 | 0.024 |
| **Cluster #5 (orange)** | | |
| The evolution of the ENERGY STAR® energy performance indicator for benchmarking industrial plant manufacturing energy use (BOYD; DUTROW; TUNNESSEN, 2008) | 71 | 0.049 |
| LCA study and environmental benefits for low temperature disinfection process in commercial laundry (EBERLE et al., 2007) | 100 | 0.016 |
| * 43% remaining attributed to Cluster #3 (blue) | | |

Source: Author's elaboration using Biblioshiny (ARIA; CUCCURULLO, 2017)

Table B.10 – Thematic map clusters' top keywords – 3rd time slice (2011 – 2014)

| Cluster | Keywords | Occurrences |
|---|---|---|
| Cluster #1 (blue) | energy efficiency | 28 |
| | energy consumption | 17 |
| | energy indicators | 8 |
| | buildings | 5 |
| | energy performance | 3 |
| | TOTAL | 70 |
| Cluster #2 (green) | energy performance indicator (enpi) | 13 |
| | energy management | 6 |
| | iso 50001 standard | 4 |
| | energy benchmarking | 3 |
| | energy management system (enms) | 3 |
| | TOTAL | 35 |
| Cluster #3 (purple) | energy efficiency indicator | 13 |
| | energy intensity | 5 |

| Cluster | Keywords | | Occurrences |
|---|---|---|---|
| | energy savings | | 3 |
| | cold roll forming | | 2 |
| | energy policy | | 2 |
| | | TOTAL | 29 |
| Cluster #4 (brown) | industry | | 4 |
| | | TOTAL | 4 |
| Cluster #5 (orange) | co2 emissions | | 3 |
| | | TOTAL | 3 |
| Cluster #6 (grey) | linear regression | | 2 |
| | | TOTAL | 2 |

Source: Author's elaboration using data processed in Bibliometrix (ARIA; CUCCURULLO, 2017)

Table B.11 – Top 3 most relevant documents of each thematic map cluster – 3rd time slice (2011 – 2014)

| Cluster and documents | BP (%) | PR |
|---|---|---|
| **Cluster #1 (blue)** | | |
| Modeling the performance of residential building envelope: the role of sustainable energy performance indicators (MWASHA; WILLIAMS; IWARO, 2011) | 100 | 0.189 |
| Significance of sub-criteria in measuring sustainable performance of building envelope development (MWASHA; WILLIAMS; IWARO, 2013) | 100 | 0.189 |
| Energy and the US hardwood industry – Part II: responses to increasing prices (ESPINOZA; BUEHLMANN; BOND, 2011) | 100 | 0.148 |
| **Cluster #2 (green)** | | |
| Energy efficiency improvement in the cement industry by wet process through integral energy management system implementation (CASTRILLON; GONZÁLEZ; QUISPE, 2013) | 97 | 0.148 |
| LeanergyTM: how lean manufacturing can improve energy efficiency (RICHE, 2013) | 97 | 0.140 |
| Energy efficiency improvement in the cement industry through energy management (GONZÁLEZ; CASTRILLÓN; QUISPE, 2012) | 91 | 0.141 |
| **Cluster #3 (purple)** | | |
| Revisiting energy efficiency fundamentals (PÉREZ-LOMBARD; ORTIZ; VELÁZQUEZ, 2013) | 95 | 0.128 |
| Minimal energy efficiency indicators for poultry industries (GIASSON et al., 2014) | 76 | 0.106 |
| Russian energy efficiency accounting system (BASHMAKOV; MYSHAK, 2014) | 100 | 0.048 |
| **Cluster #4 (brown)** | | |
| Energy efficiency indicators assessment tool for the industry sector (SIEBERT et al., 2014) | 77 | 0.047 |
| Methodological differences behind energy statistics for steel production - implications when monitoring energy efficiency (MORFELDT; SILVEIRA, 2014) | 100 | 0.014 |
| Industrial combined heat and power (CHP) planning: development of a methodology and application in Greece (SALTA; POLATIDIS; HARALAMBOPOULOS, 2011) | 100 | 0.014 |
| **Cluster #5 (orange)** | | |
| An econometric study of carbon dioxide (co2) emissions, energy consumption, and economic growth of Pakistan (HUSSAIN; JAVAID; DRAKE, 2012) | 85 | 0.046 |
| Optimal power management with GHG emissions limitation in all-electric ship power systems comprising energy storage systems (KANELLOS, 2014) | 100 | 0.009 |
| **Cluster #6 (grey)** | | |
| Estimation model and benchmarks for heating energy consumption of schools and sport facilities in Germany (BEUSKER; STOY; POLLALIS, 2012) | 55* | 0.055 |
| Investigation and analysis on the energy consumption of starred hotel buildings in Hainan province, the tropical region of China (LU et al., 2013) | 100 | 0.006 |
| * 45% remaining attributed to Cluster #2 (green) | | |

Source: Author's elaboration using (Aria & Cuccurullo, 2017)etrix (ARIA; CUCCURULLO, 2017)

Table B.12 – Thematic map clusters' top keywords – 4th time slice (2015 – 2018)

| Cluster | Keywords | Occurrences |
|---|---|---|
| Cluster #1 (red) | energy efficiency | 75 |
| | energy performance indicator (enpi) | 35 |
| | energy consumption | 18 |
| | energy benchmarking | 10 |
| | energy management | 10 |
| | TOTAL | 212 |
| Cluster #2 (green) | energy efficiency indicator | 17 |
| | buildings | 11 |
| | energy savings | 9 |
| | district heating | 4 |
| | energy policy | 4 |
| | TOTAL | 67 |
| Cluster #3 (blue) | energy performance | 12 |
| | energy indicators | 9 |
| | specific models | 5 |
| | artificial lighting | 4 |
| | smart metering | 4 |
| | TOTAL | 54 |
| Cluster #4 (purple) | co2 emissions | 5 |
| | industry | 5 |
| | ignition delay time | 2 |
| | TOTAL | 12 |
| Cluster #5 (grey) | life cycle assessment (lca) | 3 |
| | environmental impact | 2 |
| | TOTAL | 5 |
| Cluster #6 (brown) | optimization | 3 |
| | TOTAL | 3 |

Source: Author's elaboration using data processed in Bibliometrix (ARIA; CUCCURULLO, 2017)

Table B.13 – Top 3 most relevant documents of each thematic map cluster – 4th time slice (2015 – 2018)

| Cluster and documents | BP (%) | PR |
|---|---|---|
| **Cluster #1 (red)** | | |
| A new benchmark of energy performance for energy management in US and Canadian integrated steel plants (BOYD et al., 2016) | 100 | 0.203 |
| Industrial energy management systems in Italy: State of the art and perspective (BONACINA et al., 2015) | 100 | 0.200 |
| From energy targets setting to energy-aware operations control and back: an advanced methodology for energy efficient manufacturing (BENEDETTI; CESAROTTI; INTRONA, 2017) | 100 | 0.182 |
| **Cluster #2 (green)** | | |
| Involvement of individuals in the development of technical solutions and rules of management for building renovation projects: A case study of Latvia (PUKITE et al., 2017) | 93 | 0.153 |
| A harmonized calculation model for transforming EU bottom-up energy efficiency indicators into empirical estimates of policy impacts (HOROWITZ; BERTOLDI, 2015) | 97 | 0.135 |
| Building professionals' views on energy efficiency compliance requirements (NAIR et al., 2017) | 68 | 0.187 |
| **Cluster #3 (blue)** | | |
| Providing power supply to other use cases integrated in the system of public lighting (PERKO; TOPIĆ; ŠLJIVAC, 2017) | 96 | 0.187 |
| Environmental and energy performance of public lighting installations: Results of a measurement campaign (AGHEMO et al., 2018) | 89 | 0.172 |
| Towards energy efficiency of interdependent urban networks (ALONGE et al., 2016) | 99 | 0.137 |

| Cluster and documents | BP (%) | PR |
|---|---|---|
| **Cluster #4 (purple)** | | |
| Evaluation methodology for energy efficiency measures in industry and service sector (TALLINI; CEDOLA, 2016) | 83 | 0.175 |
| An energy consumption analysis on public applications in the city of Novi Sad (AŠONJA; RAJKOVIĆ, 2017) | 74 | 0.160 |
| Improving energy and climate indicators for the steel industry – The case of Sweden (MORFELDT et al., 2015) | 76 | 0.149 |
| **Cluster #5 (grey)** | | |
| Energy efficiency evaluation of coal production (PIKOŃ et al., 2015) | 98 | 0.125 |
| Efficient biomass value chains for heat production from energy crops in Ukraine (TRYBOI, 2018) | 61 | 0.132 |
| A review of key environmental and energy performance indicators for the case of renewable energy systems when integrated with storage solutions (KOURKOUMPAS et al., 2018) | 79 | 0.081 |
| **Cluster #6 (brown)** | | |
| Design and development of a software tool to assist ISO 50001 implementation in the manufacturing sector (BRUTON et al., 2018) | 57* | 0.034 |
| A multiple energy complementary strategy considering CCHP and flexible load in active distribution network (ZHOU; WANG; WANG, 2018) | 100 | 0.014 |
| A new method for the optimal control problem of path planning for unmanned ground systems (LIU et al., 2018a) | 100 | 0.007 |
| * 43% remaining attributed to Cluster #1 (red) | | |

Source: Author’s elaboration using data processed in Bibliometrix (ARIA; CUCCURULLO, 2017)

Table B.14 – Thematic map clusters’ top keywords – 5th time slice (2019 – 2022)

| Cluster | Keywords | Occurrences |
|---|---|---|
| Cluster #1 (red) | energy efficiency | 102 |
| | energy performance indicator (enpi) | 53 |
| | energy consumption | 40 |
| | renewable energy sources | 18 |
| | energy management system (enms) | 15 |
| | TOTAL | 329 |
| Cluster #2 (pink) | energy efficiency indicator | 26 |
| | energy audit | 15 |
| | energy savings | 9 |
| | analytic hierarchy process (ahp) | 3 |
| | energy services | 3 |
| | TOTAL | 59 |
| Cluster #3 (purple) | sustainability | 13 |
| | energy policy | 6 |
| | energy indicators | 6 |
| | green economy | 3 |
| | street lighting | 3 |
| | TOTAL | 31 |
| Cluster #4 (mint) | nearly zero energy building (nzeb) | 10 |
| | life cycle assessment (lca) | 4 |
| | numerical simulation | 3 |
| | TOTAL | 17 |
| Cluster #5 (blue) | co2 emissions | 12 |
| | biomass | 3 |
| | TOTAL | 15 |
| Cluster #6 (orange) | optimization | 13 |
| | TOTAL | 13 |
| Cluster #7 (cream) | energy saving management | 3 |
| | metallurgical enterprises | 3 |
| | projects portfolio | 3 |

| | | | |
|---|---|---|---|
| | | TOTAL | 9 |
| Cluster #8 (lemon) | smart metering | | 8 |
| | | TOTAL | 8 |
| Cluster #9 (light pink) | energy intensity | | 7 |
| | | TOTAL | 7 |
| Cluster #10 (brown) | linear regression | | 6 |
| | | TOTAL | 6 |
| Cluster #11 (green) | internet of things (iot) | | 5 |
| | | TOTAL | 5 |

Source: Author's elaboration using data processed in Bibliometrix (ARIA; CUCCURULLO, 2017)

Table B.15 – Top 3 most relevant documents of each thematic map cluster – 5th time slice (2019 – 2022)

| **Cluster and documents** | **BP (%)** | **PR** |
|---|---|---|
| **Cluster #1 (red)** | | |
| Specific energy consumption/use (SEC) in energy management for improving energy efficiency in industry: meaning, usage and differences (LAWRENCE et al., 2019) | 100 | 0.239 |
| Key performance indicators for energy management in the Swedish pulp and paper industry (ANDERSSON; THOLLANDER, 2019) | 100 | 0.238 |
| From energy audit to energy performance indicators (EnPI): a methodology to characterize productive sectors. The Italian cement industry case study (BRUNI et al., 2021) | 85 | 0.248 |
| **Cluster #2 (pink)** | | |
| The cost of indecision in energy efficiency. A cost of opportunity analysis for an industrial consumer (ISTRATE; GHEORGHIU; CASTRAVETE, 2020) | 92 | 0.178 |
| Energy performance improvement actions for power distribution networks in university campuses (GHEORGHIU et al., 2019b) | 80 | 0.200 |
| Rating of organization's energy efficiency based on Harrington's desirability function (LYUBCHENKO; ISKHAKOV; PAVLYUCHENKO, 2020) | 98 | 0.155 |
| **Cluster #3 (purple)** | | |
| Principles to define energy key performance indicators for the healthcare sector (LIU et al., 2020) | 70 | 0.201 |
| A decision support system for assessment of street lighting tenders based on energy performance indicators and environmental criteria: Overview, methodology and case study (DOULOS et al., 2019) | 98 | 0.142 |
| Analysis of the energy consumption structure and evaluation of energy performance indicators of the Italian ceramic industry (MARTINI et al., 2021) | 64 | 0.206 |
| **Cluster #4 (mint)** | | |
| Heating demand as an energy performance indicator: A case study of buildings built under the passive house standard in Spain (MARTÍNEZ-DE-ALEGRÍA et al., 2021) | 78 | 0.187 |
| Multi-criteria optimisation of an experimental complex of single-family nearly zero-energy buildings (FEDORCZAK-CISAK et al., 2020) | 70 | 0.154 |
| A full approach to earth-air heat exchanger employing computational modeling, performance analysis and geometric evaluation (RODRIGUES et al., 2022) | 82 | 0.091 |
| **Cluster #5 (blue)** | | |
| Review of the existing energy labelling systems and a proposal for rail vehicles (LIU; BERG; BUSTAD, 2021) | 90 | 0.122 |
| Environmental assessment of entropy control in flight process (SOGUT, 2021) | 90 | 0.122 |
| The nexus among energy consumption, economic growth and trade openness: evidence from West Africa (QI et al., 2022) | 77 | 0.057 |
| **Cluster #6 (orange)** | | |
| Decomposition of a cooling plant for energy efficiency optimization using OptTopo (THIELE et al., 2022) | 89 | 0.124 |
| Resource-energy efficiency of ESP-equipped wells operation management (approaches, models, methods) (SOLOVYEV; GOVORKOV; KONSTANTINOV, 2021) | 89 | 0.124 |
| Optimal assets management of a water distribution network for leakage minimization based on an innovative index (CAVAZZINI; PAVESI; ARDIZZON, 2020) | 80 | 0.076 |

| Cluster and documents | BP (%) | PR |
|---|---|---|
| **Cluster #7 (cream)** | | |
| Management of energy saving project and programs at metallurgical enterprises (KIVKO et al., 2019) | 99 | 0.127 |
| Model of forming and analysis of energy saving projects portfolio at metallurgical enterprises (SERGEY et al., 2020) | 99 | 0.127 |
| **Cluster #8 (lemon)** | | |
| A comprehensive review of maritime microgrids: system architectures, energy efficiency, power quality, and regulations (KUMAR; ZARE, 2019) | 93 | 0.124 |
| Decision support system to classify and optimize the energy efficiency in smart buildings: a data analytics approach (PEÑA; BISCARRI; PERSONAL ENRIQUE AND LEÓN, 2022) | 93 | 0.124 |
| Energy efficiency and power quality indicators of a micro grid. Case study: lighting systems (GHEORGHIU et al., 2019a) | 93 | 0.124 |
| **Cluster #9 (light pink)** | | |
| Analysis of energy and environmental indicators for sustainable operation of Mexican hotels in tropical climate aided by artificial intelligence (MENGUAL TORRES et al., 2022) | 96 | 0.116 |
| Load profiles clustering and knowledge extraction to assess actual usage of telecommunication sites (EIRAUDO et al., 2021) | 97 | 0.114 |
| Energy and reliability analysis of wastewater treatment plants in small communities in Ontario (HAMZA; HAMODA; ELASSAR, 2022) | 85 | 0.113 |
| **Cluster #10 (brown)** | | |
| Comparative and optimizing calculations of energy efficiency indicators for operation of CHP plants using the normative characteristics and mathematical models (TATARINOVA; SUVOROV, 2020) | 68 | 0.021 |
| Experimental study on energy efficiency of multi-functional BIPV glazed façade structure during heating season (DOMJAN et al., 2020) | 63 | 0.022 |
| Comprehensive analysis of important parameters of choline chloride-based deep eutectic solvent pre-treatment of lignocellulosic biomass (XU et al., 2021a) | 100 | 0.008 |
| **Cluster #11 (green)** | | |
| IOT based energy efficiency monitoring in stamping workshop (GAN et al., 2020) | 95 | 0.113 |
| Architecture of compressor equipment monitoring and control cyber-physical system based on influxdata platform (KYCHKIN et al., 2019) | 100 | 0.003 |
| Collaborative cloud-edge service cognition framework for DNN configuration toward smart IIOT (XIAO et al., 2022) | 100 | 0.003 |

Source: Author's elaboration using data processed in Bibliometrix (ARIA; CUCCURULLO, 2017)

In Chapter 4 – Section 4.3 – Subsection 4.3.3, findings related to content analysis were presented and complementary data related to those findings are presented in the following tables. The final selected articles references and titles are exhibited in Table B.16. Main approach, from Figure 4.26, of final selected articles are detailed in Table B.17.

Table B.16 – Final list of articles selected during content analysis

| Article | Title |
|---|---|
| (Ó GALLACHÓIR et al., 2007) | Using indicators to profile energy consumption and to inform energy policy in a university – A case study in Ireland |
| (ABRAHAM et al., 2021) | Identification of savings opportunities in a steel manufacturing industry |
| (ANDERSSON; ARFWIDSSON; THOLLANDER, 2018) | Benchmarking energy performance of industrial small and medium-sized enterprises using an energy efficiency index: Results based on an energy audit policy program |

| Article | Title |
|---|---|
| (ANDERSSON et al., 2021) | Decarbonization of industry: Implementation of energy performance indicators for successful energy management practices in kraft pulp mills |
| (ANDERSSON; THOLLANDER, 2019) | Key performance indicators for energy management in the Swedish pulp and paper industry |
| (BEISHEIM; KRÄMER; ENGELL, 2020) | Hierarchical aggregation of energy performance indicators in continuous production processes |
| (BEISHEIM et al., 2019) | Energy performance analysis of continuous processes using surrogate models |
| (BENEDETTI et al., 2018) | Explorative study on Compressed Air Systems - energy efficiency in production and use: First steps towards the creation of a benchmarking system for large and energy-intensive industrial firms |
| (BENEDETTI; CESAROTTI; INTRONA, 2017) | From energy targets setting to energy-aware operations control and back: An advanced methodology for energy efficient manufacturing |
| (BOYD; DUTROW; TUNNESSEN, 2008) | The evolution of the ENERGY STAR® energy performance indicator for benchmarking industrial plant manufacturing energy use |
| (BOYD; ZHANG, 2013) | Measuring improvement in energy efficiency of the US cement industry with the ENERGY STAR Energy Performance Indicator |
| (BRUNI et al., 2021) | From energy audit to energy performance indicators (Enpi): A methodology to characterize productive sectors. the Italian cement industry case study |
| (CABELLO ERAS et al., 2019) | Energy management in the formation of light, starter, and ignition lead-acid batteries |
| (CABELLO ERAS et al., 2020) | Energy management of compressed air systems. Assessing the production and use of compressed air in industry |
| (CASTRILLÓN-MENDOZA; REY-HERNÁNDEZ; REY-MARTÍNEZ, 2020) | Industrial decarbonization by a new energy-baseline methodology. Case study |
| (COROIU; CHINDRIS, 2014) | Energy efficiency indicators and methodology for evaluation of energy performance and retained savings |
| (COSGROVE; LITTLEWOOD; WILGEROTH, 2018) | Development of a framework of key performance indicators to identify reductions in energy consumption in a medical devices production facility |
| (FICHERA; VOLPE; CUTORE, 2020) | Energy performance measurement, monitoring and control for buildings of public organizations: Standardized practises compliant with the ISO 50001 and ISO 50006 |
| (FINNERTY et al., 2017) | Development of a Global Energy Management System for non-energy intensive multi-site industrial organisations: A methodology |
| (GHEORGHIU et al., 2021) | Energy efficiency in the building materials industry. Case study: Brick manufacturing in Romania |
| (HILLIARD; JAMIESON; JORJANI, 2014) | Communicating a model-based energy performance indicator |
| (HOANG; DO; IUNG, 2017) | Energy efficiency performance-based prognostics for aided maintenance decision-making: Application to a manufacturing platform |
| (IONESCU; DARIE, 2020) | Energy Effectiveness-New Energy Performance Indicator to optimize the Industrial Energy Consumptions |
| (IONESCU; DARIE, 2018) | New Method to Assess the Energy Efficiency and Energy Effectiveness to the Industrial End-Users |
| (JOHNSSON et al., 2019) | Energy savings and greenhouse gas mitigation potential in the Swedish wood industry |
| (KANCHIRALLA et al., 2020) | Energy end-use categorization and performance indicators for energy management in the engineering industry |
| (KANCHIRALLA et al., 2021) | Energy use categorization with performance indicators for the food industry and a conceptual energy planning framework |
| (LIU et al., 2018b) | An input-output model for energy accounting and analysis of industrial production processes: a case study of an integrated steel plant |
| (MENDOZA et al., 2019) | Analysis of the methodology to obtain several key indicators performance (KIP), by energy retrofitting of the actual building to the |

| Article | Title |
|---|---|
| | district heating fuelled by biomass, focusing on nZEB goal: Case of study |
| (MENGHI et al., 2019) | Energy efficiency of manufacturing systems: A review of energy assessment methods and tools |
| (MOGHADASI et al., 2021) | Applying machine learning techniques to implement the technical requirements of energy management systems in accordance with ISO 50001:2018, an industrial case study |
| (MORFELDT et al., 2015) | Improving energy and climate indicators for the steel industry - The case of Sweden |
| (MUTSCHLER-BURGHARD, 2019) | Improving Energy Performance Indicators with the Help of Multivariable Linear Regression |
| (NAKTHONG; KUBAHA, 2020) | A simplified model of energy performance indicators for sustainable energy management |
| (O'DRISCOLL; ÓG CUSACK; O'DONNELL, 2013) | The development of energy performance indicators within a complex manufacturing facility |
| (OCAMPO BATLLE et al., 2020) | A methodology to estimate baseline energy use and quantify savings in electrical energy consumption in higher education institution buildings: Case study, Federal University of Itajubá (UNIFEI) |
| (OCHOA; FORERO; BARRETO, 2018) | Use of energy performance indicators for the energy diagnosis of a bottling plant |
| (PÉREZ-LOMBARD et al., 2012) | Constructing HVAC energy efficiency indicators |
| (PÉREZ-LOMBARD; ORTIZ; VELÁZQUEZ, 2013) | Revisiting energy efficiency fundamentals |
| (PENA MARRIAGA et al., 2018) | Calculation of energy performance indicators of a company in the hotel sector |
| (PERRONI et al., 2018) | Measuring energy performance: A process based approach |
| (ROTH; BROWN IV; JAIN, 2020) | Harnessing smart meter data for a Multitiered Energy Management Performance Indicators (MEMPI) framework: A facility manager informed approach |
| (SAGASTUME GUTIÉRREZ et al., 2018) | Electricity management in the production of lead-acid batteries: The industrial case of a production plant in Colombia |
| (SALVATORI et al., 2018) | Inter-sectorial benchmarking of compressed air generation energy performance: Methodology based on real data gathering in large and energy-intensive industrial firms |
| (GÓMEZ SARDUY et al., 2018) | A new energy performance indicator for energy management system of a wheat mill plant |
| (SHIM; LEE, 2018) | A study of determination of energy performance indicator for applying energy management system in industrial sector |
| (SIEBERT et al., 2014) | Energy efficiency indicators assessment tool for the industry sector |
| (SIITONEN; TUOMAALA; AHTILA, 2010) | Variables affecting energy efficiency and CO2 emissions in the steel industry |
| (VALENCIA-OCHOA et al., 2017) | Energy saving in industrial process based on the equivalent production method to calculate energy performance indicators |

Source: Author's elaboration using data processed in StArt (FABBRI et al., 2016)

Table B.17 – Final list of articles selected during content analysis – Main approaches

| Article | Main approaches | | | | |
|---|---|---|---|---|---|
| | Indicators | Energy management | Benchmarking | EPIAs | Improvement evaluation |
| (Ó GALLACHÓIR et al., 2007) | X | - | X | - | - |
| (ABRAHAM et al., 2021) | - | X | - | X | - |
| (ANDERSSON; ARFWIDSSON; THOLLANDER, 2018) | X | - | X | - | - |
| (ANDERSSON et al., 2021) | - | X | - | - | - |

| Article | Main approaches | | | | |
|---|---|---|---|---|---|
| | **Indicators** | **Energy management** | **Benchmarking** | **EPIAs** | **Improvement evaluation** |
| (ANDERSSON; THOLLANDER, 2019) | X | - | X | - | - |
| (BEISHEIM; KRÄMER; ENGELL, 2020) | X | X | - | - | X |
| (BEISHEIM et al., 2019) | X | - | - | - | X |
| (BENEDETTI et al., 2018) | X | - | X | - | - |
| (BENEDETTI; CESAROTTI; INTRONA, 2017) | X | - | - | - | - |
| (BOYD; DUTROW; TUNNESSEN, 2008) | X | - | X | - | - |
| (BOYD; ZHANG, 2013) | X | - | X | - | - |
| (BRUNI et al., 2021) | X | - | X | X | - |
| (CABELLO ERAS et al., 2019) | - | X | - | - | - |
| (CABELLO ERAS et al., 2020) | - | X | X | X | - |
| (CASTRILLÓN-MENDOZA; REY-HERNÁNDEZ; REY-MARTÍNEZ, 2020) | X | X | X | - | - |
| (COROIU; CHINDRIS, 2014) | X | - | - | - | X |
| (COSGROVE; LITTLEWOOD; WILGEROTH, 2018) | X | - | - | - | - |
| (FICHERA; VOLPE; CUTORE, 2020) | X | - | X | - | - |
| (FINNERTY et al., 2017) | - | X | X | - | - |
| (GHEORGHIU et al., 2021) | X | - | - | - | - |
| (HILLIARD; JAMIESON; JORJANI, 2014) | X | - | - | - | - |
| (HOANG; DO; IUNG, 2017) | - | - | - | X | - |
| (IONESCU; DARIE, 2020) | X | - | - | - | - |
| (IONESCU; DARIE, 2018) | - | - | - | - | X |
| (JOHNSSON et al., 2019) | - | - | - | X | - |
| (KANCHIRALLA et al., 2020) | - | X | - | X | - |
| (KANCHIRALLA et al., 2021) | X | - | X | - | - |
| (LIU et al., 2018b) | X | - | - | - | - |
| (MENDOZA et al., 2019) | X | - | - | - | - |
| (MENGHI et al., 2019) | X | - | X | - | - |
| (MOGHADASI et al., 2021) | X | X | - | - | - |
| (MORFELDT et al., 2015) | X | - | - | - | - |
| (MUTSCHLER-BURGHARD, 2019) | X | - | - | - | - |
| (NAKTHONG; KUBAHA, 2020) | X | X | X | - | - |
| (O'DRISCOLL; ÓG CUSACK; O'DONNELL, 2013) | X | - | - | - | - |
| (OCAMPO BATLLE et al., 2020) | - | - | - | - | X |
| (OCHOA; FORERO; BARRETO, 2018) | X | - | - | - | - |
| (PÉREZ-LOMBARD et al., 2012) | X | - | - | - | - |
| (PÉREZ-LOMBARD; ORTIZ; VELÁZQUEZ, 2013) | X | - | - | - | - |
| (PENA MARRIAGA et al., 2018) | X | - | - | - | - |
| (PERRONI et al., 2018) | X | - | - | - | - |
| (ROTH; BROWN IV; JAIN, 2020) | X | - | X | - | - |
| (SAGASTUME GUTIÉRREZ et al., 2018) | - | X | - | - | - |
| (SALVATORI et al., 2018) | X | - | X | - | - |

| Article | Main approaches<br>Indicators | Energy management | Benchmarking | EPIAs | Improvement evaluation |
|---|---|---|---|---|---|
| (GOMEZ SARDUY et al., 2018) | - | X | - | - | - |
| (SHIM; LEE, 2018) | - | X | - | - | - |
| (SIEBERT et al., 2014) | X | - | X | - | - |
| (SIITONEN; TUOMAALA; AHTILA, 2010) | X | - | - | - | - |
| (VALENCIA-OCHOA et al., 2017) | X | - | - | - | - |

Source: Author's elaboration using data processed in StArt (FABBRI et al., 2016)

Consolidated findings presented in Figure 4.27 are detailed by article in Table B.18, Table B.19, and Table B.20. While the previous tables contained the full list of final selected articles, the two last tables contain only the articles that fulfill at least one column criterion.

Table B.18 – Final list of articles selected during content analysis – Sectoral coverage and energy performance accounting method reference mentioned

| | Sectoral coverage | | Energy performance accounting method reference mentioned | | | |
|---|---|---|---|---|---|---|
| **Article** | **Sector** | **Subsector** | **ISO 50001** | **ISO 50006** | **ENERGY STAR** | **Other standards** |
| (Ó GALLACHÓIR et al., 2007) | Buildings | Education | - | - | - | - |
| (ABRAHAM et al., 2021) | Industry | Iron and Steel | X | X | - | - |
| (ANDERSSON; ARFWIDSSON; THOLLANDER, 2018) | Industry | SMEs | - | - | X | EN 16231<br>EN 16212 |
| (ANDERSSON et al., 2021) | Industry | Pulp and Paper | X | X | - | - |
| (ANDERSSON; THOLLANDER, 2019) | Industry | Pulp and Paper | X | - | - | EN 16247-3 |
| (BEISHEIM; KRÄMER; ENGELL, 2020) | General | General | X | - | - | EN 16247-1 |
| (BEISHEIM et al., 2019) | General | General | X | X | - | - |
| (BENEDETTI et al., 2018) | Industry | Energy process | - | - | - | - |
| (BENEDETTI; CESAROTTI; INTRONA, 2017) | General | General | X | X | - | - |
| (BOYD; DUTROW; TUNNESSEN, 2008) | Industry | Manufacturing | - | - | X | - |
| (BOYD; ZHANG, 2013) | Industry | Cement | - | - | X | - |
| (BRUNI et al., 2021) | Industry | Cement | X | X | - | - |
| (CABELLO ERAS et al., 2019) | Industry | Manufacturing | X | X | - | - |
| (CABELLO ERAS et al., 2020) | Industry | Energy process | X | X | - | - |
| (CASTRILLÓN-MENDOZA; REY-HERNÁNDEZ; REY-MARTÍNEZ, 2020) | Industry | General | X | X | - | - |
| (COROIU; CHINDRIS, 2014) | General | General | - | - | - | - |
| (COSGROVE; LITTLEWOOD; WILGEROTH, 2018) | Industry | Manufacturing | X | - | - | - |
| (FICHERA; VOLPE; CUTORE, 2020) | Buildings | Public | X | X | - | - |

| Article | Sectoral coverage | | Energy performance accounting method reference mentioned | | | |
|---|---|---|---|---|---|---|
| | Sector | Subsector | ISO 50001 | ISO 50006 | ENERGY STAR | Other standards |
| (FINNERTY et al., 2017) | Industry | Manufacturing | X | - | X | VDI 4602 |
| (GHEORGHIU et al., 2021) | Industry | Ceramic | - | - | - | - |
| (HILLIARD; JAMIESON; JORJANI, 2014) | General | General | - | - | - | - |
| (HOANG; DO; IUNG, 2017) | Industry | Manufacturing | X | - | - | - |
| (IONESCU; DARIE, 2020) | Industry | General | - | - | - | - |
| (IONESCU; DARIE, 2018) | Industry | General | - | - | - | - |
| (JOHNSSON et al., 2019) | Industry | Wood | - | - | - | - |
| (KANCHIRALLA et al., 2020) | Industry | Manufacturing | - | X | - | - |
| (KANCHIRALLA et al., 2021) | Industry | Food | X | - | - | - |
| (LIU et al., 2018b) | Industry | Iron and Steel | - | - | - | - |
| (MENDOZA et al., 2019) | Buildings | Residential | X | X | - | - |
| (MENGHI et al., 2019) | General | General | X | X | X | - |
| (MOGHADASI et al., 2021) | Industry | General | X | - | - | - |
| (MORFELDT et al., 2015) | Industry | Iron and Steel | - | - | - | - |
| (MUTSCHLER-BURGHARD, 2019) | General | General | X | - | - | - |
| (NAKTHONG; KUBAHA, 2020) | General | General | X | - | - | - |
| (O'DRISCOLL; ÓG CUSACK; O'DONNELL, 2013) | Industry | Manufacturing | X | - | - | - |
| (OCAMPO BATLLE et al., 2020) | Buildings | Education | X | X | - | - |
| (OCHOA; FORERO; BARRETO, 2018) | Industry | Manufacturing | X | - | - | - |
| (PÉREZ-LOMBARD et al., 2012) | Buildings | Commercial | - | - | - | ISO 13600 |
| (PÉREZ-LOMBARD; ORTIZ; VELÁZQUEZ, 2013) | Buildings | Commercial | - | - | - | - |
| (PENA MARRIAGA et al., 2018) | Buildings | Hospitality | X | - | - | - |
| (PERRONI et al., 2018) | General | General | - | - | - | - |
| (ROTH; BROWN IV; JAIN, 2020) | Buildings | Commercial | - | - | - | - |
| (SAGASTUME GUTIÉRREZ et al., 2018) | Industry | Manufacturing | X | X | - | - |
| (SALVATORI et al., 2018) | Industry | Energy process | - | - | - | - |
| (GÓMEZ SARDUY et al., 2018) | Industry | Food | X | - | - | - |
| (SHIM; LEE, 2018) | Industry | General | X | X | - | - |
| (SIEBERT et al., 2014) | Industry | General | - | - | - | - |
| (SIITONEN; TUOMAALA; AHTILA, 2010) | Industry | Iron and Steel | - | - | - | - |
| (VALENCIA-OCHOA et al., 2017) | Industry | General | X | - | - | - |

Source: Author's elaboration using data processed in StArt (FABBRI et al., 2016)

Table B.19 – Final list of articles selected during content analysis – Energy model

| | Energy Model | | | | | | |
|---|---|---|---|---|---|---|---|
| **Article** | **Statistical method (LR)** | **Ratio** | **Statistical method (MLR)** | **Simple metric** | **Eng. model** | **Statistical method (NLR)** | **Other models** |
| (Ó GALLACHÓIR et al., 2007) | - | X | - | - | X | - | - |
| (ABRAHAM et al., 2021) | X | - | - | - | - | - | - |
| (ANDERSSON; ARFWIDSSON; THOLLANDER, 2018) | - | X | - | - | - | - | - |
| (ANDERSSON et al., 2021) | - | X | X | - | - | - | - |
| (ANDERSSON; THOLLANDER, 2019) | - | X | - | - | - | - | - |
| (BEISHEIM; KRÄMER; ENGELL, 2020) | X | - | - | - | - | X | - |
| (BEISHEIM et al., 2019) | - | - | - | - | - | X | - |
| (BENEDETTI et al., 2018) | X | - | - | - | - | - | - |
| (BENEDETTI; CESAROTTI; INTRONA, 2017) | X | X | X | X | X | - | - |
| (BOYD; DUTROW; TUNNESSEN, 2008) | X | - | X | - | - | - | - |
| (BOYD; ZHANG, 2013) | - | - | X | - | - | - | - |
| (BRUNI et al., 2021) | X | - | - | - | - | - | - |
| (CABELLO ERAS et al., 2019) | X | - | - | - | - | - | - |
| (CABELLO ERAS et al., 2020) | X | - | - | - | - | - | - |
| (CASTRILLÓN-MENDOZA; REY-HERNÁNDEZ; REY-MARTÍNEZ, 2020) | X | - | - | - | - | - | - |
| (COROIU; CHINDRIS, 2014) | - | X | - | - | - | - | - |
| (COSGROVE; LITTLEWOOD; WILGEROTH, 2018) | X | - | - | - | - | - | - |
| (FICHERA; VOLPE; CUTORE, 2020) | X | - | - | - | - | - | - |
| (FINNERTY et al., 2017) | - | X | - | - | - | - | - |
| (GHEORGHIU et al., 2021) | - | X | - | - | - | - | - |
| (HILLIARD; JAMIESON; JORJANI, 2014) | X | - | X | - | - | - | - |
| (HOANG; DO; IUNG, 2017) | - | - | - | - | - | X | - |
| (IONESCU; DARIE, 2020) | - | X | - | - | - | - | - |
| (IONESCU; DARIE, 2018) | - | X | - | - | - | - | - |
| (JOHNSSON et al., 2019) | - | X | X | - | - | - | - |
| (KANCHIRALLA et al., 2020) | X | X | - | X | - | - | - |
| (KANCHIRALLA et al., 2021) | X | X | - | X | - | - | - |
| (LIU et al., 2018b) | - | - | - | - | - | - | Input-Output model |
| (MENDOZA et al., 2019) | X | - | - | - | - | - | - |

| Article | Energy Model | | | | | | |
|---|---|---|---|---|---|---|---|
| | Statistical method (LR) | Ratio | Statistical method (MLR) | Simple metric | Eng. model | Statistical method (NLR) | Other models |
| (MENGHI et al., 2019) | X | X | X | - | - | - | - |
| (MOGHADASI et al., 2021) | - | - | - | - | - | - | Machine learning |
| (MORFELDT et al., 2015) | - | X | - | - | - | - | - |
| (MUTSCHLER-BURGHARD, 2019) | - | - | X | - | - | - | - |
| (NAKTHONG; KUBAHA, 2020) | - | - | X | - | - | - | - |
| (O'DRISCOLL; ÓG CUSACK; O'DONNELL, 2013) | - | - | X | - | - | - | - |
| (OCAMPO BATLLE et al., 2020) | X | - | - | - | - | - | - |
| (OCHOA; FORERO; BARRETO, 2018) | X | - | - | - | - | - | - |
| (PÉREZ-LOMBARD et al., 2012) | - | X | - | - | - | - | - |
| (PENA MARRIAGA et al., 2018) | X | - | - | - | - | - | - |
| (PERRONI et al., 2018) | - | - | - | - | - | - | Input-Output model |
| (ROTH; BROWN IV; JAIN, 2020) | X | - | X | - | - | - | - |
| (SAGASTUME GUTIÉRREZ et al., 2018) | X | - | - | - | - | - | - |
| (SALVATORI et al., 2018) | X | - | - | - | - | - | - |
| (GÓMEZ SARDUY et al., 2018) | - | - | X | - | - | - | - |
| (SHIM; LEE, 2018) | X | X | X | X | X | - | - |
| (SIEBERT et al., 2014) | - | X | - | - | - | - | - |
| (SIITONEN; TUOMAALA; AHTILA, 2010) | - | X | X | - | - | - | - |
| (VALENCIA-OCHOA et al., 2017) | X | - | X | - | - | - | - |

Source: Author's elaboration using data processed in StArt (FABBRI et al., 2016)

Table B.20 – Final list of articles selected during content analysis – Indicator type

| Article | SEC | Simple metric | CUSUM | Specific GHG | EEI or I100 | Energy /m$^2$ | Energy Efficiency | Intensity |
|---|---|---|---|---|---|---|---|---|
| (Ó GALLACHÓIR et al., 2007) | - | - | - | - | - | X | - | Energy |
| (ABRAHAM et al., 2021) | - | Energy | - | - | - | - | - | - |
| (ANDERSSON; ARFWIDSSON; THOLLANDER, 2018) | X | - | - | - | X | X | - | - |
| (ANDERSSON et al., 2021) | X | - | - | X | - | - | - | - |
| (ANDERSSON; THOLLANDER, 2019) | X | - | - | - | - | - | - | - |

| Article | SEC | Simple metric | CUSUM | Specific GHG | EEI or I100 | Energy /$m^2$ | Energy Efficiency | Intensity |
|---|---|---|---|---|---|---|---|---|
| (BEISHEIM; KRAMER; ENGELL, 2020) | X | - | - | X | - | - | - | - |
| (BEISHEIM et al., 2019) | X | - | - | - | - | - | - | - |
| (BENEDETTI et al., 2018) | - | Energy | - | - | - | - | - | - |
| (BENEDETTI; CESAROTTI; INTRONA, 2017) | X | Energy | X | - | - | - | X | - |
| (BOYD; DUTROW; TUNNESSEN, 2008) | X | Energy | - | - | - | - | - | - |
| (BOYD; ZHANG, 2013) | X | Energy | - | - | - | - | - | - |
| (BRUNI et al., 2021) | X | Energy | - | - | - | - | - | - |
| (CABELLO ERAS et al., 2019) | X | Energy | - | - | - | - | - | - |
| (CABELLO ERAS et al., 2020) | - | Energy | X | - | - | - | - | - |
| (CASTRILLÓN-MENDOZA; REY-HERNÁNDEZ; REY-MARTÍNEZ, 2020) | - | Energy and GHG | - | - | - | - | - | - |
| (COROIU; CHINDRIS, 2014) | X | - | - | - | X | - | - | - |
| (COSGROVE; LITTLEWOOD; WILGEROTH, 2018) | X | - | X | - | X | - | - | - |
| (FICHERA; VOLPE; CUTORE, 2020) | - | - | X | - | - | X | - | - |
| (FINNERTY et al., 2017) | - | - | - | - | - | X | - | - |
| (GHEORGHIU et al., 2021) | X | GHG | - | X | - | - | - | Energy and GHG |
| (HILLIARD; JAMIESON; JORJANI, 2014) | - | Energy | X | - | - | - | - | - |
| (HOANG; DO; IUNG, 2017) | X | Energy | - | - | X | - | - | - |
| (IONESCU; DARIE, 2020) | X | - | - | - | - | - | - | - |
| (IONESCU; DARIE, 2018) | X | - | - | - | - | - | - | - |
| (JOHNSSON et al., 2019) | X | - | - | - | - | - | - | - |
| (KANCHIRALLA et al., 2020) | X | Energy | - | X | - | - | X | Energy |
| (KANCHIRALLA et al., 2021) | X | Energy | - | X | - | - | X | Energy |
| (LIU et al., 2018b) | X | - | - | - | - | - | - | - |
| (MENDOZA et al., 2019) | - | Energy and GHG | X | - | I100 | X | - | - |
| (MENGHI et al., 2019) | X | Energy | X | - | - | - | X | - |
| (MOGHADASI et al., 2021) | - | Energy and GHG | - | - | X | - | - | - |

| Article | SEC | Simple metric | CUSUM | Specific GHG | EEI or I100 | Energy /m$^2$ | Energy Efficiency | Intensity |
|---|---|---|---|---|---|---|---|---|
| (MORFELDT et al., 2015) | X | - | - | X | X | - | - | Energy and GHG |
| (MUTSCHLER-BURGHARD, 2019) | X | Energy | - | - | - | - | - | - |
| (NAKTHONG; KUBAHA, 2020) | X | Energy | X | - | - | - | - | - |
| (O'DRISCOLL; ÓG CUSACK; O'DONNELL, 2013) | - | Energy | - | - | - | - | - | - |
| (OCAMPO BATLLE et al., 2020) | - | Energy and GHG | - | - | - | - | - | - |
| (OCHOA; FORERO; BARRETO, 2018) | X | Energy | X | - | I100 | - | - | - |
| (PÉREZ-LOMBARD et al., 2012) | - | - | - | - | - | X | - | - |
| (PÉREZ-LOMBARD; ORTIZ; VELÁZQUEZ, 2013) | X | Energy | - | - | X | - | X | Energy |
| (PENA MARRIAGA et al., 2018) | - | Energy | X | - | I100 | - | - | - |
| (PERRONI et al., 2018) | - | - | - | - | - | - | X | - |
| (ROTH; BROWN IV; JAIN, 2020) | - | Energy | - | - | - | - | - | - |
| (SAGASTUME GUTIÉRREZ et al., 2018) | X | Energy and GHG | - | - | - | - | - | - |
| (SALVATORI et al., 2018) | X | Energy | - | - | - | - | - | - |
| (GÓMEZ SARDUY et al., 2018) | X | Energy | - | - | - | - | - | - |
| (SIEBERT et al., 2014) | X | - | - | X | - | X | - | Energy |
| (SIITONEN; TUOMAALA; AHTILA, 2010) | X | - | - | X | X | - | - | - |
| (VALENCIA-OCHOA et al., 2017) | X | Energy | - | - | I100 | - | - | - |

Source: Author's elaboration using data processed in StArt (FABBRI et al., 2016)

# APPENDIX C. COMPLEMENTARY DATA TO COMBINING GHG EMISSION ACCOUNTING WITH ENERGY PERFORMANCE INDICATORS

In Chapter 5 – Section 5.3 – a case study in petroleum refining sector was developed, database information and regression analysis reports related to this case study are presented in the following tables. Database used for case study regression analysis is presented in Table C.1. Regression analysis reports are exhibited in Table C.2 and Table C.3 for Refinery 1, and in Table C.4 and Table C.5 for Refinery 2. Results from energy performance evaluation reported in Figure 5.7 are detailed in Table C.6 and Table C.7. Results from GHG emission accounting reported in Figure 5.8 are detailed in Table C.8 and Table C.9.

Table C.1 – Database for case study regression analysis

| | Refinery 1 | | | | | Refinery 2 | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Month** | **E (PJ)** | **T (MBBL /month)** | **NRGF** | **S (%)** | **Density ($kg/m^3$)** | **E (PJ)** | **T (MBBL /month)** | **NRGF** | **S (%)** | **Density ($kg/m^3$)** |
| 1 | 3292 | 5.12 | 9.51 | 0.24 | 873 | 2514.7 | 4.22 | 7.58 | 0.22% | 827 |
| 2 | 3510 | 5.31 | 9.37 | 0.27 | 880 | 2759.9 | 4.11 | 8.1 | 0.27% | 829 |
| 3 | 3317 | 5.02 | 8.92 | 0.23 | 869 | 2954.6 | 3.67 | 8.75 | 0.34 | 898 |
| 4 | 2832 | 5.48 | 7.58 | 0.22 | 867 | 2505.9 | 3.7 | 8.04 | 0.48 | 933 |
| 5 | 3068 | 4.70 | 8.47 | 0.25 | 879 | 2150.6 | 3.74 | 7.47 | 0.25 | 883 |
| 6 | 3760 | 5.60 | 9.51 | 0.26 | 885 | 2809.8 | 4.07 | 8.51 | 0.26 | 925 |
| 7 | 3383 | 5.45 | 8.74 | 0.25 | 877 | 2573.9 | 3.92 | 8.04 | 0.25 | 847 |
| 8 | 3519 | 4.96 | 9.06 | 0.29 | 883 | 2903.3 | 3.78 | 8.66 | 0.29 | 833 |
| 9 | 2888 | 5.37 | 8.03 | 0.22 | 870 | 2849.6 | 3.78 | 8.51 | 0.24 | 873 |
| 10 | 4527 | 4.56 | 11.43 | 1.05 | 920 | 2586.1 | 4 | 7.88 | 0.31 | 828 |
| 11 | 2946 | 4.92 | 8.46 | 0.63 | 893 | 2695 | 3.74 | 8.32 | 0.51 | 867 |
| 12 | 2692 | 3.89 | 9.36 | 0.45 | 867 | 3011.6 | 3.7 | 8.87 | 0.27 | 850 |
| 13 | 3010 | 3.65 | 8.93 | 0.79 | 893 | 2876.7 | 3.81 | 8.92 | 0.23 | 849 |
| 14 | 3084 | 5.42 | 8.49 | 0.26 | 837 | 2517 | 4.25 | 7.63 | 0.22 | 880 |
| 15 | 2629 | 5.25 | 7.04 | 0.45 | 853 | 3151.4 | 3.23 | 10.02 | 1.05 | 930 |
| 16 | 3005 | 5.19 | 7.79 | 0.36 | 832 | 2349.2 | 3.63 | 7.96 | 0.63 | 873 |
| 17 | 5212 | 5.60 | 11.24 | 0.54 | 873 | 2570.7 | 4.29 | 7.34 | 0.45 | 863 |
| 18 | 3585 | 5.43 | 9.53 | 0.30 | 923 | 2592.2 | 3.92 | 7.79 | 0.36 | 822 |
| 19 | 3556 | 4.90 | 8.55 | 0.50 | 882 | 4056.3 | 4.25 | 11.24 | 0.86 | 883 |
| 20 | 3489 | 5.07 | 9.01 | 0.35 | 864 | 3123.3 | 4.11 | 9.53 | 0.30 | 871 |
| 21 | 3335 | 5.68 | 8.1 | 0.27 | 869 | 3023.2 | 3.7 | 8.55 | 0.50 | 872 |
| 22 | 2884 | 4.68 | 7.55 | 0.34 | 898 | 3382.6 | 3.85 | 9.01 | 0.35 | 874 |
| 23 | 3162 | 5.26 | 8.17 | 0.48 | 903 | 3174.3 | 2.79 | 10.39 | 0.56 | 840 |
| 24 | 3553 | 4.27 | 9.39 | 0.56 | 830 | 3315 | 3.26 | 9.6 | 0.67 | 831 |
| 25 | 3215 | 4.46 | 8.5 | 0.67 | 841 | 2759.3 | 3.85 | 7.99 | 0.41 | 843 |
| 26 | 2974 | 5.42 | 7.99 | 0.41 | 833 | 3279.3 | 2.93 | 10.03 | 0.43 | 902 |
| 27 | 2828 | 5.28 | 7.48 | 0.31 | 852 | 3262.5 | 3.89 | 9.03 | 0.33 | 838 |
| 28 | 4357 | 5.55 | 10.32 | 0.51 | 867 | 3097.5 | 3.34 | 9.74 | 0.96 | 868 |
| 29 | 4546 | 5.01 | 10.03 | 0.43 | 832 | 3466.6 | 3.96 | 9.93 | 0.76 | 858 |
| 30 | 3392 | 5.12 | 8.03 | 0.33 | 848 | 2886.6 | 3.23 | 9.21 | 0.84 | 865 |
| 31 | 4310 | 5.22 | 9.74 | 0.96 | 878 | 3349.3 | 3.12 | 10.41 | 0.93 | 909 |
| 32 | 4041 | 5.24 | 9.93 | 0.76 | 858 | 2710.4 | 4.22 | 7.63 | 0.53 | 853 |
| 33 | 3315 | 4.26 | 9.21 | 0.84 | 910 | 2772 | 3.23 | 8.54 | 0.29 | 925 |

| Month | Refinery 1 E (PJ) | T (MBBL /month) | NRGF | S (%) | Density (kg/m$^3$) | Refinery 2 E (PJ) | T (MBBL /month) | NRGF | S (%) | Density (kg/m$^3$) |
|---|---|---|---|---|---|---|---|---|---|---|
| 34 | 3946 | 4.09 | 10.41 | 0.93 | 909 | 2628.2 | 4.11 | 7.69 | 0.40 | 834 |
| 35 | 3535 | 5.35 | 8.38 | 0.34 | 839 | 3155.3 | 4.18 | 9.45 | 0.74 | 838 |
| 36 | 3862 | 4.34 | 9.88 | 0.44 | 833 | 3223.4 | 4.33 | 9.03 | 0.28 | 887 |
| 37 | 3198 | 5.69 | 7.63 | 0.53 | 894 | 3593 | 3.37 | 10.36 | 0.61 | 843 |
| 38 | 3459 | 4.50 | 8.54 | 0.29 | 825 | 2680.6 | 4.18 | 7.85 | 0.88 | 827 |
| 39 | 3015 | 5.39 | 7.69 | 0.40 | 912 | 3122.1 | 2.93 | 10.1 | 0.36 | 932 |
| 40 | 2873 | 3.87 | 7.92 | 0.36 | 830 | 3107.3 | 3.92 | 8.73 | 0.34 | 892 |
| 41 | 3397 | 5.18 | 8.17 | 0.34 | 842 | 2818.7 | 4 | 8.17 | 0.65 | 848 |
| 42 | 3758 | 5.26 | 9.43 | 0.65 | 848 | 3705.1 | 4.14 | 10.32 | 1.12 | 903 |
| 43 | 4312 | 5.49 | 10.32 | 1.12 | 903 | 2230.3 | 3.45 | 7.34 | 0.42 | 856 |
| 44 | 2591 | 4.55 | 7.34 | 0.42 | 846 | 3442.6 | 3.48 | 10.02 | 0.85 | 832 |
| 45 | 4050 | 4.59 | 10.02 | 0.85 | 852 | 2422.9 | 3.56 | 7.8 | 0.55 | 885 |
| 46 | 2818 | 4.70 | 7.8 | 0.55 | 865 | 2899.4 | 3.92 | 8.67 | 0.32 | 871 |
| 47 | 3337 | 5.15 | 8.67 | 0.32 | 911 | 3048.5 | 4.07 | 8.38 | 0.34 | 934 |
| 48 | 3107 | 5.53 | 8.16 | 0.40 | 859 | 3277.4 | 3.3 | 9.88 | 0.44 | 833 |
| 49 | 3441 | 4.89 | 8.42 | 0.50 | 883 | 2706.9 | 4.18 | 8.16 | 0.40 | 829 |
| 50 | 3269 | 4.47 | 7.89 | 0.43 | 852 | 2935.1 | 3.7 | 8.42 | 0.50 | 883 |
| 51 | 3601 | 5.49 | 9.45 | 0.74 | 868 | 3547.8 | 3.67 | 9.79 | 0.45 | 912 |
| 52 | 3287 | 5.69 | 8.03 | 0.28 | 887 | 2665 | 3.37 | 7.89 | 0.43 | 852 |
| 53 | 3307 | 4.45 | 8.06 | 0.61 | 843 | 3026.3 | 3.89 | 9.01 | 0.93 | 917 |
| 54 | 2981 | 5.59 | 7.85 | 0.88 | 827 | 3049.1 | 3.23 | 9.68 | 0.35 | 917 |
| 55 | 3640 | 5.20 | 9.23 | 0.93 | 917 | 3191.5 | 3.41 | 9.69 | 0.61 | 840 |
| 56 | 3989 | 4.57 | 9.68 | 0.35 | 883 | 2375.8 | 3.37 | 7.72 | 0.24 | 899 |
| 57 | 3371 | 4.67 | 8.39 | 0.61 | 829 | 3099.5 | 3.92 | 8.69 | 0.76 | 824 |
| 58 | 2947 | 4.61 | 7.72 | 0.24 | 839 | 2382.4 | 3.37 | 8.36 | 0.45 | 860 |
| 59 | 3626 | 5.19 | 8.69 | 0.76 | 874 | 2900.7 | 2.79 | 10.13 | 0.79 | 853 |
| 60 | 4114 | 4.85 | 9.49 | 0.45 | 912 | 3133.1 | 4.25 | 9.49 | 0.26 | 877 |

Source: Author's elaboration using data from

Table C.2 – First regression analysis report for Refinery 1

**Linear Regression**

| | |
|---|---|
| *Dependent variable* | E |
| *Independent variables* | T, NRGF, S, Density |
| *N* | 48 |

**Regression Statistics**

| | | | | | |
|---|---|---|---|---|---|
| *R* | 0.93153 | ***R-Squared*** | **0.86774** | *Adjusted R-Squared* | 0.85544 |
| *MSE* | 46,136.57990 | ***S*** | **214.79427** | *MAPE* | 4.61358 |
| *Durbin-Watson (DW)* | 1.33697 | *Log likelihood* | -323.21370 | | |
| *Akaike inf. criterion (AIC)* | 13.67557 | *AICc* | 13.69495 | | |
| *Schwarz criterion (BIC)* | 13.87049 | *Hannan-Quinn criterion (HQC)* | 13.74923 | | |
| *PRESS* | 2,533,112.30214 | *PRESS RMSE* | 229.72412 | *Predicted R-Squared* | 0.83113 |

**E = 101.67922 + 360.45462 * T + 476.14392 * NRGF + 39,178.42070 * S - 3.29992 * Density**

**ANOVA**

| | *d.f.* | *SS* | *MS* | *F* | *p-value* |
|---|---|---|---|---|---|
| *Regression* | 4. | 13,016,387.52197 | 3,254,096.88049 | 70.53182 | 0.00000 |
| *Residual* | 43. | 1,983,872.93579 | 46,136.57990 | | |
| *Total* | 47. | 15,000,260.45776 | | | |

| | *Coefficients* | *Std Err* | *LCL* | *UCL* | *t Stat* | *p-value* | *H0 (5%)* | *VIF* | *TOL* | *Beta* |
|---|---|---|---|---|---|---|---|---|---|---|
| **Intercept** | 101.67922 | 1,059.11758 | -2,034.23494 | 2,237.59338 | 0.09600 | 0.92396 | *Accepted* | | | |
| **T** | 360.45462 | 65.25210 | 228.86122 | 492.04802 | 5.52403 | 1.79227E-6 | *Rejected* | 1.15777 | 0.86373 | 0.32964 |
| **NRGF** | 476.14392 | 36.44592 | 402.64372 | 549.64411 | 13.06440 | 0.00000 | *Rejected* | 1.41927 | 0.70459 | 0.86317 |
| **S** | 39,178.42070 | 17,245.30082 | 4,399.95705 | 73,956.88434 | 2.27183 | 0.02816 | *Rejected* | 1.65785 | 0.60319 | 0.16223 |
| **Density** | -3.29992 | 1.23606 | -5.79267 | -0.80717 | -2.66971 | 0.01067 | *Rejected* | 1.14661 | 0.87214 | -0.15854 |
| *T (5%)* | 2.01669 | | | | | | | | | |

*LCL - Lower limit of the 95% confidence interval*
*UCL - Upper limit of the 95% confidence interval*

Source: Author's elaboration using Statplus

Table C.3 – Second regression analysis report for Refinery 1

**Linear Regression**

| | |
|---|---|
| *Dependent variable* | E |
| *Independent variables* | T, NRGF, S, Density |
| *N* | 48 |

**Regression Statistics**

| | | | | | |
|---|---|---|---|---|---|
| *R* | 0.99828 | ***R-Squared*** | **0.99657** | *Adjusted R-Squared* | 0.99634 |
| *MSE* | 45,097.68553 | ***S*** | **212.36216** | *MAPE* | 4.60571 |
| *Durbin-Watson (DW)* | 1.33442 | *Log likelihood* | -323.21885 | | |
| *Akaike inf. criterion (AIC)* | 13.63412 | *AICc* | 13.65306 | | |
| *Schwarz criterion (BIC)* | 13.79005 | *Hannan-Quinn criterion (HQC)* | 13.69305 | | |
| *PRESS* | 2,449,867.51762 | *PRESS RMSE* | 225.91792 | *Predicted R-Squared* | 0.99577 |

**E = 361.29087 * T + 476.71811 * NRGF + 38,803.32174 * S - 3.19160 * Density**

**ANOVA**

| | *d.f.* | *SS* | *MS* | *F* | *p-value* |
|---|---|---|---|---|---|
| *Regression* | 4. | 576,592,455.68741 | 144,148,113.92185 | 3,196.35281 | 0.00000 |
| *Residual* | 44. | 1,984,298.16339 | 45,097.68553 | | |
| *Total* | 48. | 578,576,753.85080 | | | |

| | *Coefficients* | *Std Err* | *LCL* | *UCL* | *t Stat* | *p-value* | *H0 (5%)* | *VIF* | *TOL* | *Beta* |
|---|---|---|---|---|---|---|---|---|---|---|
| **Intercept** | 0 | | | | | | | | | |
| **T** | 361.29087 | 63.93585 | 232.43663 | 490.14511 | 5.65083 | 1.09718E-6 | *Rejected* | 1.15777 | 0.86373 | 0.33041 |
| **NRGF** | 476.71811 | 35.54474 | 405.08238 | 548.35383 | 13.41178 | 0.00000 | *Rejected* | 1.41927 | 0.70459 | 0.86421 |
| **S** | 38,803.32174 | 16,606.67588 | 5,334.76565 | 72,271.87784 | 2.33661 | 0.02408 | *Rejected* | 1.65785 | 0.60319 | 0.16067 |
| **Density** | -3.19160 | 0.49914 | -4.19756 | -2.18564 | -6.39415 | 8.87967E-8 | *Rejected* | 1.14661 | 0.87214 | -0.15334 |
| *T (5%)* | 2.01537 | | | | | | | | | |

*LCL - Lower limit of the 95% confidence interval*
*UCL - Upper limit of the 95% confidence interval*

Source: Author's elaboration using Statplus

Table C.4 – First regression analysis report for Refinery 2

**Linear Regression**

| | |
|---|---|
| *Dependent variable* | E |
| *Independent variables* | T, NRGF, S (%), Density |
| *N* | 48 |

**Regression Statistics**

| | | | | | |
|---|---|---|---|---|---|
| *R* | 0.95281 | ***R-Squared*** | **0.90785** | *Adjusted R-Squared* | 0.89927 |
| *MSE* | 15,476.82688 | ***S*** | **124.40590** | *MAPE* | 3.16594 |
| *Durbin-Watson (DW)* | 1.83519 | *Log likelihood* | -296.99941 | | |
| *Akaike inf. criterion (AIC)* | 12.58331 | *AICc* | 12.60269 | | |
| *Schwarz criterion (BIC)* | 12.77823 | *Hannan-Quinn criterion (HQC)* | 12.65697 | | |
| *PRESS* | 809,421.34821 | *PRESS RMSE* | 129.85740 | *Predicted R-Squared* | 0.88792 |

**E = - 1,588.84608 + 313.52805 * T + 424.07633 * NRGF - 5,740.84097 * S (%) - 0.40496 * Density**

**ANOVA**

| | *d.f.* | *SS* | *MS* | *F* | *p-value* |
|---|---|---|---|---|---|
| *Regression* | 4. | 6,556,208.00639 | 1,639,052.00160 | 105.90362 | 0.00000 |
| *Residual* | 43. | 665,503.55586 | 15,476.82688 | | |
| *Total* | 47. | 7,221,711.56225 | | | |

| | *Coefficients* | *Std Err* | *LCL* | *UCL* | *t Stat* | *p-value* | *H0 (5%)* | *VIF* | *TOL* | *Beta* |
|---|---|---|---|---|---|---|---|---|---|---|
| **Intercept** | -1,588.84608 | 596.19586 | -2,791.18962 | -386.50253 | -2.66497 | 0.01080 | *Rejected* | | | |
| **T** | 313.52805 | 51.68165 | 209.30206 | 417.75404 | 6.06653 | 2.92610E-7 | *Rejected* | 1.28878 | 0.77593 | 0.31882 |
| **NRGF** | 424.07633 | 23.67477 | 376.33161 | 471.82105 | 17.91259 | 0.00000 | *Rejected* | 1.68985 | 0.59177 | 1.07796 |
| **S (%)** | -5,740.84097 | 8,731.79591 | -23,350.18568 | 11,868.50373 | -0.65746 | 0.51439 | *Accepted* | 1.39896 | 0.71482 | -0.03600 |
| **Density** | -0.40496 | 0.56934 | -1.55313 | 0.74322 | -0.71128 | 0.48075 | *Accepted* | 1.06089 | 0.94260 | -0.03392 |
| *T (5%)* | 2.01669 | | | | | | | | | |

*LCL - Lower limit of the 95% confidence interval*
*UCL - Upper limit of the 95% confidence interval*

Source: Author's elaboration using Statplus

Table C.5 – Second regression analysis report for Refinery 2

**Linear Regression**

| | |
|---|---|
| *Dependent variable* | E |
| *Independent variables* | T, NRGF |
| *N* | 48 |

**Regression Statistics**

| | | | | | |
|---|---|---|---|---|---|
| *R* | 0.95179 | ***R-Squared*** | **0.90591** | *Adjusted R-Squared* | 0.90173 |
| *MSE* | 15,099.56456 | ***S*** | **122.88029** | *MAPE* | 3.23982 |
| *Durbin-Watson (DW)* | 1.74078 | *Log likelihood* | -297.49823 | | |
| *Akaike inf. criterion (AIC)* | 12.52076 | *AICc* | 12.52632 | | |
| *Schwarz criterion (BIC)* | 12.63771 | *Hannan-Quinn criterion (HQC)* | 12.56496 | | |
| *PRESS* | 758,893.53189 | *PRESS RMSE* | 125.73894 | *Predicted R-Squared* | 0.89492 |

**E = - 1,905.37471 + 318.30015 * T + 414.87237 * NRGF**

**ANOVA**

| | *d.f.* | *SS* | *MS* | *F* | *p-value* |
|---|---|---|---|---|---|
| *Regression* | 2. | 6,542,231.15697 | 3,271,115.57849 | 216.63642 | 0.00000 |
| *Residual* | 45. | 679,480.40528 | 15,099.56456 | | |
| *Total* | 47. | 7,221,711.56225 | | | |

| | *Coefficients* | *Std Err* | *LCL* | *UCL* | *t Stat* | *p-value* | *H0 (5%)* | *VIF* | *TOL* | *Beta* |
|---|---|---|---|---|---|---|---|---|---|---|
| **Intercept** | -1,905.37471 | 314.21317 | -2,538.23251 | -1,272.51690 | -6.06396 | 2.50910E-7 | *Rejected* | | | |
| **T** | 318.30015 | 50.51088 | 216.56601 | 420.03429 | 6.30162 | 1.11230E-7 | *Rejected* | 1.26181 | 0.79251 | 0.32368 |
| **NRGF** | 414.87237 | 20.20691 | 374.17356 | 455.57118 | 20.53121 | 0.00000 | *Rejected* | 1.26181 | 0.79251 | 1.05457 |
| *T (5%)* | 2.01410 | | | | | | | | | |

*LCL - Lower limit of the 95% confidence interval*
*UCL - Upper limit of the 95% confidence interval*

Source: Author's elaboration using Statplus

Table C.6 – Energy performance evaluation results for Refinery 1

| Month | EnPI(E) (PJ) | EnB (E) (PJ) | CUSUM (PJ) | EnPI (SEC) (MJ/MJ of crude) | EnB (SEC) (MJ/MJ of crude) |
|---|---|---|---|---|---|
| 49 | 3441.35 | 3156.05 | 285.31 | 0.1150 | 0.1055 |
| 50 | 3268.68 | 2822.30 | 731.69 | 0.1196 | 0.1033 |
| 51 | 3600.54 | 4006.78 | 325.45 | 0.1071 | 0.1192 |
| 52 | 3287.45 | 3160.74 | 452.16 | 0.0945 | 0.0908 |
| 53 | 3307.39 | 2994.99 | 764.56 | 0.1216 | 0.1101 |
| 54 | 2981.32 | 3462.13 | 283.75 | 0.0872 | 0.1013 |
| 55 | 3639.87 | 3711.66 | 211.96 | 0.1145 | 0.1167 |
| 56 | 3988.92 | 3581.71 | 619.17 | 0.1428 | 0.1282 |
| 57 | 3371.09 | 3277.30 | 712.95 | 0.1180 | 0.1147 |
| 58 | 2947.28 | 2761.23 | 899.01 | 0.1045 | 0.0979 |
| 59 | 3625.82 | 3523.41 | 1001.42 | 0.1142 | 0.1109 |
| 60 | 4114.43 | 3540.76 | 1575.09 | 0.1386 | 0.1193 |

Source: Author's elaboration

Table C.7 – Energy performance evaluation results for Refinery 2

| Month | EnPI(E) (PJ) | EnB (E) (PJ) | CUSUM (PJ) | EnPI (SEC) (MJ/MJ of crude) | EnB (SEC) (MJ/MJ of crude) |
|---|---|---|---|---|---|
| 49 | 2706.93 | 2810.12 | -103.19 | 0.1059 | 0.1099 |
| 50 | 2935.12 | 2766.31 | 65.62 | 0.1296 | 0.1221 |
| 51 | 3547.77 | 3323.02 | 290.38 | 0.1582 | 0.1481 |
| 52 | 2665.03 | 2441.41 | 513.99 | 0.1291 | 0.1183 |
| 53 | 3026.27 | 3069.42 | 470.83 | 0.1273 | 0.1291 |
| 54 | 3049.07 | 3137.36 | 382.54 | 0.1545 | 0.1589 |
| 55 | 3191.49 | 3199.85 | 374.18 | 0.1530 | 0.1534 |
| 56 | 2375.77 | 2370.89 | 379.06 | 0.1151 | 0.1149 |
| 57 | 3099.52 | 2948.33 | 530.25 | 0.1291 | 0.1228 |
| 58 | 2382.35 | 2636.40 | 276.19 | 0.1154 | 0.1278 |
| 59 | 2900.71 | 3184.04 | -7.14 | 0.1702 | 0.1868 |
| 60 | 3133.12 | 3385.24 | -259.26 | 0.1204 | 0.1301 |

Source: Author's elaboration

Table C.8 – GHG emission accounting results for Refinery 1

| Month | EmI (AF: EnPI(E)) ($MtCO_{2eq}$) | EmI (AF: EnB (E)) ($MtCO_{2eq}$) | EmI (AF: CUSUM) ($MtCO_{2eq}$) | EmI (AF: EnPI (SEC)) ($gCO_{2eq}$/ MJ of crude) | EmI (AF: EnB (SEC)) ($gCO_{2eq}$/ MJ of crude) |
|---|---|---|---|---|---|
| 49 | 328.98 | 301.71 | 27.27 | 11.00 | 10.09 |
| 50 | 312.48 | 269.80 | 69.95 | 11.44 | 9.87 |
| 51 | 344.20 | 383.04 | 31.11 | 10.24 | 11.39 |
| 52 | 314.27 | 302.16 | 43.23 | 9.03 | 8.68 |
| 53 | 316.18 | 286.31 | 73.09 | 11.62 | 10.52 |
| 54 | 285.01 | 330.97 | 27.13 | 8.34 | 9.68 |
| 55 | 347.96 | 354.82 | 20.26 | 10.94 | 11.16 |
| 56 | 381.33 | 342.40 | 59.19 | 13.65 | 12.26 |
| 57 | 322.27 | 313.30 | 68.16 | 11.28 | 10.97 |
| 58 | 281.75 | 263.97 | 85.94 | 9.99 | 9.36 |
| 59 | 346.62 | 336.83 | 95.73 | 10.91 | 10.61 |
| 60 | 393.33 | 338.49 | 150.57 | 13.25 | 11.40 |

Source: Author's elaboration

Table C.9 – GHG emission accounting results for Refinery 2

| **Month** | **EmI (AF: EnPI(E)) ($MtCO_{2eq}$)** | **EmI (AF: EnB (E)) ($MtCO_{2eq}$)** | **EmI (AF: CUSUM) ($MtCO_{2eq}$)** | **EmI (AF: EnPI (SEC)) ($gCO_{2eq}$/ MJ of crude)** | **EmI (AF: EnB (SEC)) ($gCO_{2eq}$/ MJ of crude)** |
|---|---|---|---|---|---|
| 49 | 258.77 | 268.64 | -9.86 | 10.12 | 10.51 |
| 50 | 280.59 | 264.45 | 6.27 | 12.39 | 11.67 |
| 51 | 339.16 | 317.67 | 27.76 | 15.12 | 14.16 |
| 52 | 254.77 | 233.39 | 49.14 | 12.35 | 11.31 |
| 53 | 289.30 | 293.43 | 45.01 | 12.17 | 12.34 |
| 54 | 291.48 | 299.92 | 36.57 | 14.77 | 15.19 |
| 55 | 305.10 | 305.90 | 35.77 | 14.63 | 14.66 |
| 56 | 227.12 | 226.65 | 36.24 | 11.01 | 10.98 |
| 57 | 296.30 | 281.85 | 50.69 | 12.35 | 11.74 |
| 58 | 227.75 | 252.03 | 26.40 | 11.04 | 12.21 |
| 59 | 277.30 | 304.39 | -0.68 | 16.27 | 17.86 |
| 60 | 299.52 | 323.62 | -24.78 | 11.51 | 12.44 |

Source: Author’s elaboration