Environmental and Climate Technologies
2024, vol. 28, no. 1, pp. 286–302
https://doi.org/10.2478/rtuect-2024-0023
https://content.sciendo.com

Bibliometric Analysis of the Modelling of Low-Quality Biomass Pellets Combustion

Oskars SVEDOVS[1*], Mikelis DZIKEVICS[2], Vladimirs KIRSANOVS[3], Izabela WARDACH-ŚWIĘCICKA[4]

[1–3]*Institute of Energy Systems and Environment, Riga Technical University, Āzenes iela 12/1, Riga, LV-1048, Latvia*
[4]*The Szewalski Institute of Fluid-Flow Machinery, Polish Academy of Sciences, Fiszera 14 street, Gdańsk, 80-231, Poland*

Received 02.04.2024; accepted 18.06.2024

***Abstract* – Diversification of energy resources is a current objective that several countries want to achieve, including in northern Europe. Demand for wood fuels is increasing in Latvia, which is reflected in consumer expenditure. Using low-quality biomass (LQB) to produce fuel pellets for market stabilisation and diversification is possible. LQB pellets can theoretically and practically be used in low-capacity solid fuel boilers to provide different types of individual heating systems with an alternative energy source. Before starting mass production of LQB fuel pellets, it is necessary to clarify the properties of the raw materials. Any fuel study shall be divided into two phases: determination of the parameters of the fuel or raw material (calorific values, moisture content, and ash content) and analysis of the combustion process. The combustion process can be studied in two ways: experimentally and by mathematical modelling. Knowing the parameters that would need to be clarified during the study of the LQB fuel pellets combustion process (thermodynamics, gaseous emissions, particulate matter emissions, bottom ash, and slag), the authors have set the goal of clarifying the software applied to mathematical modelling of these parameters. A bibliometric analysis method was chosen to identify the software. The bibliometric analysis was carried out in the Scopus database. As a result, two software were identified: ANSYS Fluent software is suitable for modelling thermodynamic processes and gaseous emission streams. At the same time, XDEM software is the most suitable for modelling particle streams and ash/slag generation. This software will be used in future studies.**

***Keywords* – ANSYS Fluent; bibliometrics; biomass; combustion modelling; computational fluid dynamics; discrete element method; performance analysis; scientific mapping analysis; XDEM.**

Nomenclature		
DH	District heating	–
LH	Local heating	–
IH	Individual heating	–
LQB	Low-quality biomass	–
PM	Particulate matter	–
PA	Performance analysis	–

* Corresponding author.
E-mail address: oskars.svedovs@rtu.lv

SMA	Scientific mapping analysis	–
WoS	Web of Science	–
GS	Google Scholar	–
DOAJ	Directory of Open Access Journals	–
XDEM	eXtended Discrete Element Method	–

1. INTRODUCTION

1.1. Overview of the Current Situation

Thermal energy is a resource used in various technological processes since the beginning of the Industrial Revolution [1]–[3], including electricity generation in power plants [4], [5]. Historically, thermal energy generation has been a valuable combustion process using solid [6]–[8], liquid [9], [10] or gaseous [11], [12] (as well as plasma [13]) energy sources (fossil or renewable), e.g. heating coolant [14] for space heating/hot water preparation or for production of thrust [15], [16]. Globally, primary energy consumers are the energy sector [17], buildings (including office and residential heating and hot water preparation) [18], [19], industry [20]–[22], and transport [23].

Existing widely used technologies for thermal energy generation clearly have an environmental impact [24]–[26]. The 21st century trend is the development of alternative sources of thermal energy that work without the combustion process – heat pumps [27], [28], geothermal energy [29], [30], and solar collectors [31], [32]. In addition, other approaches are being developed and phased in, focusing mainly on improving energy efficiency through a behaviour change-oriented activities (e.g., specific information sources (seminars, posters, podcasts etc.)) or rethinking of the system's operating principle [33]–[35].

An example of a successful approach is to collect excess heat from several sources where it exists – wastewater [36], [37], heat generated by different installations/appliances/machinery (e.g., servers in data centres [38], [39]) etc. [40]. Nevertheless, the consumption of solid fuels remains high, and the use of biomass will increase by 2050, especially given that wood fuels are the main alternative to replacing fossil fuels [41]. Moreover, the global energy crisis, caused by the war in Ukraine, forces countries all over the world to find alternative local energy sources, which can make them independent from external supplies. Given the volatility of the energy market, it would be necessary to ensure the diversification of energy resources and to offer alternative wooden/non-wooden fuels [42]–[44].

The distribution of the use of thermal energy between the sectors mentioned above, as well as within individual sectors, tends to vary according to climatic conditions [45]–[47]. In temperate climate countries such as Northern and Eastern Europe, most of the thermal energy in the private sector is spent on heating (including maintaining the regulatory temperature indoors (accommodation, offices, etc.) [48], [49]) and hot water preparation, while in dry climate countries, cooking accounts for a significant part of the distribution of thermal energy consumption [50]. In industry, heat is mainly used for different technological purposes in production (e.g., drying [51], [52]).

Three types of heat supply – district heating (DH) [53]–[55], local heating (LH) [56], [57], and individual heating (IH) [58], [59] – are distributed in Northern and Eastern Europe (including Latvia). The main differences are the types, fractions, and volumes of fuels used, the capacities of combustion/incineration plants, and the number of users covered. DH typically uses high-capacity boilers. LH and IH are sometimes considered synonymous, given that low-capacity boilers are used in both cases.

1.2. Main Aspects Related to Low-Quality Biomass Combustion

The combustion process is a process of thermochemical transformation of fuels. The combustion process is based on the reaction of a combustible substance (fuel) and an oxidiser (mainly oxygen in the form of air), during which heat (exothermic reaction), combustion products and usually a flame are released. The complexity of organising the combustion process is because several physical processes take place simultaneously during the process: heat and mass transfer, evaporation, and diffusion. The combustion process of solid biomass (including low-quality biomass (LQB)) is significantly more complex compared to the combustion of liquid or gaseous fuels. This is largely due to changes in the state of aggregation of substances occurring several times during combustion. The main flows are the transformation of solid (fuel) and liquid (fuel moisture) into gaseous form (combustion products). However, reversible processes occur most often, during which part of the combustion products returned to liquid phase (condensate) or solid phase (soot, tar and other) [60].

The combustion process of solid biomass can be divided into several stages. The result of the combustion process from a thermodynamic aspect (e.g., efficiency of the combustion process), gaseous emissions aspect (including particulate matter (PM)) and solid residues aspect (bottom ash and slag) depend on the progress of each stage of combustion, as they are all interrelated. The first step is to dry biomass and evaporate moisture. The duration of this stage depends mainly on the moisture content of the fuel, the biomass fraction size and the drying temperature. The amount of moisture influences the temperature in the furnace of the technological energy transformation plant (e.g., biomass boiler) and the necessary amount of energy input for organising the drying process, thus having a significant impact on the whole expression of the combustion process [61], [62].

The second stage of combustion starts after evaporation of moisture and releases volatile substances contained in the fuel. At first, carbon monoxide (CO), carbon dioxide (CO_2), hydrogen (H), oxygen (O_2), methane (CH_4) and other hydrocarbons (C_xH_y), as well as hydrogen cyanide (HCN) and amines ($R-NH_2$), begin to release. The water vapour (H_2O) also engages in reactions. At a temperature of between 500 °C and 600 °C, the excreted substances react in the form of endothermic and exothermic reactions with the ignition of the substances. The most important products resulting from this stage are nitrogen oxides (NO_x), CO_2 and CO, and the prescribed amount of O_2 and H_2O that did not participate in the reactions remains. The quantity of products produced may vary significantly depending on the conditions of combustion and their characteristics [61], [62].

In the third stage of the combustion process, volatile substances have already been released and reacted, but a certain number of solids remains. This amount of solid fraction also depends on the conditions of the combustion process (e.g., temperature in the furnace, oxygen presence, combustion products flow rate), as well as the characteristics of the fuel (density, fraction size, ash content etc.). The residual mass is called coke (AKA char, charcoal, coal), which consists mainly of carbon (C) compounds, as well as various non-combustible compounds. During combustion, C inside the coke reacts with gaseous compounds present in the combustion plant furnace. This also results in a variety of NO_x, HCN, CO_2 and CO. If the temperature in the combustion zone is above 800 °C, the amount of combustion products decreases significantly and consists exclusively of CO_2 and CO. The combustion process also results in a completely different product – ash, the quantity of which also depends on a set of factors (the nature of the combustion process, the properties of the fuel etc.). Depending on the ash melting temperature, a product such as slag can also occur, causing major problems during cleaning of the combustion plant [61], [62].

1.3. Importance of Combustion Process Research of Low-Quality Biomass

The fuel is characterised mainly by three parameters: net calorific value [63]–[65], ash content [66]–[68], and moisture content [69]–[71]. These parameters can be used to predict the fuel combustion result, e.g., the net calorific value is used to calculate combustion efficiency [72], [73]. In addition, chemical analysis may be carried out to assess, e.g., the presence of heavy metals [74].

The result of the fuel combustion may vary depending on the scale and design of the combustion plant. Therefore, appropriate tests may be carried out in specially equipped laboratories. Combining the experimental method with mathematical modelling to facilitate the test procedure is possible [75], [76]. Mathematical modelling makes it possible to reduce the number of experiments required and to perform scientifically based optimisation in order to, e.g., choose the appropriate boiler operation mode to combust specific LQB pellets efficiently [77] or to gain knowledge about the variability of all significant parameters during oxidation, both in the entire cross-section of the heating chamber unit [78]–[81] as well as in individual fuel particles [82], [83]. The latter is exceedingly challenging task to achieve experimentally.

Boilers used in DH boiler houses using wooden biomass can adapt to using different LQB more easily than IH [84]–[87]. The main reason for this is flue gas treatment plants (e.g., electrostatic precipitator [88] and wet scrubbers [89] (or combination of technologies mentioned [90])), which allow for the reduction of particulate matter (PM) and gaseous emissions under controlled conditions. There are currently low-capacity boilers on the market with integrated similar flue-gas treatment technologies. However, some developments can act as an additional component for relatively old-type small-capacity boilers [91], [92], but wet methods have a problem with sustainable water treatment on a small scale [93]–[95]. This aspect should also be considered when investigating the LQB combustion process within the IH.

1.4. Nature of the Study

The authors conducted this study considering their own experience in the field of combustion process research and their lack of knowledge of the possibilities for modelling the combustion process. The research plan is divided into three phases:

1. Search for software relevant to biomass combustion mathematical simulation that takes into account main aspects of solid biomass combustion process (see Section 1.2);
2. Design and setup of an appropriate mathematical model;
3. Run the model in the simulation tool and validate the results.

This Article shows the results of the first phase. Authors chose a bibliometric analysis to search for appropriate software for investigating the combustion process of LQB pellets within the framework of a project. The focus is to select mathematical, numerical, and computational methods based on which relevant programs operate.

2. METHODOLOGY

Bibliometrics is a scientific field of study [96]. Two bibliometric analysis methods – performance analysis (PA) and science mapping, also called scientific mapping analysis (SMA) – can be applied differently depending on the intended purpose [97], [98]. PA in bibliometric studies mainly reflects the historical process and current popularity of developing a separately considered research area, the relevance of the research subject globally, the contribution of scientific institutions and journals, etc. [99], [100]. SMA, on the other hand, is used primarily to answer three general types of research questions [101]: 1) to identify the knowledge base of a topic or field of study and its structure/aspects, 2) by studying the research front [102] (also called "core (scientific) papers/studies" [103]) of a topic or field of study, and 3) to create the structure of social networks of a particular scientific community (e.g., for mobility purposes [104]). The authors based the bibliometric analysis on a structure described by M. Aria and C. Cuccurullo [101] that includes five key stages: study design, data collection, data analysis, data visualisation, and interpretation.

2.1. Study Design: Defining the Expected Outcome

The study aims to identify the mathematical modelling software used in environmental engineering to study various parameters related to the combustion process and implement optimisation. The feasibility study, partly reflected in the *Introduction*, concluded that emphasis should be placed on four aspects that mainly characterise wooden and non-wooden fuel combustion output (each aspect is assigned its own colour as part of this study, see Fig. 1):

- Thermodynamics (green);
- Gaseous emissions (yellow);
- PM emissions (red);
- Bottom ash/slag formation (blue).

These aspects represent the groups of output parameters that usually occur when studying the combustion process experimentally. During the study, these groups of output parameters, or research topic names, were used during creation of queries. Keywords related to specific combustion process modelling methods can be found when the query is created by separating "Thermal Energy" research field into categories or parts, including fuel type names, combustion technology names, research topic names, and basic modelling methods names.

2.2. Data Collection: Selecting a Database, Composing a Query, and Choosing Bibliometric Parameters

There are several indexing databases of scientific literature relating to the different fields of study, including environmental engineering – Web of Science (WoS), Scopus, Google Scholar (GS) and Directory of Open Access Journals (DOAJ) [105]. Each database has its advantages and disadvantages from a bibliometric research point of view, e.g., the tool embedded in the WoS database allows the export of up to 1000 records for further PA, while the Scopus database has a limit of 2000 records [106]. GS and DOAJ, on the other hand, do not have any tools to allow bibliometric analysis – they are primarily suitable for searching for articles on a given field of study, like the ScienceDirect or MDPI. The authors chose to use the Scopus database because of the high quality of records and the possibility of exporting a larger number of records.

Before using a database, a structured query (one or many) must be prepared, checked, and, if necessary, the logical operators that link individual parts of the query to each other must be used. Scopus database search tool allows Boolean logic operators to be used in queries:

- AND – Finds only those documents that contain all of the terms included in query;
- OR – Finds documents that contain any of the terms included in query;
- AND NOT – Excludes documents that include the specified term from the search.

The query-making algorithm is shown in Fig. 1. The algorithm serves as a reference point for current research because there is a risk that queries may be invalid or incomplete. By this approach, queries are surrounded by additional keywords, narrowing the number of articles searched for and increasing the study's accuracy. As can be seen, the proposed algorithm contains four levels of search to narrow down the number of selected items at each stage. Black dots reflect the components of an algorithm other than the parameters being studied. Coloured dots reflect the components of the algorithm with which found keywords was associated during the SMA.

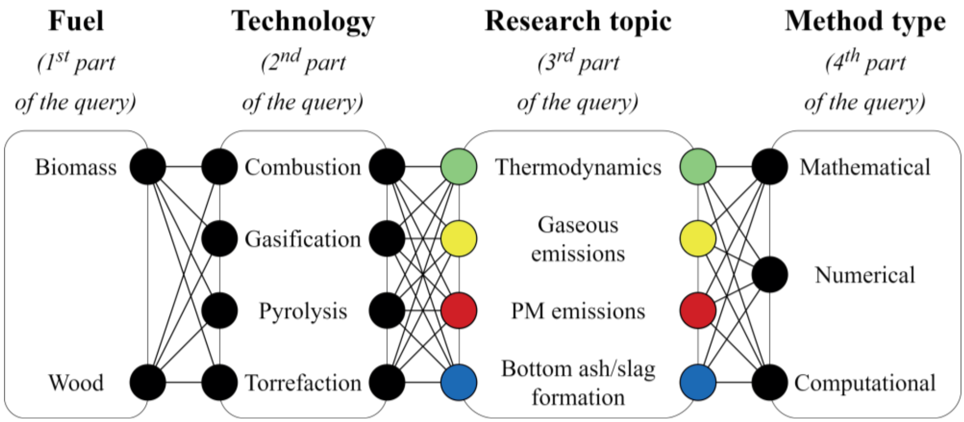

Fig. 1. Query-making algorithm.

The next step after creating the query algorithm is to choose bibliometric parameters. Bibliometric parameters in Scopus database mainly refer to the study boundaries in which queries will search for records:

- "Search within" option: "Article title, Abstract, Keywords" combination (this is the search option that is most commonly used [107]);
- Range of years: the period from 2000 to 2023 (selected to examine trends from the beginning of the 21st century);
- Subject area: Energy, Engineering, Environmental science, Chemical Engineering, Earth and Planetary Sciences, Chemistry, Physics and Astronomy, Agricultural and Biological Sciences, Mathematics, Materials Science, Computer Science;
- Document type: all types of publications;
- Country/territory: worldwide;
- Language: publications in all languages for which the abstract is duplicated in English;
- Citation: total citations, including self-citation;
- Data export options: download in CSV data file format by selecting citation information (e.g., author(s), year, citation count, etc.), abstract, and keywords [98].

2.3. Data Analysis: Assessing the Suitability of the Tools Integrated into the Database Selected

The Scopus database integrates at least two tools to implement PA – "Analyzer" and "Citation overview". The "Analyzer" allows to view automatically visualized charts that reflect changes in different data (number of documents by year, by author, by country, etc.). Data about the number of documents was exported in .CSV format in the framework of this study. On the other hand, the "Citation overview" makes it possible to assess the quotability of all or individually taken documents, which in turn also reflects the topic's popularity. Data about the number of citations was exported in .CSV format in the framework of this study. Exported files was processed in relevant programs, such as *Microsoft Excel*.

2.4. Data Visualisation: Selecting the Appropriate Programme

Several applications are suitable for SMA [98], but only two programmes – *VOSviewer* and *Bibexcel* – are usually used for network visualisation.

VOSviewer is software specifically designed to create and visualize bibliometric maps, focusing on the graphical representation of such maps. It is helpful to display large maps since zoom functionality, special labelling algorithms, and density metaphors are used. Developed by the Leiden University, Centre for Science and Technology Studies (Netherlands). The software tool is freely available. *Bibexcel* is a bibliometric tool developed at the University of Umeå (Sweden). This tool was specifically designed to manage bibliometric data and create maps that can be read using software such as *Microsoft Excel*. *Bibexcel* is freely available for academic non-profit use [108].

The authors have chosen *VOSviewer* because it is a program recognised by various scientific industries [109], has an intuitive and functional interface, and can process data exported from the Scopus database. The choice is also based on previous experience with this programme.

2.5. Interpretation: Analysing of Data and Diagrams Obtained and Drawing Conclusions

The data resulting from the used bibliometric methods is analysed. The results of the PA are used to assess the overall trends in "Thermal Energy" research field related to the categories chosen. The results of SMA are used to identify keywords linking aspects of the combustion process and the choice of mathematical modelling methods. Additional research was made to identify computer programmes that perform appropriate calculations based on such methods.

3. RESULTS

In Table 1 the classic bibliometric analysis results are shown. The third column gives information about the number of articles found by entering a query based on the algorithm presented in Figure 1 into the Scopus database search system. The publications starting from year 2000 are included in further analysis. For all of the four cases the first two terms narrow the search with AND between them and the last one defines queries. Each case differs from the other by the third term (written in bold in the table) occurring after AND, which is strictly connected with the research topic.

The largest number of retrieved literature items is in the field of thermodynamics, for which there are over 1900 items, followed by those related to gas emission with almost 1470 items and PM emissions with 200 fewer articles, and finally the works devoted to bottom ash/slag formation with three times lower number of searches. The order of these items on the list is directly related to the possible scope covering a given section. On the one hand, there is thermodynamics as a field of knowledge representing a wide range of possibilities, and on the other hand, the subtopic of specific combustion products such as ash deposition and slagging.

TABLE 1. NUMBER OF ARTICLES FOUND DEPENDING ON THE RESEARCH TOPIC

Research topic	**Defined queries used in Scopus database search**	**Number of publications**
Thermodynamics	(wood OR biomass) AND (combustion OR gasification OR pyrolysis OR torrefaction) AND **(heat OR thermodynamic OR {fluid dynamic})** AND ({mathematical modelling} OR simulation OR {numerical methods} OR {computational methods} OR {mathematical methods})	1918
Gaseous emissions	(wood OR biomass) AND (combustion OR gasification OR pyrolysis OR torrefaction) AND **(emission OR {air pollution} OR {flue gas})** AND ({mathematical modelling} OR simulation OR {numerical methods} OR {computational methods} OR {mathematical methods})	1466
PM emissions	(wood OR biomass) AND (combustion OR gasification OR pyrolysis OR torrefaction) AND **(particle OR smoke OR dust OR {fly ash})** AND ({mathematical modelling} OR simulation OR {numerical methods} OR {computational methods} OR {mathematical methods})	1273
Bottom ash/slag formation	(wood OR biomass) AND (combustion OR gasification OR pyrolysis OR torrefaction) AND **(ash OR slag OR clinker)** AND ({mathematical modelling} OR simulation OR {numerical methods} OR {computational methods} OR {mathematical methods})	368

3.1. PA results

Below the results of PA are displayed. The solid colour line in the graphs in Fig. 2 reflects the number of publications (actual in each year), and the grey area represents the total cumulative number of citations in each case.

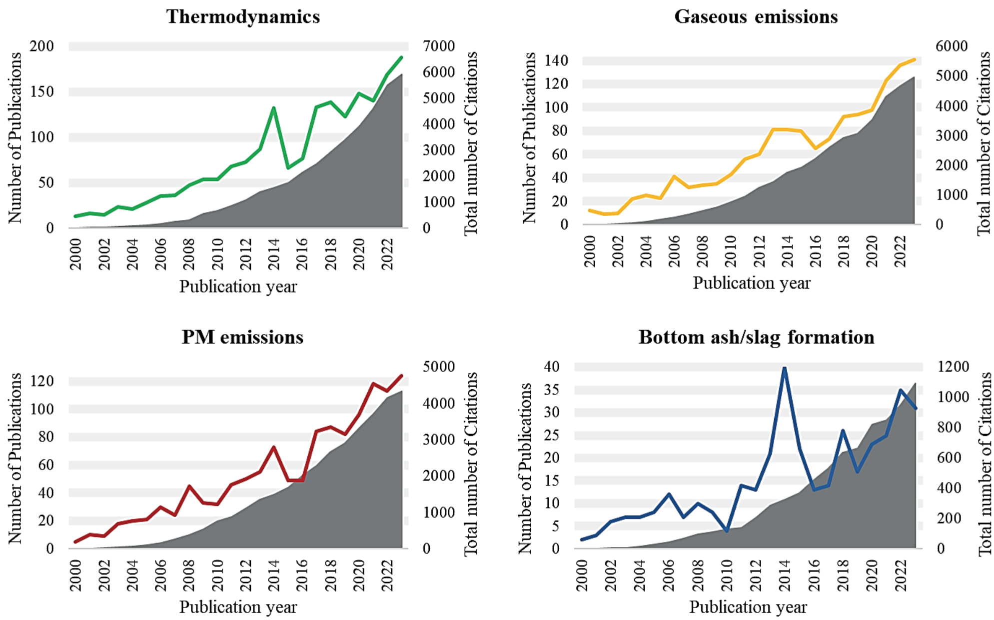

Fig. 2. Changes in the number of articles (solid lines) and the total number of citations over the selected time period depending on the research topic.

From the analysis of the presented graphs, a significant increase in the number of articles published in each considered research area can be observed. The number of publications in each topic reflects the data listed in Table 1, i.e., the largest number of publications can be seen in the field of thermodynamics (in 2023 there were over 180 papers), and if it concerns ashes and slags, 6 times less were published at the same time. Moreover, an annual increase in the number of articles is non-linear. Thus, in the case of thermodynamics, over the 23 years studied, this number increased around 9 times. In the area of gaseous emissions' studies, the number of works increased by over 9 times, in the case of issues on PM emissions it increased by 24 times, whereas in terms of ashes and slags analyses it increased by 15 times. Therefore, this suggests not only the increased interest in gaining knowledge about the biomass combustion process in detail itself but also the increasing emphasis of researchers on topics related to the emission of pollutants into the environment. The peak visible in 2013 and the subsequent decline in later years are primarily related to the plans to tighten the EU climate policy for 2020–2030 period towards reducing CO_2 emissions by using renewable energy sources. Still, it may also be related to the economic crisis of the Eurozone caused in 2009/2010, the effects of which were felt until 2014.

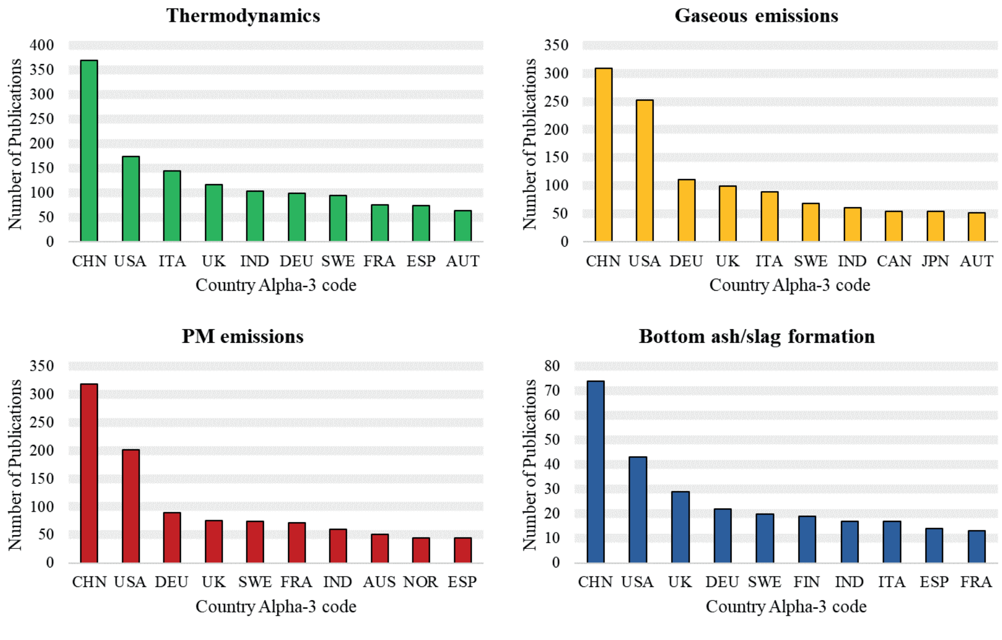

Fig. 3. Popularity of research topics in different countries (TOP10) based on the number of publications.

The charts presented in Fig. 3 reflect the popularity of each research topic in different countries based on the information available in the Scopus search tool. Each chart covers the same time period (2000–2023) but it concerns only TOP10 countries. As can be seen, the most publicity takes place in China and the USA. This is not a surprise because these countries have large population compared to other countries, and additionally, the USA is an economically highly developed region. The remaining leaders are individual European countries. One should be pointed out: summing them up, it turns out that in each examined area, the European Community is a leader. In the field of thermodynamics, EU scientists published around 670 publications, on gaseous emissions topics – about 400, for dust emissions the number is around 360, and those related to ashes amounted to about 140. In the presented rankings India and Japan also appear as countries with increased interest in combating high levels of pollution and smog in the atmosphere.

3.2. SMA Results

The results of SMA are presented graphically in Fig. 4. *VOSwiever* allows to upload multiple files with data a time, however, this may make it difficult to perform an analysis, e.g., because of the need to disable repetitions of individual keywords (e.g., synonyms, plural form) for each file. Therefore, all files were combined and adjusted. Combined file was obtained with all the articles included (no repeats) found using the queries in Table 1.

Fig. 4 includes study methods such as life cycle analysis, experimental study, computational fluid dynamics and other. The oxidation process of different types of solid fuels can be modelled using computational fluid dynamics (CFD) with different approaches: first of all, using the finite volume method for predicting the gas flow behaviour [80]–[83], [110], [111], or finite element method for predicting the change of the parameters in solids [112], or discrete element method for predicting the movement of the particles [113]. By using computational power, it is possible to obtain numerous data for analysing the oxidation process of different types of biomasses considering different operational conditions to obtain various product yields [114]. There is also the possibility of making a parametrical analysis to optimize both operational conditions as well as the geometrical parameters for the considered heating unit [115]. Modelling of solid fuel oxidation is an overly complex phenomenon. The researchers should take into account its multicomponent and multiphase nature (gas mixtures, solid particles, liquids such as moisture and tars), with regard to different scales (particles pores, particulate matter, pellets, pipes, combustion chambers, industrial boilers) with heat and mass transfer (heating, cooling, evaporation, liquefaction of ashes) and structure change (particle shrinking, cracking, ash slagging). To validate the mathematical models in computer simulations, calculations must be verified by experimental tests, in laboratory and real scale [116], [117]. Discrete element method (DEM) usually used to study particles and their evolution in combustion process.

The outcomes of the bibliometric analysis are shown in Fig. 5. The proposed method gives the response about the possibility of using specific numerical methods that realistically reproduce the processes during the oxidation of LQB pellets. From the whole Scopus publication database, by applying PA and SMA methods, two software that could meet the set expectations were selected: the commercial software ANSYS Fluent [118] and XDEM based on the open-source codes [119], [120]. ANSYS Fluent software most often uses the CFD method to model thermodynamics and gaseous emissions. On the other hand, the DEM is used to model particles (PM emissions, ash and slag formation), which is used by XDEM software.

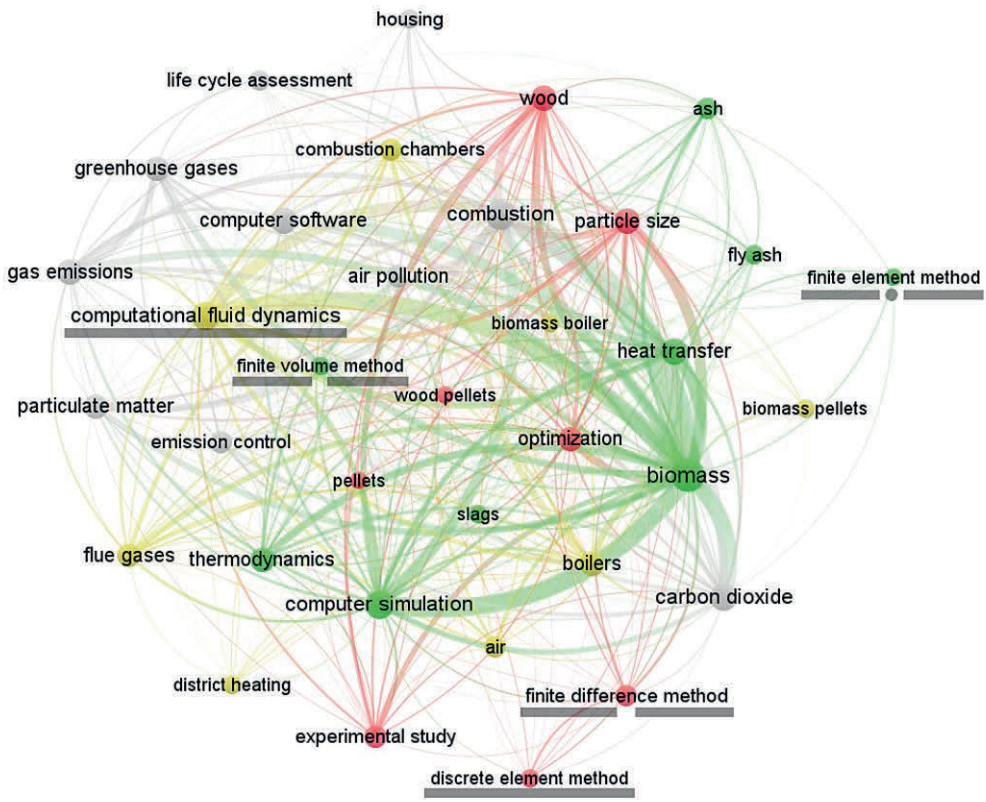

Fig. 4. Keyword network with marked specific methods for mathematical modelling of the combustion process.

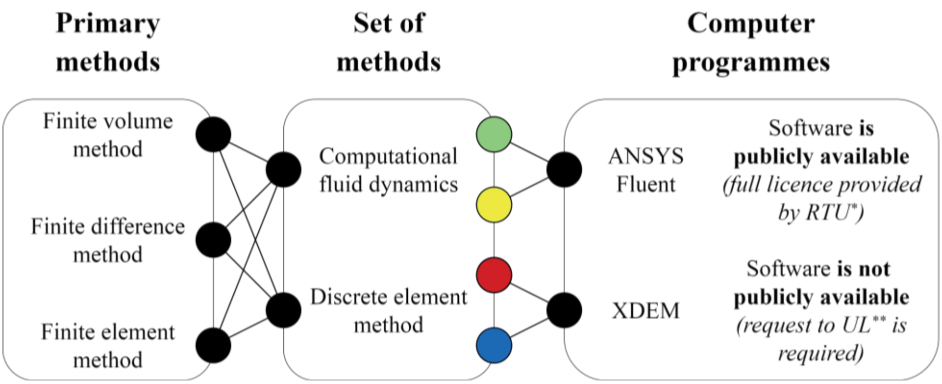

Fig. 5. The algorithm for obtaining the results of the study based on bibliometric analysis (* – Riga Technical University, ** – University of Luxembourg).

4. Conclusions

The use of two main methods of bibliometric analysis identified trends in topics related to the combustion process of biomass. The conclusions are as follows:

- the annual number of publications and citations on analysed topics has been significantly increasing since 2000. This trend is associated not only with the general increase in scientific output worldwide but also in connection with search for independent and locally available energy sources, environmental protection and human health;
- the total number of publications on the thermodynamics of combustion is higher than those that are related to emissions and solid residues. This trend can be explained mainly by the fact that thermodynamics are a fundamental part of the combustion process. This aspect was historically explored to find out the mechanics of heat flows, predict the efficiency of energy transformation and, accordingly, offer optimisation solutions. Interest and the need to identify emissions and solid residual flows as the products of combustion process appeared relatively recently, influenced by the overall vision of minimising emission sources;
- the majority of publications on relevant topics are developed in China and in the USA, but the European Union is still the leader as a community;
- based on the keyword co-occurrence network map, the two software tools selected as suitable for the numerical modelling of the different aspects of the combustion process are *ANSYS Fluent* and *XDEM*.

Acknowledgement

This research was developed within the framework of the Fundamental and Applied Research project "Alternative biomass knowledge for the transition towards energy independence and climate targets (Bioenergy Observatory)", project No. Lzp-2022/1-0414, financed by Latvian Council of Science.

References

[1] 40 – Heat energy, in *Newnes Engineering and Physical Science Pocket Book*. Bird J. O., Chivers P. J. (Eds.), Newnes, 1993:307–313. https://doi.org/10.1016/B978-0-7506-1683-6.50043-6

[2] Belyakov N. Chapter One – Concept of energy, in *Sustainable Power Generation,* Academic Press, 2019:3–22. https://doi.org/10.1016/B978-0-12-817012-0.00010-4

[3] Akram M. W., Hasanuzzaman M. Chapter 1 – Fundamentals of thermal energy and solar system integration. In *Technologies for Solar Thermal Energy*, M. Hasanuzzaman, (Ed.), Academic Press 2022:1–24. https://doi.org/10.1016/B978-0-12-823959-9.00003-9

[4] Islas J., Manzini F., Masera O., Vargas V. Chapter Four – Solid Biomass to Heat and Power, in *The Role of Bioenergy in the Bioeconomy*. Lago C., Caldés N., Lechón Y. (Eds.), Academic Press 2019:145–177. https://doi.org/10.1016/B978-0-12-813056-8.00004-2

[5] Fitts C. R. Chapter 12 – Subsurface heat flow and geothermal energy, in *Groundwater Science (Third Edition).* Fitts C. R., (Ed.), Academic Press 2024:581–612. https://doi.org/10.1016/B978-0-12-811455-1.00018-6

[6] Pudasainee D., Kurian V., Gupta R. 2 – Coal: Past, Present, and Future Sustainable Use. In *Future Energy (Third Edition)*, Letcher T. M., (Ed.), Elsevier, 2020:21–48. https://doi.org/10.1016/B978-0-08-102886-5.00002-5

[7] Yin C. 4 – Coal and biomass cofiring: CFD modelling. In *New Trends in Coal Conversion*. Suárez-Ruiz I., Diez M. A., Rubiera F. (Eds.), Woodhead Publishing 2019:89–116. https://doi.org/10.1016/B978-0-08-102201-6.00004-2

[8] Caillat S., Vakkilainen E. 9 – Large-scale biomass combustion plants: an overview. In *Biomass Combustion Science, Technology and Engineering.* Rosendahl L., (Ed.), In Woodhead Publishing Series in Energy. Woodhead Publishing, 2013:189–224. https://doi.org/10.1533/9780857097439.3.189

[9] Zhou L. Chapter 3 – Fundamentals of Combustion Theory. In *Theory and Modeling of Dispersed Multiphase Turbulent Reacting Flows*. Zhou L., (Ed.), Butterworth-Heinemann, 2018:15–70. https://doi.org/10.1016/B978-0-12-813465-8.00003-X

[10] Chong C. T., Ng J.-H. Chapter 4 – Combustion performance of biojet fuels. In *Biojet Fuel in Aviation Applications*, Chong C. T., Ng J.-H., (Eds.), Elsevier, 2021:175–230. https://doi.org/10.1016/B978-0-12-822854-8.00002-0

[11] Okawa T., *et al.* 3 – Fundamentals for power engineering. In *Fundamentals of Thermal and Nuclear Power Generation*, vol. 1, Koizumi Y., Okawa T., Mori S. (Eds.), in JSME Series in Thermal and Nuclear Power Generation. Elsevier, 2021:77–226. https://doi.org/10.1016/B978-0-12-820733-8.00003-0

[12] Jenkins R. G. Chapter 16 – Thermal Gasification of Biomass – A Primer. In *Bioenergy*, Dahiya A., (Ed.), Boston: Academic Press, 2015:261–286. https://doi.org/10.1016/B978-0-12-407909-0.00016-X

[13] Morales-Máximo M., *et al.* Multifactorial Assessment of the Bioenergetic Potential of Residual Biomass of Pinus spp. in a Rural Community: From Functional Characterization to Mapping of the Available Energy Resource. *Fire* 2023:6(8):317. https://doi.org/10.3390/fire6080317

[14] Dincer I., Rosen M. A. Chapter 3 – Industrial Heating and Cooling Systems, in *Exergy Analysis of Heating, Refrigerating and Air Conditioning*. Dincer I., Rosen M. A. (Eds.), Boston: Elsevier, 2015:99–129. https://doi.org/10.1016/B978-0-12-417203-6.00003-X

[15] Sehili Y., Loubar K., Tarabet L., Cerdoun M., Lacroix C. Computational Investigation of the Influence of Combustion Chamber Characteristics on a Heavy-Duty Ammonia Diesel Dual Fuel Engine. *Energies (Basel)* 2024:17(5):1231. https://doi.org/10.3390/en17051231

[16] Tolley A. 10 – Heavy-duty vehicles and powertrains: technologies and systems that enable “zero” air quality and greenhouse gas emissions with enhanced levels of efficiency, in *Alternative Fuels and Advanced Vehicle Technologies for Improved Environmental Performance (Second Edition)*, Folkson R., Sapsford S. (Eds.), in Woodhead Publishing Series in Energy. Woodhead Publishing 2022:263–289. https://doi.org/10.1016/B978-0-323-90979-2.00014-7

[17] Keiner D., *et al.* Global-local heat demand development for the energy transition time frame up to 2050. *Energies (Basel)* 2021:14(13):3814. https://doi.org/10.3390/en14133814

[18] Santamouris M., Vasilakopoulou K. Present and future energy consumption of buildings: Challenges and opportunities towards decarbonisation. *e-Prime – Advances in Electrical Engineering, Electronics and Energy* 2021:1:100002. https://doi.org/10.1016/j.prime.2021.100002

[19] Hasanuzzaman M., Islam M. A., Rahim N. A., Yanping Y. Chapter 3 – Energy demand. In *Energy for Sustainable Development*. Hasanuzzaman M. D., Rahim N. A. (Eds.), Academic Press 2020:41–87. https://doi.org/10.1016/B978-0-12-814645-3.00003-1

[20] Mcmillan C., Boardman R., Mckellar M., Sabharwall P., Ruth M., Bragg-Sitton S. Generation and Use of Thermal Energy in the U.S. Industrial Sector and Opportunities to Reduce its Carbon Emissions. 2016. [Online]. [Accessed: 28.03.2024]. Available: http://www.inl.gov

[21] Ong B. H. Y., Bhadbhade N., Olsen D. G., Wellig B. Characterizing sector-wide thermal energy profiles for industrial sectors. *Energy* 2023:282:129028. https://doi.org/10.1016/j.energy.2023.129028

[22] Zhang S., *et al.* Study on global industrialization and industry emission to achieve the 2 °C goal based on message model and LMDI approach. *Energies (Basel)* 2020:13(4). https://doi.org/10.3390/en13040825

[23] Chanthakett A., Arif M. T., Khan M. M. K., Subhani M. Chapter 4 – Hydrogen production from municipal solid waste using gasification method. In *Hydrogen Energy Conversion and Management*. Khan M. M. K., Azad A. K., Oo A. M. T. (Eds.), Elsevier, 2024:103–131. https://doi.org/10.1016/B978-0-443-15329-7.00012-0

[24] Kud K., Woźniak M., Badora A. Impact of the energy sector on the quality of the environment in the opinion of energy consumers from southeastern Poland. *Energies (Basel)* 2021:14(17). https://doi.org/10.3390/en14175551

[25] Syrtsova E., Pyzhev A., Zander E. Social, Economic, and Environmental Effects of Electricity and Heat Generation in Yenisei Siberia: Is there an Alternative to Coal? *Energies (Basel)* 2023:16(1). https://doi.org/10.3390/en16010212

[26] Klavins M., Bisters V., Burlakovs J. Small scale gasification application and perspectives in circular economy. *Environmental and Climate Technologies* 2020:22(1):42–54. https://doi.org/10.2478/rtuect-2018-0003

[27] Wang Z., Luther M. B., Amirkhani M., Liu C., Horan P. State of the art on heat pumps for residential buildings. *Buildings* 2021:11(8):350. https://doi.org/10.3390/buildings11080350

[28] Kwon Y., Bae S., Nam Y. Development of Design Method for River Water Source Heat Pump System Using an Optimization Algorithm. *Energies (Basel)* 2022:15(11):4019. https://doi.org/10.3390/en15114019

[29] Soltani M., *et al.* Environmental, economic, and social impacts of geothermal energy systems. *Renewable and Sustainable Energy Reviews* 2021:140:110750. https://doi.org/10.1016/j.rser.2021.110750

[30] Chomać-Pierzecka E., Sobczak A., Soboń D. The Potential and Development of the Geothermal Energy Market in Poland and the Baltic States—Selected Aspects. *Energies (Basel)* 2022:15(11):4142. https://doi.org/10.3390/en15114142

[31] Pakere I., Blumberga D. Solar Energy in Low Temperature District Heating. *Environmental and Climate Technologies* 2019:23(3):147–158. https://doi.org/10.2478/rtuect-2019-0085

[32] Sukumaran S., Laht J., Volkova A. Overview of Solar Photovoltaic Applications for District Heating and Cooling. *Environmental and Climate Technologies* 2023:27(1):964–979. https://doi.org/10.2478/rtuect-2023-0070.

[33] Bohvalovs G., Vanaga R., Brakovska V., Freimanis R., Blumberga A. Energy Community Measures Evaluation via Differential Evolution Optimization. *Environmental and Climate Technologies* 2022:26(1):606–615. https://doi.org/10.2478/rtuect-2022-0046
[34] Narbuts J., Vanaga R. Revolutionizing the Building Envelope: A Comprehensive Scientific Review of Innovative Technologies for Reduced Emissions. *Environmental and Climate Technologies* 2023:27(1):724–737. https://doi.org/10.2478/rtuect-2023-0053
[35] Albatayneh A., Alterman D., Page A., Moghtaderi B. The significance of temperature based approach over the energy based approaches in the buildings thermal assessment. *Environmental and Climate Technologies* 2017:19(1):39–50. https://doi.org/10.1515/rtuect-2017-0004
[36] Nagpal H., Spriet J., Murali M. K., McNabola A. Heat recovery from wastewater – A review of available resource. *Water (Switzerland)* 2021:13(9):1274. https://doi.org/10.3390/w13091274
[37] Wehbi Z., Taher R., Faraj J., Lemenand T., Mortazavi M., Khaled M. Waste Water Heat Recovery Systems types and applications: Comprehensive review, critical analysis, and potential recommendations. *Energy Reports* 2023:9:16–33. https://doi.org/10.1016/j.egyr.2023.05.243
[38] Yuan X., Liang Y., Hu X., Xu Y., Chen Y., Kosonen R. Waste heat recoveries in data centers: A review. *Renewable and Sustainable Energy Reviews* 2023:188:113777. https://doi.org/10.1016/j.rser.2023.113777
[39] Narloch P., Rosicki Ł. Using waste heat from data centers in different climate zones. *Builder* 2020:272(3):56–59. https://doi.org/10.5604/01.3001.0013.8482
[40] Abugabbara M. Modelling and Simulation of the Fifth-Generation District Heating and Cooling. Thesis for: Licentiate degree. Technical University of Denmark. 2021. https://doi.org/10.13140/RG.2.2.18483.96809
[41] Lazarou S., Christodoulou C., Vita V. Global Change Assessment Model (GCAM) considerations of the primary sources energy mix for an energetic scenario that could meet Paris agreement. In 2019 54th International Universities Power Engineering Conference, UPEC 2019 – Proceedings. Institute of Electrical and Electronics Engineers Inc., Sep. 2019. https://doi.org/10.1109/UPEC.2019.8893507
[42] Ekpeni L. E. N., Benyounis K. Y., Nkem-Ekpeni F., Stokes J., Olabi A. G. Energy Diversity through Renewable Energy Source (RES) – A Case Study of Biomass. *Energy Procedia* 2014:61:1740–1747. https://doi.org/10.1016/j.egypro.2014.12.202
[43] Andreev O., Lomakina O., Aleksandrova A. Diversification of structural and crisis risks in the energy sector of the ASEAN member countries. *Energy Strategy Reviews* 2021:35:100655. https://doi.org/10.1016/j.esr.2021.100655
[44] Ślusarz G., Gołębiewska B., Cierpiał-Wolan M., Gołębiewski J., Twaróg D., Wójcik S. Regional diversification of potential, production and efficiency of use of biogas and biomass in Poland. *Energies (Basel)* 2021:14(3):742. https://doi.org/10.3390/en14030742
[45] Li J., Yang L., Long H. Climatic impacts on energy consumption: Intensive and extensive margins. *Energy Economics* 2018:71:332–343. https://doi.org/10.1016/j.eneco.2018.03.010
[46] Botzen W. J. W., Nees T., Estrada F. Temperature effects on electricity and gas consumption: Empirical evidence from mexico and projections under future climate conditions. *Sustainability (Switzerland)* 2021:13(1):1–28. https://doi.org/10.3390/su13010305
[47] Hepf C., Gottkehaskamp B., Miller C., Auer T. International Comparison of Weather and Emission Predictive Building Control. *Buildings* 2024:14(1):288. https://doi.org/10.3390/buildings14010288
[48] Geikins A., Borodinecs A., Daksa G., Bogdanovics R., Zajecs D. Typology of Unclassified Buildings and Specifics of Input Parameters for Energy Audits in Latvia. In *IOP Conference Series: Earth and Environmental Science Institute of Physics Publishing*, June 2019. https://doi.org/10.1088/1755-1315/290/1/012131.
[49] Olsson D., Filipsson P., Trüschel A. Weather Forecast Control for Heating of Multi-Family Buildings in Comparison with Feedback and Feedforward Control. *Energies (Basel)* 2024:17(1):261. https://doi.org/10.3390/en17010261.
[50] Ding Y., *et al.* Passive climate regulation with transpiring wood for buildings with increased energy efficiency. *Materials Horizons* 2023:10(1):257–267. https://doi.org/10.1039/d2mh01016j
[51] Bumanis G., Bajare D. Case Study of EPS Aggregate Insulation Material Used in Construction Sites. *Environmental and Climate Technologies* 2024:28(1):21–31. https://doi.org/10.2478/rtuect-2024-0003
[52] Selivanovs J., Blumberga D., Ziemele J., Blumberga A., Barisa A. Research of woody biomass drying process in pellet production. *Environmental and Climate Technologies* 2012:10(1):46–50. https://doi.org/10.2478/v10145-012-0017-7
[53] Polikarpova I., Lauka D., Blumberga D., Vigants E. Multi-Criteria Analysis to Select Renewable Energy Solution for District Heating System. *Environmental and Climate Technologies* 2019:23(3):101–109. https://doi.org/10.2478/rtuect-2019-0082
[54] Stennikov V., Mednikova E., Postnikov I., Penkovskii A. Optimization of the Effective Heat Supply Radius for the District Heating Systems. *Environmental and Climate Technologies* 2019:23(2):207–221. https://doi.org/10.2478/rtuect-2019-0064
[55] Interreg. District Heating in North-West Europe: A Guide for Energy Consumers, 2020.
[56] Liu C., *et al.* Effects of local heating of body on human thermal sensation and thermal comfort. *Journal of Building Engineering* 2022:53:104543. https://doi.org/10.1016/j.jobe.2022.104543

[57] Hooshmand S. M., Zhang H., Javidanfar H., Zhai Y., Wagner A. A review of local radiant heating systems and their effects on thermal comfort and sensation. *Energy Build* 2023:296:113331. https://doi.org/10.1016/j.enbuild.2023.113331

[58] Balode L., *et al.* Carbon Neutrality in Municipalities: Balancing Individual and District Heating Renewable Energy Solutions. *Sustainability (Switzerland)* 2023:15(10):8415. https://doi.org/10.3390/su15108415

[59] Kramens J., Svedovs O., Sturmane A., Vigants E., Kirsanovs V., Blumberga D. Exploring Energy Security and Independence for Small Energy Users: A Latvian Case Study on Unleashing Stirling Engine Potential. *Sustainability (Switzerland)* 2024:16(3):1224. https://doi.org/10.3390/su16031224

[60] Turns Stephen R. An Introduction to Combustion: Concepts and Applications. Second edition. 2000. [Online]. [Accepted: 17.06.2024]. Available: https://fenix.ciencias.ulisboa.pt/downloadFile/1126037345803917/An%20Introduction%20To%20Combustion.hm(booksformech.blogspot.com).pdf

[61] Saidur R., Abdelaziz E. A., Demirbas A., Hossain M. S., Mekhilef S. A review on biomass as a fuel for boilers. *Renewable and Sustainable Energy Reviews* 2011:15(5):2262–2289. https://doi.org/10.1016/j.rser.2011.02.015

[62] Sjaak V. L., Jaap K. The Handbook of Biomass Combustion and Co-firing, First edition. 2008. [Online]. [Accessed: 17.06.2024]. Available: https://renewable-carbon.eu/news/book-presentation-the-handbook-of-biomass-combustion-and-co-firing/

[63] Erol M., Haykiri-Acma H., Küçükbayrak S. Calorific value estimation of biomass from their proximate analyses data. *Renewable Energy* 2010:35(1):170–173. https://doi.org/10.1016/j.renene.2009.05.008

[64] Ariņa D., Bendere R., Denafas G., Kalnačs J., Kriipsalu M. Characterization of Refuse Derived Fuel Production from Municipal Solid Waste: The Case Studies in Latvia and Lithuania. *Environmental and Climate Technologies* 2021:24(3):112–118. https://doi.org/10.2478/rtuect-2020-0090

[65] Zaman B., Samadikun B. P., Hardyanti N., Purwono P. Waste to Energy: Calorific Improvement of Municipal Solid Waste through Biodrying. *Environmental and Climate Technologies* 2021:25(1):176–187. https://doi.org/10.2478/rtuect-2021-0012

[66] Vassilev S. V., Vassileva C. G., Song Y.-C., Li W.-Y., Feng J. Ash contents and ash-forming elements of biomass and their significance for solid biofuel combustion. *Fuel* 2017:208:377–409. https://doi.org/10.1016/j.fuel.2017.07.036

[67] Arina D., Orupe A. Characteristics of mechanically sorted municipal wastes and their suitability for production of refuse derived fuel. *Environmental and Climate Technologies* 2012:8(1):18–23. https://doi.org/10.2478/v10145-012-0003-0

[68] Sarkar D. K. Chapter 3 – Fuels and Combustion, in *Thermal Power Plant.* Elsevier 2015:91–137. https://doi.org/10.1016/B978-0-12-801575-9.00003-2

[69] Kirsanovs V., Timma L., Zandeckis A., Romagnoli F. The quality of pellets available on the market in Latvia: Classification according EN 14961 requirements. *Environmental and Climate Technologies* 2012:8(1):36–40. https://doi.org/10.2478/v10145-012-0006-x

[70] Samuelsson R., Burvall J., Jirjis R. Comparison of different methods for the determination of moisture content in biomass. *Biomass Bioenergy* 2006:30(11):929–934. https://doi.org/10.1016/j.biombioe.2006.06.004

[71] Demirbaş A. Effect of initial moisture content on the yields of oily products from pyrolysis of biomass. *Journal of Analytical and Applied Pyrolysis* 2004:71:803–815. https://doi.org/10.1016/j.jaap.2003.10.008

[72] Chapter 9 – Thermal reactions, in *Air Pollution Calculations*. Vallero D. A., (Ed.), Elsevier, 2019:207–218. https://doi.org/10.1016/B978-0-12-814934-8.00009-0

[73] Fedorov R. V., Generalov D. A., Sherkunov V. V., Sapunov V. V., Busygin S. V. Improving the Efficiency of Fuel Combustion with the Use of Various Designs of Embrasures. *Energies (Basel)* 2023:16(11):4452. https://doi.org/10.3390/en16114452

[74] Poisa L., Hlebnikov A., Adamovics R. Hemp (*Cannabis sativa* L.) as an Environmentally Friendly Energyplant. *Environmental and Climate Technologies* 2010:5(1):80–85. https://doi.org/10.2478/v10145-010-0038-z

[75] Popescu F., Mahu R., Ion I. V., Rusu E. A Mathematical Model of Biomass Combustion Physical and Chemical Processes. *Energies (Basel)* 2020:13(23):6232. https://doi.org/10.3390/en13236232

[76] Pełka G., *et al.* Comparison of Emissions and Efficiency of Two Types of Burners When Burning Wood Pellets from Different Suppliers. *Energies (Basel)* 2023:16(4):1695. https://doi.org/10.3390/en16041695

[77] Mätzing H., Gehrmann H.-J., Seifert H., Stapf D. Modelling grate combustion of biomass and low rank fuels with CFD application. *Waste Management* 2018:78:686–697. https://doi.org/10.1016/j.wasman.2018.05.008

[78] Aminnia N., *et al.* Three-dimensional CFD-DEM simulation of raceway transport phenomena in a blast furnace. *Fuel* 2023:334:126574. https://doi.org/10.1016/j.fuel.2022.126574

[79] Wardach-Święcicka I., Kardaś D. Prediction of Pyrolysis Gas Composition Based on the Gibbs Equation and TGA Analysis. *Energies (Basel)* 2023:16(3):1147. https://doi.org/10.3390/en16031147

[80] Bieniek A., Jerzak W., Magdziarz A. Numerical investigation of biomass fast pyrolysis in a free fall reactor. *Archives of Thermodynamics* 2021:42(3):173–196.

[81] Wardach-Święcicka I., Polesek-Karczewska S., Kardaś D. Biomass Combustion in the Helically Coiled Domestic Boiler Combined with the Equilibrium/Chemical Kinetics CFD Approach. *Applied Mechanics* 2023:4(2):779–802. https://doi.org/10.3390/applmech4020040

[82] Wardach-Święcicka I., Kardaś D. Modeling of heat and mass transfer during thermal decomposition of a single solid fuel particle. *Archives of Thermodynamics* 2013:34:53–71. https://doi.org/10.2478/aoter-2013-0010
[83] Wardach-Święcicka I., Kardaś D. Modelling thermal behaviour of a single solid particle pyrolysing in a hot gas flow. *Energy* 2021:221:119802. https://doi.org/10.1016/j.energy.2021.119802
[84] Balode L., Dolge K., Blumberga D. The contradictions between district and individual heating towards Green Deal targets. *Sustainability (Switzerland)* 2021:13(6):3370. https://doi.org/10.3390/su13063370
[85] Henrich B. A., Hoppe T., Diran D., Lukszo Z. The use of energy models in local heating transition decision making: Insights from ten municipalities in the Netherlands. *Energies (Basel)* 2021:14(2):423. https://doi.org/10.3390/en14020423
[86] Stec S., Szymańska E. J., Stec-Rusiecka J., Puacz-Olszewska J. Transformation of the Polish Heating Sector Based on an Example of Select Heat Energy Companies Supplying Energy to Local Government Units. *Energies (Basel)* 2023:16(22):7550. https://doi.org/10.3390/en16227550
[87] Wang H., Di Pietro G., Wu X., Lahdelma R., Verda V., Haavisto I. Renewable and sustainable energy transitions for countries with different climates and renewable energy sources potentials. *Energies (Basel)* 2018:11(12):1–32. https://doi.org/10.3390/en11123523
[88] Gulyurtlu I., Pinto F., Abelha P., Lopes H., Crujeira A. T. 9 – Pollutant emissions and their control in fluidised bed combustion and gasification. In *Fluidized Bed Technologies for Near-Zero Emission Combustion and Gasification* Scala F., (Ed.), in Woodhead Publishing Series in Energy. Woodhead Publishing. 2013:435–480. https://doi.org/10.1533/9780857098801.2.435
[89] Di Natale F., Carotenuto C., Parisi A., Flagiello D., Lancia A. Wet electrostatic scrubbing for flue gas treatment. *Fuel* 2022:325:124888. https://doi.org/10.1016/j.fuel.2022.124888
[90] Järvinen A., *et al.* Performance of a Wet Electrostatic Precipitator in Marine Applications. *J Mar Sci Eng* 2023:11(2):393. https://doi.org/10.3390/jmse11020393
[91] Blumberga D., Priedniece V., Kalniņš E., Kirsanovs V. Small scale pellet boiler gas treatment in fog unit. *International Journal of Energy and Environmental Engineering* 2021:12:191–202. https://doi.org/10.1007/s40095-020-00357-x
[92] Ciupek B., Urbaniak R., Kinalska D., Nadolny Z. Flue Gas Recirculation System for Biomass Heating Boilers – Research and Technical Applications for Reductions in Nitrogen Oxides (NO_x) Emissions. *Energies (Basel)* 2024:17(1):259. https://doi.org/10.3390/en17010259
[93] Švedovs O., Dzikēvičs M., Kirsanovs V. Methods for Determining the Performance and Efficiency Parameters of the Flue-gas Condenser Sedimentation Tank. *Environmental and Climate Technologies* 2020:24(2):337–347. https://doi.org/10.2478/rtuect-2020-0077
[94] Svedovs O., Dzikevics M., Kirsanovs V., Veidenbergs I. Development of New Compact Water Treatment System for Flue-Gas Condenser for Households. *Environmental and Climate Technologies* 2021:25(1):563–573. https://doi.org/10.2478/rtuect-2021-0041
[95] Svedovs O., Dzikevics M., Kirsanovs V., Veidenbergs I. A New Approach to Water Treatment: Investigating the Performance of Compact Particulate Matter Collector for Use in Compact Flue Gas Condenser. *Environmental and Climate Technologies* 2023:27(1):212–219. https://doi.org/10.2478/rtuect-2023-0016
[96] Sittig D. F. Category Definitions. In *Clinical Informatics Literacy*, Sittig D. F., (Ed.), Academic Press, 2017:1–170. https://doi.org/10.1016/B978-0-12-803206-0.00001-8
[97] Donthu N., Kumar S., Mukherjee D., Pandey N., Lim W. M. How to conduct a bibliometric analysis: An overview and guidelines. *J Business Research* 2021:133:285–296. https://doi.org/10.1016/j.jbusres.2021.04.070
[98] Svedovs O., Dzikevics M., Kirsanovs V. Bibliometric Analysis of the Alternative Biomass Types and Biomass Combustion Technologies. *Environmental and Climate Technologies* 2023:27(1):559–569. https://doi.org/10.2478/rtuect-2023-0041
[99] Cucari N., Tutore I., Montera R., Profita S. A bibliometric performance analysis of publication productivity in the corporate social responsibility field: Outcomes of SciVal analytics. *Corporate Social Responsibility and Environmental Management* 2023:30(1):1–15. John Wiley and Sons Ltd, 2023. https://doi.org/10.1002/csr.2346
[100] Bota-Avram C. Bibliometrics Performance Analysis. In *Science Mapping of Digital Transformation in Business: A Bibliometric Analysis and Research Outlook*. Springer, 2023:15–22. https://doi.org/10.1007/978-3-031-26765-9_3
[101] Aria M., Cuccurullo C. bibliometrix: An R-tool for comprehensive science mapping analysis. *J Informetrics* 2017:11(4):959–975. https://doi.org/10.1016/j.joi.2017.08.007
[102] Wang L., Zhang G., Wang Z., Liu J., Shang J., Liang L. Bibliometric analysis of remote sensing research trend in crop growth monitoring: A case study in China. *Remote Sensing (Basel)* 2019:11(7):809. https://doi.org/10.3390/rs11070809
[103] Liu J. S., Lu L. Y. Y., Lu W. M. Research fronts in data envelopment analysis. *Omega* 2016:58:33–45. https://doi.org/10.1016/j.omega.2015.04.004
[104] Kişi N. Bibliometric Analysis and Visualization of Global Research on Employee Engagement. *Sustainability (Switzerland)* 2023:15(13). https://doi.org/10.3390/su151310196
[105] Toom K. Chapter 10 – Indicators. In *Research Management* Andersen J., Toom K., Poli S., Miller P. F., (Eds.), Boston: Academic Press, 2018:213–230. https://doi.org/10.1016/B978-0-12-805059-0.00010-9

[106] Pranckutė R. Web of Science (WoS) and Scopus: the titans of bibliographic information in today's academic world. *Publications* 2021:9(1). Multidisciplinary Digital Publishing Institute (MDPI). https://doi.org/10.3390/publications9010012

[107] Ullah R., Asghar I., Griffiths M. G. An Integrated Methodology for Bibliometric Analysis: A Case Study of Internet of Things in Healthcare Applications. *Sensors* 2023:23(1). https://doi.org/10.3390/s23010067

[108] Cobo M. J., López-Herrera A. G., Herrera-Viedma E., Herrera F. Science mapping software tools: Review, analysis, and cooperative study among tools. *Journal of the American Society for Information Science and Technology* 2011:62(7):1382–1402. https://doi.org/10.1002/asi.21525

[109] Kirby A. Exploratory Bibliometrics: Using VOSviewer as a Preliminary Research Tool. *Publications* 2023:11(1):10. https://doi.org/10.3390/publications11010010

[110] Kardaś D., Polesek-Karczewska S., Tiutiurski P., Wardach-Święcicka I. Applying dynamic mesh to examine evolution of effective thermal conductivity in porous medium undergoing macrostructure change. *Applied Thermal Engineering* 2021:187:116583. https://doi.org/10.1016/j.applthermaleng.2021.116583

[111] Kardaś D., Hercel P., Wardach-Święcicka I., Polesek-Karczewska S. On the kinetic rate of biomass particle decomposition – Experimental and numerical analysis. *Energy* 2021:219:119575. https://doi.org/10.1016/j.energy.2020.119575

[112] Awny A., *et al.* Finite element modeling of the breakage behavior of agricultural biomass pellets under different heights during handling and storage. *Saudi J Biological Sciences* 2022:29(3):1407–1415. https://doi.org/10.1016/j.sjbs.2021.11.034

[113] Peters B., Džiugys A., Navakas R. Simulation of thermal conversion of solid fuel by the discrete particle method. *Lith. J. Phys.* 2011:51:91–105. https://doi.org/10.3952/lithjphys.51204

[114] Zarzycki R., Kobyłecki R., Bis Z. Numerical analysis of the combustion of gases generated during biomass carbonization. *Entropy* 2020:22(2):181. https://doi.org/10.3390/e22020181

[115] Ismail T. M., El-Salam M. A. Parametric studies on biomass gasification process on updraft gasifier high temperature air gasification. *Appl Therm Eng* 2017:112:1460–1473. https://doi.org/10.1016/j.applthermaleng.2016.10.026

[116] Kardaś D., Kluska J., Kazimierski P. The course and effects of syngas production from beechwood and RDF in updraft reactor in the light of experimental tests and numerical calculations. *Thermal Science and Engineering Progress* 2018:8:136–144. https://doi.org/10.1016/j.tsep.2018.08.020

[117] Džiugys A., Peters B., Hunsinger H., Krebs L. Experimental and numerical evaluation of the transport behaviour of a moving fuel bed on a forward acting grate. *Granular Matter* 2007:9:387–399. https://doi.org/10.1007/s10035-007-0064-0

[118] Ansys Fluent: Fluid Simulation Software. [Online]. [Accessed: 01.04.2024]. Available: https://www.ansys.com/products/fluids/ansys-fluent

[119] Peters B., *et al.* XDEM multi-physics and multi-scale simulation technology: Review of DEM–CFD coupling, methodology and engineering applications. *Particuology* 2019:44:176–193. https://doi.org/10.1016/j.partic.2018.04.005

[120] LuXDEM: Luxembourg XDEM Research Centre, 'Extended Discrete Element Method (XDEM)', 2024. [Online]. [Accessed: 01.04.2024]. Available: https://luxdem.uni.lu/