Journal of Thermal Analysis and Calorimetry (2023) 148:8747–8763
https://doi.org/10.1007/s10973-023-12287-x

# Research trends and performance evaluation of natural gas in the web of science category of energy and fuels: a bibliometric study

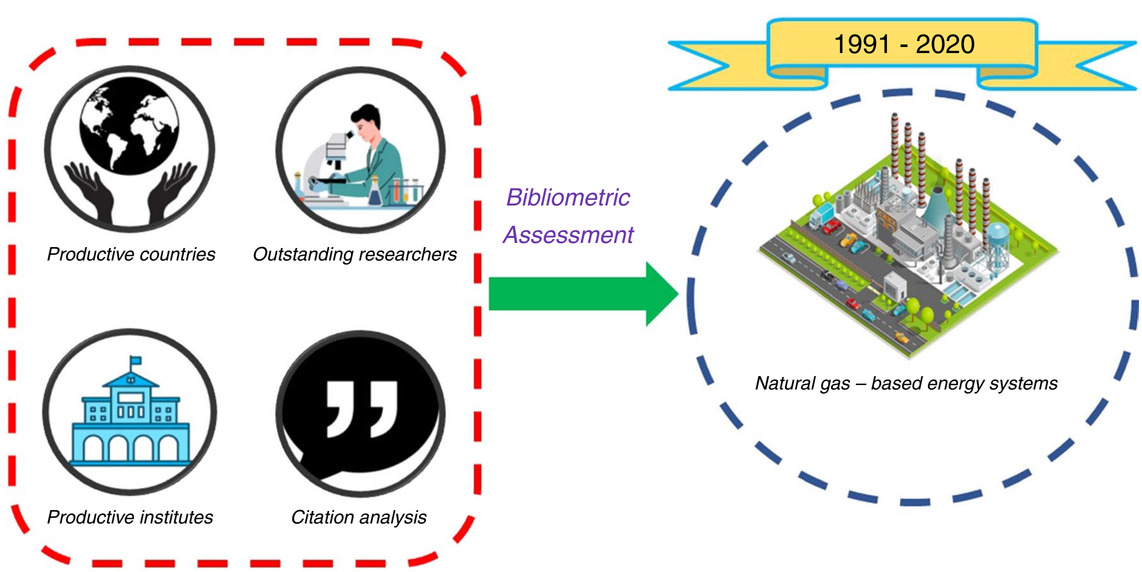
Mehdi Mehrpooya[1] · Chia-Ming Chang[2] · Seyed Ali Mousavi[1] · Mohammad Reza Ganjali[3,4] · Yuh-Shan Ho[5]

Received: 4 February 2023 / Accepted: 23 May 2023 / Published online: 9 June 2023


## Abstract

This investigation deals with the bibliometric analysis of research trends and performances of Natural Gas (NG) in the Web of Science (WOS). Search keywords: "natural gas" and "natural gases" were utilized to explore the documents from 1991 to 2020. The results were refined by WOS category of energy and fuels. The journal impact factors ($IF_{2020}$) are adapted from the Journal Citation Reports (JCR) published in 2020. Despite the huge number of original and review articles related to the NG-based systems, no bibliometric investigation of this field has been conducted to our knowledge. In order to track the scholarly trends and project results, a bibliometric investigation is the best tool. Microsoft Excel 2016 is utilized to collect and check the number of citations and the full record of SCI-EXPANDED of each document in each year. The evaluations indicated that the article type was the most popular, with an overall of 11,687 articles (91% of 12,837 documents). 99% of the articles were published in English, followed by German (70), Polish (44), French (22), Russian (14), and Japanese (5). Based on the citation assessment, the USA published the most top ten cited articles of the six articles; followed by Australia, China, Greece, Russia, Turkey, and the UK, one each. It was found that 5577 articles (49% of 11,288 articles) were published in a single institution while 5711 articles (51%) were inter-institutionally collaborative. Eventually, the trends of development of productive countries, citation life, main topics, and the number of NG papers are explored and the results are plotted in figures. The current bibliometric investigation illustrated the current outlook and future trends in the NG-based systems to simplify the knowledge exchange.

### Graphical abstract




Extended author information available on the last page of the article

**Keywords** Web of science core collection · Bibliometric analysis · Natural gas · Highly cited publications · Outstanding researchers · Citation analysis

## Introduction

Nowadays, Natural gas (NG) is known as one of the main energy resources and plays an outstanding role in meeting the required energy. In the last years, the utilization of NG as a low-emission fuel has increased. According to the prediction of the International Energy Outlook, the global demand for NG will increase by 70% from up to 2040 [1]. Actually, NG is used as the inlet fuel to drive many different energy systems, such as hydrogen production, hydrogen purification, carbon storage and capture, and fuel cell technology [2].

The pipelines and NG liquefaction are most effective industrial methods to transport NG [3].

The most important problem in LNG plants is improvement of the technical performance of the liquefaction units [4]. Based on the prior studies, the required electricity in most LNG production systems varied between 250 and 800 kWh/ton LNG [5]. The largest contribution to the overall electricity consumption was related to the compressors [6]. The huge amount of energy consumption is one of the most problems in LNG production process, indicating that the selection of a suitable liquefaction unit play an important role in LNG production plants.

Therefore, in recent years, energy researchers have tried to increase system efficiency and diminish the fuel consumption by introducing novel processes.

To evaluate the NG-based systems, the exergy, advanced exergy, exergoeconomic, and exergoenvironmental analyses have been accomplished. So far, many investigations regarding the mentioned evaluations have been conducted, which in this study are presented and summarized. For instance, the techno-financial assessment is applied to an LNG generation configuration assisted by the auto–cascade refrigeration unit [5]. This structure can generate 31.71 kg $s^{-1}$ LNG. The total exergetic proficiency and total irreversibility rate are computed as 91.68% and 67,688 kW, respectively. Also, the prime cost of product and Net Present Value (NPV) are obtained to be 0.1959 US$.$kg^{-1}$ LNG and 2829 MMUS$.$year^{-1}$, respectively. The exergoeconomic and exergoenvironmental assessments are conducted for an LNG production system driven by the diffusion–absorption refrigeration configuration [4]. The cost per unit exergy of LNG stream is calculated as 13.54 $.$GJ^{-1}$, as well as the greatest total environmental impact belonged to the air coolers. Advanced exergoeconomic investigation is implemented for a single mixed refrigerant LNG process [7]. The results demonstrated that most of the investment and exergy-related costs are endogenous, as well as most of the irreversibilities costs in the compressors are avoidable. The advanced exergoeconomic assessment is performed on an innovative LNG generation structure assisted by the single effect absorption refrigeration unit [8]. The precooling unit can supply the refrigeration at − 30 °C with a Coefficient of Performance (COP) of 0.49. According to the obtained outcomes, share of the endogenous destruction cost for all devices is higher than 55%. Also, it was found that the most minor portion of irreversibility costs is related to the avoidable exogenous destruction. In another investigation, the exergy analysis and Life cycle assessment (LCA) methodologies are applied to a multi-generation configuration employing LNG cold energy [9]. The total exergy efficiency and the destroyed exergy rate are found as 42.95% and 11,382 kW, respectively. Also, the highest overall environmental impact rate (187.03 Pts.$h^{-1}$) belonged to one of the heat exchangers. An NG-based multi-generation configuration providing potable water, electrical energy, oxygen, and syngas is proposed, and evaluated in terms of energy, financial, and environmental [10]. Thereafter, three scenarios are introduced. The third scenario is recognized as the most affordable system with a Cost of Electricity (COE) of 0.02 US$.$kWh^{-1}$, as well as the energy and $CO_2$ capture efficiencies of this scenario are accounted for 83.72% and 76.61%, respectively.

Also, in many investigations, the NG-based systems have been integrated with renewable configurations. Namely, a novel solar-driven structure for the generation of methanol and LNG is proposed and techno-economically analyzed [11]. The entire exergetic efficiency is gained to be 68.72%, as well as the greatest contribution to the total irreversibility is related to the photovoltaic panels (81.33%). Regarding the financial assessment, the payback period and the prime cost of product are found as 4.29 years and 0.3967 US$.$kg^{-1}$ methanol, respectively. A cogeneration configuration of electricity and liquid ammonia utilizing LNG regasification and solar energy is developed and exergetically assessed [12]. The overall exergetic efficiency and the destroyed exergy are computed with the values of 57.36% and 116,763 kW, respectively. An innovative solar-biomass-assisted cogeneration system of freshwater and LNG is developed and evaluated using the exergy and exergoeconomic methods [13]. According to the achieved findings, the overall exergy efficiency and product cost rate of the system are 11.2% and 15.16 $.$h^{-1}$, respectively. The techno-economic-environmental study is carried out on a solar-based cogeneration system for providing 520.2 kW electricity and 2 $kg.s^{-1}$ LNG [14]. The overall exergetic efficiency, total product cost rate, and total environmental impact rate are computed as 6.48%, 80.82 $/h, and 78.23 Pts/h, respectively.

Also, several investigations on $CO_2$ capture systems of natural gas have been conducted, some of which are presented below:

Techno-financial evaluation and optimization of NG-based combined power system with $CO_2$ capture are performed by A. Kazem et al. [15]. An innovative configuration for the generation of electrical energy and synthetic NG from captured $CO_2$ is developed, and Multi-objective optimization, parametric analysis, and financial assessment are accomplished [16]. The values of net electricity produced and payback period are computed as 95,700 kW and 4 years, respectively. Thermodynamic and financial analyses are applied to the chemical looping reforming of NG and $CO_2$ capture unit [17]. It was determined that the net electrical proficiency varied between 40 and 43.4%, as well as the values of Levelized Cost of Electricity (LCOE) were variable between 75.3 and 144.8 $\$.MWh^{-1}$. In another research, the technical assessment of industrial $CO_2$ Capture from NG employing the Diglycolamine is implemented [18].

Due to the high growth rate of NG-based article, the bibliometric assessment tool to track the research trends and scientific production is necessary [19]. Conventional bibliometric tools often assess the research trend by recognizing productive countries, active institutes, high-impact journals, and outstanding researchers [20]. Moreover, citation analysis can be a powerful tool for a more in-depth understanding of the universal research trends [21]. The bibliometric methodology permits scholars to evaluate and develop indexes on the progress of scientific data in a specific field [22]. This method evaluates the specifications of the existing literature on a topic to determine future research paths and to improve the decision-making process by decreasing the border of error [23]. In fact, to indicate a comprehensive NG-based energy systems investigation image in the whole scientific world, the multi-assessments of publications performance must be conducted [24]. Highly cited articles are helpful indexes for specifying “world-class” investigation.

Due to the vital and important role of NG in supplying energy to drive the hybrid energy systems, in this investigation, for the first time, a comprehensive bibliometric evaluation of the NG-based investigations is conducted within a period of 1991 to 2020. The bibliometrics could be a powerful tool for drawing the latest progress around a research field. By evaluating the yearly citations, leading countries, outstanding researchers, successful journals, and distribution pattern of subjects, the publication performance of NG-based systems could be properly analyzed. The document types according to the WOS collection are characterized. In the next step, the yearly number of NG papers and their citations per year is investigated. Thereafter, publication performance regarding the countries and institutions is investigated, as well as the top ten NG papers in terms of the number of citations have been recognized. Finally, the development of the 7 hot and important research foci in NG-based research is investigated. The bibliometric investigation of NG-based systems can help a more in-depth understanding the universal research trends and hotspots.

## Methodology

The information of the current investigation has been adapted from the WOS Core Collection and SCI-EXPANDED database of the Clarivate Analytics. The data has been updated on 31 August 2020. Based on the impact factor’s definition, the published documents in 2020 from SCI-EXPANDED are presented after $IF_{2020}$. The SCI-EXPANDED indicates an overall of 9531 journals across 178 WOS classes, and 114 of them are categorized in the class of energy and fuels in 2020. Search keywords: "natural gas" and "natural gases" were utilized to explore the documents from 1991 to 2020 [25]. The outcomes are refined using the WOS category of the energy and fuels. Microsoft Excel 2016 is utilized to collect and check the number of citations and the full record of SCI-EXPANDED of each document in each year. The extra coding was manually conducted [26, 27]. The Journal Citation Reports (*JCR*) is employed to gain the journal impact factors ($IF_{2020}$).

The ‘reprint’ author is considered as the corresponding author. "Corresponding author" remains the primary term rather than reprint author [28]. In multiple corresponding-authors papers, only the affiliation of the last corresponding author has been specified [29]. For single-author papers where authorship is not specified, the single-author can be considered both the first author and the corresponding author.

Affiliations in the countries of Northern Ireland, Scotland, and Wales have been turned to the United Kingdom (UK). The papers published from Hong Kong before 1997 were turned to the China category. Affiliations in Yugoslavia have been turned to the Serbia.

## Outcomes and discussion

### Specifications of document kinds

Table 1 represents the thirteen document kinds indexed by the WOS. The most popular type belonged to the articles, with an overall of 11,687 articles (91% of 12,837 documents) and an APP of 3.7. The document type of the reviews had the greatest $CPP_{2020}$ of 65 which was 3.2 times than the

**Table 1** The results of citation evaluation based on the document kind

| Document kind | TP | % | TP* | AU | APP | $TC_{2020}$ | $CPP_{2020}$ |
|---|---|---|---|---|---|---|---|
| Article | 11,687 | 91 | 11,548 | 42,483 | 3.7 | 241,228 | 21 |
| Proceedings paper | 994 | 7.7 | 985 | 3,343 | 3.4 | 27,749 | 28 |
| Review | 729 | 5.7 | 729 | 2,562 | 3.5 | 47,670 | 65 |
| Editorial material | 199 | 1.6 | 149 | 181 | 1.2 | 213 | 1.1 |
| News item | 158 | 1.2 | 45 | 54 | 1.2 | 8 | 0.051 |
| Letter | 18 | 0.14 | 18 | 21 | 1.2 | 22 | 1.2 |
| Book review | 18 | 0.14 | 18 | 18 | 1.0 | 2 | 0.11 |
| Correction | 16 | 0.12 | 16 | 52 | 3.3 | 6 | 0.38 |
| Note | 8 | 0.062 | 5 | 6 | 1.2 | 10 | 1.3 |
| Retracted publication | 2 | 0.016 | 2 | 3 | 1.5 | 63 | 32 |
| Reprint | 2 | 0.016 | 1 | 2 | 2.0 | 0 | 0 |
| Discussion | 1 | 0.0078 | 1 | 1 | 1.0 | 0 | 0 |
| Retraction | 1 | 0.0078 | 1 | 2 | 2.0 | 0 | 0 |

*TP** number of publications with author information in SCI-EXPANDED, *AU* number of authors

$CPP_{2020}$ of the articles. An overall of 994 articles have been published in 57 journals mainly in *International Journal of Hydrogen Energy* (143 proceedings papers; 14% of 994 proceedings papers) and *Energy* (133; 13%). An overall of 729 reviews have been published in the 72 journals mainly in *Renewable & Sustainable Energy Reviews* (344 reviews; 47% of 729 reviews) with a $CPP_{2020}$ of 56 and an APP of 3.3. 8/10 of the top most frequently cited documents were review. Using the WOS Core Collection, documents can be classified into two document kinds, resulting in the sum of more than 100% percentages in Table 1 [30].

The document type, article usually includes all of the investigation ideas, methodologies, outcomes, and discussion. Accordingly, the articles are usually employed for bibliometric assessment [31]. 99% of the papers have been published in English, followed by German (70 articles), Polish (44), French (22), Russian (14), and Japanese (5) were also used. English papers had much more $CPP_{2020}$ of 21 than non-English papers with a $CPP_{2020}$ of 1.9. Also, the highest value of APP belonged to the English articles (3.7).

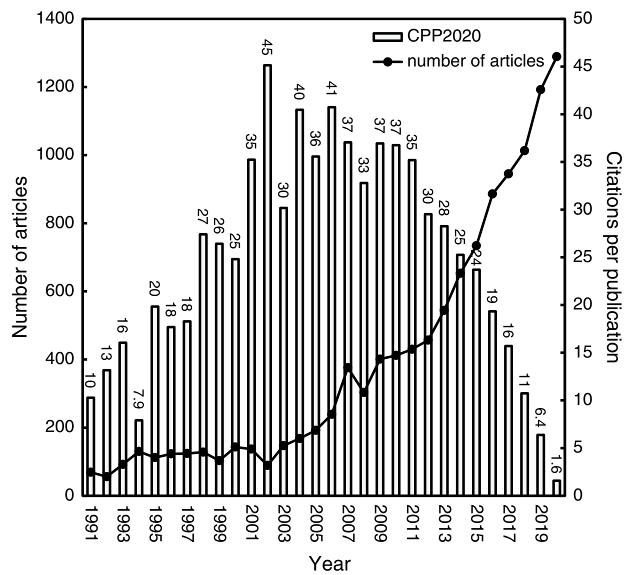



**Fig. 1** Changes of TP and $CPP_{2020}$ from 1991 to 2020

## Specifications of the publication outputs

Figure 1 illustrates the variations of TP and $CPP_{2020}$ from 1991 to 2020, which was named as the $TC_{2020}$/TP [32]. The number of papers has grown from 1991 to 2003, despite slight fluctuations. Followed a sharper increase was found from 2003 to 2012. The articles have sharply increased natural gas research after 2012 and reached 1289 articles in 2020. It always takes time to gather citations for a paper. According to Fig. 1, it takes $CPP_{2020}$ about a decade to reach a plateau. Similarly, artificial intelligence [33], as well as environmental related topics: bioaccumulation [34] and wind tunnel [21]. A total of 7804 NG-based papers (67% of 11,687 papers) were without citations in the publication year ($C_0$=0). It was reported that articles have higher $C_0$ in recent years [35]. The top seven natural gas articles in $C_0$ were all published in 2020. Moreover, among the top 100 $C_0$ papers, only 6.0% and 16% of them were among the top 100 $TC_{2020}$ and $C_{2020}$ papers, respectively. In 2002 with 89 articles, had the greatest value of $CPP_{2020}$ (45). The most cited natural gas paper was published in 2002 with a $TP_{2020}$ of 875.

## Journals

In total, 11,687 NG-based papers have been published in 144 journals in the WOS category of energy and fuels. Among them, 40 journals (28% of 144 journals) have not been categorized in the group in 2020 without $IF_{2020}$. A total of 10,943 natural gas articles were published in 104 of 114 journals in the WOS category of energy and fuels in 2020. Table 2 presents the top ten high-yielding journals with publication indicator (TP), citation indicator ($CPP_{2020}$), journal impact factor in 2020 ($IF_{2020}$), and number of authors per publication (APP). The *Energy* with $IF_{2020}$ of 7.147 ranked 22nd in the WOS category of energy and fuels, published the most 1077 natural gas articles (9.2% of 11,687 articles). According to the top ten productive journals, a total of 830 natural gas articles were published in the *International Journal of Hydrogen Energy* ($IF_{2020}$ = 5.816, ranked 37th in the Web of Science category of energy and fuels) with the highest $CPP_{2020}$ of 31 while 496 articles published in the *Energies* ($IF_{2020}$ = 3.004, ranked 70th) had lower $CPP_{2020}$ of 6.9. Ten articles were published in the *Nature Energy* ($IF_{2020}$ = 60.858, ranked 1st) with an APP of 6.9 and a $CPP_{2020}$ of 18. The journal ranked not only top in WOS category of energy and fuels but also 2nd in the class of multidisciplinary materials science.

## Performance assessment of publication in terms of institutions and countries

A total of 399 articles (3.4% of 11,687 papers) were without author affiliation data in SCI-EXPANDED. Of the 11,288 natural gas articles with author affiliations from 106 countries, 8946 papers (79% of 11,288 articles) were single-country papers from 84 countries while 2342 (21%) papers were internationally collaborative papers from 99 countries. The top 10 productive countries with 6 publication indexes are presented in Table 3 [36]. These useful indicators can be expressed as follows:

- TP*:* Total number of papers
- IP*:* Single-country papers
- CP*:* Internationally collaborative articles
- FP*:* First-author papers
- RP*:* Corresponding-author papers
- SP*:* Single-author articles [29]

**Table 2** The most high-yielding journals

| Journal | TP/ % | Rank/*IF*$_{2020}$ | APP | *CPP*$_{2020}$ |
|---|---|---|---|---|
| Energy | 1,077 (9.2) | 22 (7.147) | 3.6 | 25 |
| International journal of hydrogen energy | 830 (7.1) | 37 (5.816) | 3.8 | 31 |
| Applied energy | 827 (7.1) | 9 (9.746) | 4.1 | 28 |
| Energy policy | 795 (6.8) | 32 (6.142) | 2.8 | 27 |
| Journal of natural gas science and engineering | 730 (6.2) | 46 (4.965) | 4.0 | 13 |
| Energy conversion and management | 581 (5.0) | 10 (9.709) | 3.6 | 28 |
| Fuel | 572 (4.9) | 27 (6.609) | 4.4 | 25 |
| Energies | 496 (4.2) | 70 (3.004) | 4.2 | 6.9 |
| Energy and fuels | 487 (4.2) | 67 (3.605) | 4.3 | 20 |
| Applied thermal engineering | 466 (4.0) | 41 (5.295) | 3.7 | 22 |

**Table 3** Top ten high-yielding countries with six main indicators

| Country | TP | TP | | IPR /% | CPR /% | FP | | RP | | SP | | APP |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | *R* /% | $CPP_{2020}$ | | | *R* /% | $CPP_{2020}$ | *R* /% | $CPP_{2020}$ | *R* /% | $CPP_{2020}$ | |
| China | 2,411 | 1 (21) | 16 | 1 (16) | 2 (27) | 1 (20) | 16 | 1 (19) | 16 | 9 (2.8) | 11 | 5.1 |
| USA | 2,242 | 2 (20) | 27 | 2 (13) | 1 (33) | 2 (15) | 29 | 2 (16) | 29 | 1 (23) | 36 | 3.7 |
| Iran | 730 | 3 (6.5) | 19 | 3 (4.6) | 6 (8.8) | 3 (6.1) | 19 | 3 (5.7) | 19 | 11 (2.3) | 9.0 | 3.4 |
| UK | 702 | 4 (6.2) | 22 | 6 (3.3) | 3 (14) | 6 (4.3) | 23 | 5 (4.5) | 22 | 4 (6.8) | 30 | 3.7 |
| Canada | 643 | 5 (5.7) | 24 | 5 (3.6) | 4 (10) | 5 (4.3) | 25 | 6 (4.5) | 24 | 5 (5.0) | 18 | 3.6 |
| Italy | 623 | 6 (5.5) | 23 | 4 (3.8) | 8 (8.2) | 4 (4.6) | 24 | 4 (4.7) | 24 | 8 (3.2) | 22 | 3.9 |
| Germany | 539 | 7 (4.8) | 19 | 8 (3.0) | 7 (8.7) | 7 (3.6) | 18 | 7 (3.6) | 18 | 3 (7.4) | 10 | 3.7 |
| Turkey | 422 | 8 (3.7) | 25 | 7 (3.1) | 20 (3.1) | 8 (3.5) | 25 | 8 (3.5) | 25 | 2 (14) | 24 | 2.2 |
| Australia | 397 | 9 (3.5) | 23 | 11 (1.7) | 5 (8.9) | 10 (2.3) | 23 | 10 (2.5) | 23 | 10 (2.5) | 18 | 3.9 |
| South Korea | 356 | 10 (3.2) | 20 | 9 (2.3) | 14 (3.9) | 9 (2.7) | 20 | 9 (2.8) | 19 | 18 (0.91) | 41 | 4.3 |

*IPR* /%: the rank and the percentage of single-country articles in the total single-country articles; *CPR* /%: the rank and the percentage of internationally collaborative articles in the total internationally collaborative articles; *FPR* /%: the rank and the percentage of first-author articles in the total first-author articles; *RPR*/%: the rank and the percentage of the corresponding-author articles in the total corresponding-author articles; *SPR* /%: the rank and the percentage of the single-author articles in the total single-author articles

China ranked top in four of the six mentioned indexes with a *TP* of 2411 papers (21% of 11,288 articles), an IP of 1778 papers (16% of 8,946 single-country articles), an FP of 2,255 articles (20% of 11,288 first-author articles), and an RP of 2158 articles (19% of 11,256 corresponding-author articles) while USA ranked top with a CP of 773 articles (33% of 2342 internationally collaborative articles) and an SP of 230 articles (23% of 987 single-author articles). The USA dominated in the citation indicator with a $CPP_{2020}$ of 27 for total articles, a $CPP_{2020}$ of 29 for first-author articles, a $CPP_{2020}$ of 29 for corresponding-author articles while South Korea ranked top with $CPP_{2020}$ of 41 for single-author articles. Articles published by authors from the USA as first author and corresponding author had higher $CPP_{2020}$ but a lower $CPP_{2020}$ was found in Germany. China had a much higher APP with 5.1 that was higher than APP in natural gas articles with an APP of 3.7. Figure 2 indicates the development trends of the top four high-yielding countries. China (2,411 articles) and the USA (2242 articles) published a similar number of natural gas articles from 1991 to 2020. However, their development trends were very different. The USA published the most articles from 1991 to 2013 but 2010. China had a sharp development trend from 2011 and ranked top in an annual number of articles from 2014. China is the dominant country in natural gas research.

With regard to institutes, 5577 articles (49% of 11,288 articles) were published in a single institution while 5711 articles (51%) were inter-institutionally collaborative. The properties of the top 10 high-yielding institutes with the six main publication indicators [36], as well as their citation indicator ($CPP_{2020}$) and number of authors per publication (APP) are tabulated in Table 4. 8/10 of the top high-yielding institutes were located in China and two in Iran. The China University of Petroleum in China took the first rank for four of the six publication indexes with a TP of 266 articles, an IP of 72 articles, an FP of 210 articles, and an RP of 199 articles while the Chinese Academy of Sciences in China had the first rank with a CP of 225 articles (3.9% of 5,711 inter-institutionally collaborative articles). In addition, the Sila Science in Turkey ranked 20th and published 172 articles including the most single-author articles with an *SP* of 18 articles (1.3% of 987 single-author articles). Eight and seven of the 18 single-author articles were published by M. Balat and A. Demirbas, respectively. Seven of the top ten productive institutes had a low $CPP_{2020}$ that is lower than average of $CPP_{2020}$ in the natural gas articles with 21. Compare the ten in states in Table 4, the Xi An Jiao Tong University in China dominated in the citation indicator with a $CPP_{2020}$ of 34 for their all articles, a $CPP_{2020}$ of 38 for their first-author articles, and a $CPP_{2020}$ of 38 for their corresponding-author articles. The PetroChina in China had the largest value of $CPP_{2020}$ for their single-author articles with 11.

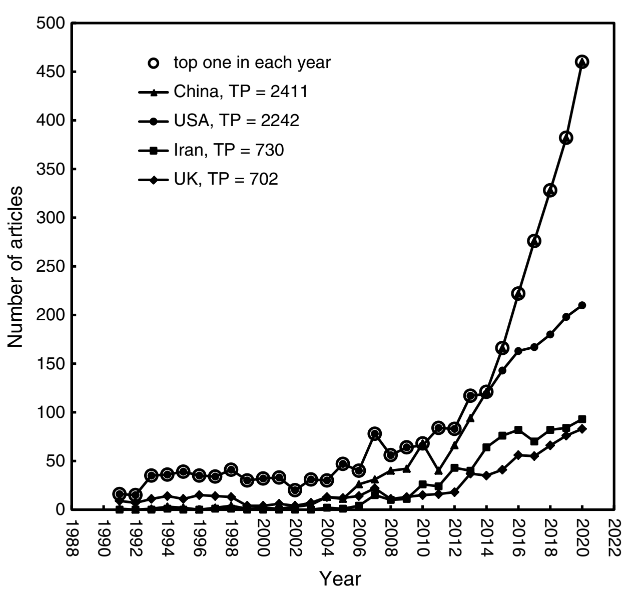



**Fig. 2** The performance evaluation of the top four high-yielding countries

## Top ten most cited NG-based papers

Based on the WOS Collection, the overall number of citations of a document can be updated. Ho's group introduced $TC_{year}$ and $C_{year}$ citation indexes [28, 37]. The mentioned indicators are invariant and repeatable compared with the other indicators of WOS Core Collection [25]. Some argue that the number of citations to an article can indicate the impact of scientific publications, although not necessarily the quality [38]. The top articles can be defined as articles that most scholars can read and cite in high-impact journals [39]. By using the title of the article, reasonable details about the topic of the paper can be specified [40]. Author keywords are presented by authors to introduce more information about the main investigations focused on papers. Articles that included search keywords in their abstract only might not relate to the search subject directly [19]. Search keywords: "natural gas" and "natural gases" can be found in 4027 article titles (34% of 11,687 articles), 10,578 abstracts (93% of 11,327 articles with abstract information in SCI-EXPANDED), and 3228 author keywords (34% of 9547 articles with author keywords information in SCI-EXPANDED). 5/8 of the top articles on $TC_{2019}$ included search keywords in their abstract only. For instance, articles by Dunn [41], Zhang et al. [42], Serrano-Ruiz and Dumesic [43], Rubin et al. [44], and Davison [45] ranked 1st with $TC_{2019}$ of 875, 2nd with $TC_{2019}$ of 569, 3rd with $TC_{2019}$ of 558, 5th with $TC_{2019}$ of 485, and 6th with $TC_{2019}$ of 476, respectively. Table 5 lists the 10 most frequently cited NG-based articles with two citation indicators [28]. Three of the

**Table 4** Top 10 high-yielding institutions with 6 main indexes

| Institute | TP | TP | | IPR /% | CPR /% | FP | | RP | | SP | | APP |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | *R* /% | CPP | | | R % | CPP | *R* /% | CPP | *R* /% | CPP | |
| China University of Petroleum, China | 266 | 1 (2.4) | 12 | 1 (0.64) | 2 (3.4) | 1 (1.9) | 12 | 1 (1.8) | 12 | 70 (0.20) | 7.0 | 5.5 |
| Chinese Academy of Sciences, China | 264 | 2 (2.3) | 19 | 8 (0.35) | 1 (3.9) | 2 (1.4) | 19 | 2 (1.4) | 20 | N/A | N/A | 5.4 |
| Tsinghua University, China | 145 | 3 (1.3) | 26 | 3 (0.50) | 5 (1.6) | 3 (0.94) | 29 | 3 (0.92) | 28 | 164 (0.10) | 2.0 | 5.1 |
| University of Tehran, Iran | 132 | 4 (1.2) | 23 | 7 (0.35) | 4 (1.6) | 5 (0.80) | 25 | 4 (0.83) | 25 | 164 (0.10) | 43 | 3.7 |
| Islamic Azad University, Iran | 113 | 5 (1.0) | 18 | 62 (0.13) | 3 (1.7) | 18 (0.44) | 18 | 20 (0.43) | 17 | 70 (0.20) | 1.5 | 4.0 |
| China University of Petroleum (East China), China | 108 | 6 (0.96) | 9.1 | 29 (0.19) | 6 (1.5) | 7 (0.78) | 10 | 8 (0.72) | 10 | N/A | N/A | 5.8 |
| Southwest Petroleum University, China | 108 | 6 (0.96) | 7.3 | 10 (0.33) | 10 (1.2) | 4 (0.86) | 7.2 | 5 (0.81) | 7.1 | N/A | N/A | 5.2 |
| Shanghai Jiao Tong University, China | 106 | 8 (0.94) | 18 | 2 (0.52) | 18 (0.82) | 6 (0.79) | 16 | 6 (0.78) | 16 | 164 (0.10) | 4.0 | 4.3 |
| Xi An Jiao Tong University, China | 106 | 8 (0.94) | 34 | 5 (0.43) | 11 (1.0) | 8 (0.75) | 38 | 7 (0.76) | 38 | N/A | N/A | 4.7 |
| PetroChina, China | 100 | 10 (0.89) | 9.4 | 35 (0.18) | 8 (1.4) | 12 (0.53) | 9.3 | 14 (0.48) | 8.5 | 164 (0.10) | 11 | 6.2 |

10 articles were published in the *International Journal of Hydrogen Energy* ($IF_{2020}$ = 5.816). The USA published the most top ten cited articles of the six articles; followed by Australia, China, Greece, Russia, Turkey, and the UK, one each. No author and institute published more than one the ten most frequently cited articles.

Figure 3 exhibits the citation assessment of the top ten most frequently cited papers. Five of the articles by Elvidge et al. [46], Makogon et al. [47], Laubach et al. [48], Huang et al. [49], and Rufford et al. [50] were ranked in both top 31st of $TC_{2020}$ and $C_{2020}$ (Table 5). It was pointed that highly cited publications might not be always in high-impact positions [35]. A typical example was the article entitled "A comparative study of fuels for on-board hydrogen production for fuel-cell-powered automobiles" by Brown [51] had a $TC_{2020}$ of 494 (ranked 4th) but a $C_{2020}$ of 11 (ranked 795th). Furthermore, highly cited articles might not be the most impactful in the most recent year [27]. Some recent publications, which did not get enough time to accumulate numbers of citations, would be omitted if only $TC_{year}$ was considered for evaluation of the most frequently cited articles, for example, an article published in 2018 by Keith et al. [52] ranked 76th with a $TC_{2020}$ of 198 but ranked top in $C_{2020}$ with 109. The article had a high citation in 2020 shows the related research is popular in the WOS category of biomedical engineering in recent years. Similarly, article by Comesaña-Gándara et al. [53] had a $C_{2020}$ of 64 (ranked 8th) and a $TC_{2020}$ of 196 (ranked 668th). Only using the $TC_{year}$ was not enough to identify some excellent articles in the most recent years. The top three most frequently cited articles by Dunn (2002) [41], Zhang et al. (2010), and Serrano-Ruiz and Dumesic [43] contained search keywords only in their abstract. They might not relate to natural gas directly.

## Outstanding subjects in NG-based systems

In this section, with the use of distribution of words in article titles, abstracts, and author keywords, the hot topics in NG-based systems are investigated and their development trends are determined [58]. The 6715 NG-based articles were investigated using their title, abstract, and author keywords from 1991 to 2020. A total of 4,027 articles (34% of 11,687 articles); 10,578 articles (93% of 11,327 articles with abstract); and 3,228 articles (34% of 9547 articles with author keywords) included search keywords in their title, abstract, and author keywords, respectively. Table 6 presents the twenty hottest subjects in four subperiods (1990s, 2000s, and 2010s). The most frequently used author keywords, except for the searching words such as "optimization," "renewable energy," "$CO_2$ capture," "life cycle assessment," and "exergy analysis" were getting popular to be used in the recent decade. The findings of keyword evaluation indicate information about the hot

**Table 5** The top 10 most cited papers

| Rank ($TC_{2020}$) | Rank ($C_{2020}$) | Title | Country | Reference |
|---|---|---|---|---|
| 4 (494) | 795 (11) | A comparative study of fuels for on-board hydrogen production for fuel-cell-powered automobiles | USA | [51]Brown (2001) |
| 7 (470) | 5 (68) | A fifteen-year record of global natural gas flaring derived from satellite data | USA, Russia | [46]Elvidge et al. (2009) |
| 8 (431) | 13 (59) | Natural gas-hydrates: A potential energy source for the 21st Century | USA | [47]Makogon et al. (2007) |
| 9 (427) | 7 (66) | Characteristics and origins of coal cleat: A review | USA | [48]Laubach et al. (1998) |
| 15 (349) | 21 (51) | Measurements of laminar burning velocities for natural gas-hydrogen-air mixtures | China | [49]Huang et al. (2006) |
| 19 (306) | 1155 (9) | Hydrogen generation from natural gas for the fuel cell systems of tomorrow | UK | [54]Dicks (1996) |
| 24 (297) | 190 (21) | Catalytic dry reforming of natural gas for the production of chemicals and hydrogen | Greece | [55] Verykios (2003) |
| 25 (292) | 18 (53) | The removal of $CO_2$ and $N_2$ from natural gas: A review of conventional and emerging process technologies | Australia | [50] Rufford et al. (2012) |
| 28 (285) | 145 (23) | Internal combustion engines fueled by natural gas: Hydrogen mixtures | Turkey, USA | [56]Akansu et al. (2004) |
| 31 (276) | 795 (11) | Catalytic partial oxidation of natural gas to syngas | USA | [57]Bharadwaj and Schmidt (1995) |

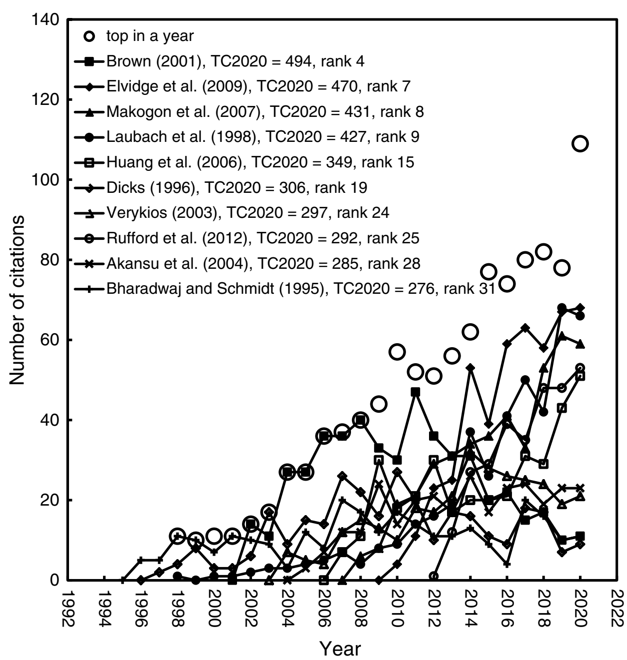



**Fig. 3** The citation analysis of the top ten most frequently cited papers

and possible research foci in the recent years as each word cluster comprised several supporting words. Therefore, the development of the seven hot and popular topics in NG-based research was investigated. Figure 4 illustrates the development trends of the seven hot subjects. After 2015, the number of articles published in the mentioned fields has grown significantly.

### Topic: renewable energy

In this section, some recent articles related to the integration of NG units and renewable energy configurations are summarized (see Table 7). It can be shown that renewable resources, especially wind and solar energies can be coupled with the NG stream to drive the single and multi-generation systems to generate the main products, such as methanol, LNG, electricity, and potable water. Also, in most investigations, the technical and financial analyses have been implemented, as well as in some articles, the optimization process has been employed. In order to find the related papers, the following support keywords can be used: renewable energy, renewable energy sources, renewable energy storage, renewable energy integration, renewable energy policy, and renewable energy resources.

### Topic: capture

The next hot and popular topic is $CO_2$ capture. As mentioned earlier, the NG-based combined power plants play an important role in meeting the required energy, which have the highest share of greenhouse gas emissions (GHG) [65]. So, the exploration of an alternative energy generation source is essential, such as increasing renewable resources. One of the effective solutions to diminish GHG is the utilization of $CO_2$ capture technology [66]. For implementing $CO_2$ capture in each plant, there are three common methods including oxy-fuel combustion, pre-combustion, and post-combustion [67]. So, many investigations regarding the $CO_2$ capture techniques of NG-based systems have been conducted, and some of the

**Table 6** The 20 hot topics in NG-based with publication indicators

| Author keywords | TP | 1991–2020 *R* /% | 1991–2000 *R* /% | 2001–2010 *R* /% | 2011–2020 *R* /% |
|---|---|---|---|---|---|
| Natural gas | 1,484 | 1 (16) | 1 (21) | 1 (20) | 1 (14) |
| hydrogen | 474 | 2 (5.0) | 7 (3.2) | 2 (9.2) | 2 (4.0) |
| methane | 222 | 3 (2.3) | 3 (3.8) | 3 (3.0) | 6 (2.1) |
| Optimization | 221 | 4 (2.3) | 71 (0.59) | 34 (1.1) | 3 (2.7) |
| Renewable energy | 200 | 5 (2.1) | 71 (0.59) | 11 (2.0) | 4 (2.2) |
| LNG | 192 | 6 (2.0) | 26 (1.5) | 20 (1.5) | 5 (2.2) |
| Biomass | 172 | 7 (1.8) | 11 (2.9) | 7 (2.2) | 9 (1.6) |
| $CO_2$ capture | 164 | 8 (1.7) | 71 (0.59) | 14 (1.9) | 7 (1.7) |
| Combustion | 149 | 9 (1.6) | 7 (3.2) | 5 (2.5) | 20 (1.3) |
| Hydrogen production | 149 | 9 (1.6) | 71 (0.59) | 4 (2.8) | 18 (1.3) |
| Life cycle assessment | 149 | 9 (1.6) | 163 (0.29) | 27 (1.3) | 8 (1.7) |
| Liquefied natural gas | 148 | 12 (1.6) | 33 (1.2) | 27 (1.3) | 10 (1.6) |
| energy | 147 | 13 (1.5) | 14 (2.6) | 11 (2.0) | 16 (1.4) |
| emissions | 145 | 14 (1.5) | 19 (2.1) | 15 (1.8) | 14 (1.4) |
| Exergy | 145 | 14 (1.5) | 44 (0.88) | 20 (1.5) | 11 (1.6) |
| Energy efficiency | 142 | 16 (1.5) | 44 (0.88) | 15 (1.8) | 13 (1.4) |
| Cogeneration | 139 | 17 (1.5) | 7 (3.2) | 6 (2.4) | 24 (1.2) |
| Biogas | 138 | 18 (1.4) | 26 (1.5) | 22 (1.4) | 12 (1.5) |
| Exergy analysis | 135 | 19 (1.4) | N/A | 17 (1.7) | 15 (1.4) |
| Carbon dioxide | 125 | 20 (1.3) | 2 (5.0) | 31 (1.2) | 23 (1.2) |

*R*—rank in a period, *N/A*—not available

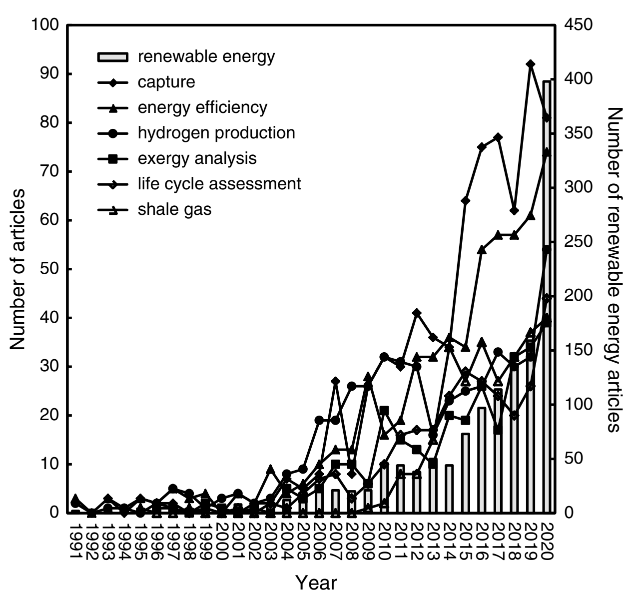



**Fig. 4** Development of the seven main topics

outstanding investigations are summarized in Table 8. As can be noticed, in most projects, the hydrogen and electricity production systems have been investigated, as well as technical–economic optimization has been conducted to determine the optimal operating conditions. Multi-generation systems have been used as power plants. In order to find the related articles, the following support keywords can be utilized: capture, captures, $CO_2$ capture, carbon capture, carbon dioxide capture, post-combustion $CO_2$ capture, and dioxide capture.

### Topic: energy efficiency

The energy assessment is the most common technique to evaluate the technical aspect of each energy system [75, 76]. By implementing the first law of thermodynamics, the quantity of energy is investigated, as well as the quality of energy can be evaluated using exergy analysis (topic 5) [77, 78]. Based on the energy analysis outputs, such as electrical efficiency, thermal efficiency, specific electricity consumption, COP, and overall energy efficiency, the NG-based systems can be compared together technically. Table 9 presents the details of energy analysis of some recent NG-based energy systems. As can be seen, in most LNG production systems that are integrated with a refrigeration unit, COP and specific electricity consumption as the two important parameters have been computed. In order to find the related articles, the following support keywords can be utilized: energy efficiency, building energy efficiency, energy efficiency programs, energy efficiency enhancement, energy efficiency improvement, energy efficiency index, energy efficiency resource standards, energy efficient, and primary energy efficiency.

**Table 7** The summary of the last investigations on the integration of NG units and renewable energy configurations

| Ref. | Type of renewable source | Main products | Parametric analysis | Technical or financial evaluation | Optimization |
|---|---|---|---|---|---|
| [11] | Solar | Methanol and LNG | | | |
| [12] | Solar | Ammonia, electricity, and $CO_2$ | | | – |
| [13] | Solar and biomass | Freshwater and LNG | | | |
| [14] | Solar | Electricity and LNG | | | |
| [59] | Solar | Cooling, heating, and electricity | | | |
| [60] | Solar | Cooling and electricity | | | |
| [61] | Wind and hydrogen | Electricity | | | |
| [62] | Wind | Electricity | | | |
| [63] | Wind | Methanol | | | – |
| [64] | Wind | Electricity | | | |

**Table 8** The summary of the last investigations on the $CO_2$ capture of NG-based plants

| Ref. | $CO_2$ capture technology | Type of plant | Parametric analysis | Technical or financial evaluation | Optimization |
|---|---|---|---|---|---|
| [15] | Pre- and post-combustion | Organic Rankine Cycle (ORC) | | | |
| [16] | Oxy-fuel combustion | Multi-generation system | | | |
| [17] | Pre-combustion | Hydrogen and electricity generation system | | | – |
| [68] | Pre-combustion | Hydrogen and electricity generation system | | | – |
| [69] | – | Hydrogen generation system | | | |
| [70] | Pre-combustion | Gas turbine system | | | – |
| [71] | Post-combustion | Multi-generation system | | | – |
| [72] | Post-combustion | Steam turbine system | | | |
| [73] | Combined cryogenic system | Multi-generation system | | | |
| [74] | Post-combustion | Coal-fired power plant | | | |

**Table 9** Details of energy analysis of some recent NG-based energy systems

| Ref. | Type of plant | Thermal efficiency | Electrical efficiency | Specific electricity consumption | Parametric analysis | Optimization |
|---|---|---|---|---|---|---|
| [5] | LNG production | – | | | | – |
| [4] | LNG production | – | – | | | – |
| [11] | Methanol and LNG production | – | | | | |
| [69] | Hydrogen generation system | – | – | – | | |
| [71] | LNG, freshwater, and electricity production | – | – | | | – |
| [14] | Electricity and LNG | | | – | | |
| [79] | LNG production | | | | | |
| [59] | Cooling, heating, and electricity production | | – | – | | |

## Topic: hydrogen production

Hydrogen is the most abundant element on earth that can be considered alternative clean energy and sustainable source [80]. Hydrogen can be produced using several techniques, such as steam reforming, gasification, dry reforming, and electrolysis [81]. Among the mentioned methods, NG steam reforming is the prominent technique in which hydrocarbons are converted to hydrogen. This section presents some outstanding investigations on hydrogen production from natural gas (see Table 10). As can be seen, in some projects, the renewable resources have been integrated with hydrogen production unit, as well as technical–economic optimization has been conducted to specify the optimal operating

**Table 10** Some outstanding investigations on hydrogen production from natural gas

| Ref. | Integrated with a renewable resource | Exergy analysis | Economic analysis | Environmental analysis | Parametric analysis | Optimization |
|---|---|---|---|---|---|---|
| [17] | – | – | | – | | – |
| [69] | – | – | – | – | | |
| [82] | – | | | – | | – |
| [83] | | | | | | |
| [84] | | | – | – | | – |
| [85] | – | – | – | – | | |
| [86] | | – | | | | – |
| [87] | | – | – | – | – | – |
| [88] | – | – | | | | |
| [89] | – | – | | | | – |

conditions. For a better search on this topic, the following keywords can be helpful: hydrogen production, biohydrogen production, distributed hydrogen production, and hydrogen production from hydrogen sulfide.

## Topic: exergy analysis

In this section, some outstanding investigations on exergy evaluation of the NG-based energy units are summarized (see Table 11). In many NG-based systems, for evaluating the technical aspect, the exergetic assessment is implemented. With the use of exergetic outputs, such as overall exergy efficiency and overall exergy destruction rate, the NG-based researches can be compared together [90]. Additionally, to recognize the origin of the irreversibilities in each device, the advanced exergy methodology is employed. Also, to generalize the results to the other operating conditions, parametric analyses on exergetic parameters are performed [91]. To find these articles, the following support keywords can be used: exergy analysis, exergy analyses, advanced exergy analysis, energy and exergy analysis, and advanced exergy analysis.

## Topic: life cycle assessment (LCA)

This section presents the outstanding investigations on implementing the LCA method for the NG-based energy units (see Table 12). In order to evaluate the environmental footprint of a product, the LCA concept is employed [102]. This methodology deeply scans the system and characterizes the environmental effect on the system's performance. Actually, the LCA method investigates the environmental impacts of service over the three phases of construction, operation, and decommissioning. The amounts of environmental effects resulting from the depletion and emissions of a natural resource can be determined employing various LCA methods. Heretofore, many methods, such as CML 2001, ReCiPe Endpoint, and Eco—indicator 99 have been employed for implementation of the LCA in various energy systems [47].

**Table 11** The summary of the last investigations on exergetic analysis of the NG-based energy systems

| Ref. | Overall exergy efficiency | Overall exergy destruction rate | Recognition of the main exergy-wasting devices | Sustainability index | Parametric analysis | Sankey diagrams | Exergy parameters for each device | Advanced exergy evaluation |
|---|---|---|---|---|---|---|---|---|
| [92] | | | | | | 0000 | | – |
| [93] | | | | – | – | – | | – |
| [94] | | | | – | | – | | – |
| [95] | | | | – | | – | | – |
| [96] | | | | – | – | – | | |
| [97] | | | | – | – | – | | |
| [98] | | | | | – | – | | |
| [99] | | | | – | | | | – |
| [100] | | | | – | | – | | – |
| [101] | | | | – | | – | | |

**Table 12** The summary of the last investigations on the implementation of the LCA approach on the NG-based energy configurations

| Ref. | Main products | Methodology used | Calculation of the $CO_2$ emissions | Link to exergy analysis (exergoenvironmental concept) Pts or mPts | Parametric analysis |
|---|---|---|---|---|---|
| [104] | Methanol and dimethyl ether (DME) | Not reported | | – | |
| [4] | LNG | Eco—indicator 99 | – | | |
| [105] | Electricity | ISO 14040–14,040 | | – | – |
| [106] | Methanol | CML 2001—Jan 2016 | | – | |
| [9] | Pure water, net electricity, hot water, and cold water | Eco—indicator 99 | – | | |
| [107] | Electricity | Eco-indicator 99 | | | – |
| [108] | Methanol | Eco-indicator 99 | | | – |
| [109] | Electricity | Eco-indicator 99 | – | | |
| [110] | Methanol | CML 2001 using GaBi 6.0 software | | – | |
| [111] | Cooling, heating, and electricity | Eco-indicator 99 | – | | |

Also, in many projects, the LCA method has been integrated into the exergy analysis to form the exergoenvironmental evaluation. The exergoenvironmental analysis is applied to each device by combining the findings of exergetic analysis and LCA method [103]. In most exergoenvironmental assessment projects, the Eco—indicator 99 is utilized, and this index utilizes the mean European data. To find these articles, the following support keywords can be utilized: life cycle assessment, LCA, exergoenvironmental analysis, and life cycle assessments. Based on the outcomes of LCA, the eco-friendly indicator of NG-based systems can be compared together. As can be seen, in most exergoenvironmental investigations, the environmental impacts are reported as the Pts or mPts, as well as to generalize the results and find the effective parameters, sensitivity analyses are conducted.

## Topic: shale gas

The NG that is found trapped within shale formations is called shale gas. In fact, Shale gas is trapped within shale formations with low permeability [112]. Shale gas is recognized as a key fuel in the universal energy basket [113]. In last years, many investigations have been implemented on shale gas production. Also, in several studies, the technical, financial and environmental investigations have been conducted on shale gas reservoirs. Some outstanding investigations on shale gas development can be found in Table 13. For a better search on this topic, the following keywords can be useful: shale gas, shale gases, gas shale, gas shales, shale gas reservoir, shale gas development, shale gas exploitation, shale gas revolution, unconventional shale gas, and wet shale gas.

**Table 13** Some outstanding investigations on shale gas development

| Ref. | Location | Technical analysis | Economic analysis | Environmental analysis | Parametric analysis | Optimization |
|---|---|---|---|---|---|---|
| [114] | U.S | – | – | | | – |
| [115] | China | | | | | |
| [116] | China | | – | – | | – |
| [117] | China | | | | | – |
| [118] | U.S | | | | | – |
| [119] | U.S | | | | | |
| [120] | U.S | | | | | – |
| [121] | China | | | – | – | – |
| [122] | China | | | | | |
| [123] | Spain | | | | | |

## Concluding remarks

In this investigation, a bibliometric investigation on research trends and performances of NG in the WOS category of energy and fuels is conducted. The current bibliometric assessment has brought together the knowledge of publications on the NG-based energy systems accessible from the WOS database. According to the findings of this investigation, the most outstanding researchers, publishers, countries, and research categories are recognized. The SCI-EXPANDED indexes an overall of 9531 journals across 178 WOS categories, and 114 of them are classified in the category of energy and fuels in 2020.

The most noticeable outputs of the current study can be listed as follows:

- The highest value of $CPP_{2020}$ (65) belonged to the reviews. Also, an overall of 729 reviews have been published in 72 journals mainly in *Renewable & Sustainable Energy Reviews* (344 reviews; 47% of 729 reviews). Additionally, the values of $CPP_{2020}$ for reprint, discussion, and retraction types were equal to zero.
- Ninety-nine percent of the papers have been published in English, followed by German (70), Polish (44), French (22), Russian (14), and Japanese (5). Also, English papers had the greatest APP of 3.7 than non-English papers with $CPP_{2020}$ of 1.8.
- The articles have sharply increased NG-based researches after 2012 and reached 1,289 articles in 2020. A total of 7804 NG-based papers (67% of 11,687 articles) were without citations in the publication year ($C_0 = 0$).
- With regard to the articles, The *Energy* journal ($IF_{2020} = 7.147$) with 1077 NG-based papers is recognized as the most productive journal, followed by the *International Journal of Hydrogen Energy* ($IF_{2020} = 5.816$) and *Applied Energy* ($IF_{2020} = 9.746$) stood for the second and third ranks, respectively.
- The publication performance evaluation demonstrated that 3.4% of the total articles (399 papers) were without author affiliation data in the SCI-EXPANDED. China had the highest amount of article (2,411), followed by USA (2242) and Iran (730). The greatest values of CP (773) and *SP* (230) are related to the USA.
- Articles published by authors from the USA as first author and corresponding author had higher $CPP_{2020}$ but a lower $CPP_{2020}$ was found in Germany. China had a sharp development trend from 2011 and ranked top in an annual number of articles from 2014. China is the dominant country in NG-based investigations.
- It was found that 5,577 articles (49% of 11,288 articles) were published in a single institution while 5,711 articles (51%) were inter-institutionally collaborative. 8/10 of the top high-yielding institutes were located in China and two in Iran. The highest value of TP belonged to the China University of Petroleum (266), followed by Chinese Academy of Sciences (264), Tsinghua University (145), and University of Tehran (132). Academy of Sciences in China ranked top with a *CP* of 225 articles (3.9% of 5,711 inter-institutionally collaborative articles).
- According to the citation analysis, the USA published the most top ten cited articles of the six articles; followed by Australia, China, Greece, Russia, Turkey, and the UK, one each. The 5/8 of the top papers on $TC_{2019}$ included exploring keywords in their abstract only.
- A total of 4,027 articles (34% of 11,687 articles); 10,578 articles (93% of 11,327 articles with abstract); and 3,228 articles (34% of 9,547 articles with author keywords) included exploring keywords in their title, abstract, and author keywords, respectively. The most frequently utilized author keywords, excluding for the exploring words, such as "optimization," "renewable energy," "$CO_2$ capture," "life cycle assessment," and "exergy analysis" were getting popular to be used in the recent decade.

**Data availability** The data that support the findings of this study are available in the paper.

## Declarations

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

## References

1. Hajji A, Chahartaghi M, Kahani M. Thermodynamic analysis of natural gas liquefaction process with propane pre-cooled mixed refrigerant process (C3MR). Cryogenics. 2019;103:102978.
2. Sharifi M, Heidaryan E. Thermal rectification in ultra-narrow hydrogen functionalized graphene: a non-equilibrium molecular dynamics study. J Mol Model. 2022;28(10):298.
3. Mehrpooya M, Omidi M, Vatani A. Novel mixed fluid cascade natural gas liquefaction process configuration using absorption refrigeration system. Appl Therm Eng. 2016;98:591–604.
4. Mehrpooya M, Mousavi SA, Delpisheh M, Zaitsev A, Nikitin A. 4E assessment and 3D parametric analysis of an innovative liquefied natural gas production process assisted by a diffusion–absorption refrigeration unit. Chem Pap. 2022;76:5231.
5. Mehrpooya M, Ghorbani B, Mousavi SA, Zaitsev A. Proposal and assessment of a new integrated liquefied natural gas generation process with auto–cascade refrigeration (exergy and economic analyses). Sustain Energy Technol Assess. 2020;40:100728.
6. Ghorbani B, Hamedi M-H, Amidpour M, Shirmohammadi R. Implementing absorption refrigeration cycle in lieu of DMR and

C3MR cycles in the integrated NGL, LNG and NRU unit. Int J Refrig. 2017;77:20–38.
7. Mehrpooya M, Ansarinasab H. Advanced exergoeconomic evaluation of single mixed refrigerant natural gas liquefaction processes. J Nat Gas Sci Eng. 2015;26:782–91.
8. Ansarinasab H, Mehrpooya M. Advanced exergoeconomic analysis of a novel process for production of LNG by using a single effect absorption refrigeration cycle. Appl Therm Eng. 2017;114:719–32.
9. Ansarinasab H, Hajabdollahi H, Fatimah M. Life cycle assessment (LCA) of a novel geothermal-based multigeneration system using LNG cold energy-integration of Kalina cycle, stirling engine, desalination unit and magnetic refrigeration system. Energy. 2021;231:120888.
10. Fadaei A, Aslani A, Ghenaatpisheh Senani A, Bekhrad K. Conceptual design and energy, economic and environmental (3E) analysis of a natural gas-based integrated system with reduced $CO_2$ emission for multigeneration of electricity, freshwater, syngas, and oxygen. Int J Energy Res. 2022;46:15981.
11. Jouybari AK, Ilinca A, Ghorbani B. Thermo-economic optimization of a new solar-driven system for efficient production of methanol and liquefied natural gas using the liquefaction process of coke oven gas and post-combustion carbon dioxide capture. Energy Convers Manage. 2022;264:115733.
12. Moradi M, Ghorbani B, Ebrahimi A, Ziabasharhagh M. Process integration, energy and exergy analyses of a novel integrated system for cogeneration of liquid ammonia and power using liquefied natural gas regasification, $CO_2$ capture unit and solar dish collectors. J Environ Chem Eng. 2021;9(6):106374.
13. Ghasemi A, Heidarnejad P, Noorpoor A. A novel solar-biomass based multi-generation energy system including water desalination and liquefaction of natural gas system: thermodynamic and thermoeconomic optimization. J Clean Prod. 2018;196:424–37.
14. Boyaghchi FA, Sohbatloo A. Assessment and optimization of a novel solar driven natural gas liquefaction based on cascade ORC integrated with linear Fresnel collectors. Energy Convers Manage. 2018;162:77–89.
15. Kazemi A, Moreno J, Iribarren D. Techno-economic comparison of optimized natural gas combined cycle power plants with $CO_2$ capture. Energy. 2022;255:124617.
16. Beyrami J, Jalili M, Ziyaei M, Chitsaz A, Rosen MA. A novel system for electricity and synthetic natural gas production from captured $CO_2$: techno-economic evaluation and multi-objective optimization. J CO2 Util. 2022;63:102116.
17. Nazir SM, Morgado JF, Bolland O, Quinta-Ferreira R, Amini S. Techno-economic assessment of chemical looping reforming of natural gas for hydrogen production and power generation with integrated $CO_2$ capture. Int J Greenh Gas Control. 2018;78:7–20.
18. Zahid U, Al Rowaili FN, Ayodeji MK, Ahmed U. Performance analysis of industrial $CO_2$ capture from natural gas using diglycolamine. Comput Aid Chem Eng. 2017;40:2641–6.
19. Zhang G, Xie S, Ho Y-S. A bibliometric analysis of world volatile organic compounds research trends. Scientometrics. 2010;83(2):477–92.
20. Zhou F, Guo H-C, Ho Y-S, Wu C-Z. Scientometric analysis of geostatistics using multivariate methods. Scientometrics. 2007;73(3):265–79.
21. Mo Z, Fu H-Z, Ho Y-S. Global development and trend of wind tunnel research from 1991 to 2014: a bibliometric analysis. Environ Sci Pollut Res. 2018;25(30):30257–70.
22. Chuang K-Y, Huang Y-L, Ho Y-S. A bibliometric and citation analysis of stroke-related research in Taiwan. Scientometrics. 2007;72(2):201–12.
23. Vanzetto GV, Thomé A. Bibliometric study of the toxicology of nanoescale zero valent iron used in soil remediation. Environ Pollut. 2019;252:74–83.
24. Mo Z, Fu H-Z, Ho Y-S. Highly cited articles in wind tunnel-related research: a bibliometric analysis. Environ Sci Pollut Res. 2018;25(16):15541–53.
25. Fu H-Z, Wang M-H, Ho Y-S. The most frequently cited adsorption research articles in the science citation index (expanded). J Colloid Interface Sci. 2012;379(1):148–56.
26. Li Z, Ho Y-S. Use of citation per publication as an indicator to evaluate contingent valuation research. Scientometrics. 2008;75(1):97–110.
27. Ho Y-S. A bibliometric analysis of highly cited publications in web of science category of emergency medicine. Signa Vitae. 2021;17(1):11–9.
28. Ho Y-S. Top-cited articles in chemical engineering in science citation index expanded: a bibliometric analysis. Chin J Chem Eng. 2012;20(3):478–88.
29. Ho Y-S. Bibliometric analysis of the journal of orthopaedic research from 1991 to 2018. Orthop Res Online J. 2019;6(2):574–84.
30. Usman M, Ho Y-S. A bibliometric study of the Fenton oxidation for soil and water remediation. J Environ Manage. 2020;270:110886.
31. Ho Y-S, Satoh H, Lin S-Y. Japanese lung cancer research trends and performance in science citation index. Intern Med. 2010;49(20):2219–28.
32. Ho Y-S. The top-cited research works in the science citation index expanded. Scientometrics. 2013;94(3):1297–312.
33. Ho Y-S, Wang M-H. A bibliometric analysis of artificial intelligence publications from 1991 to 2018. COLLNET J Scientometr Inform Manage. 2020;14(2):369–92.
34. Lei J, Fu H-Z, Ho Y-S. A global perspective of bioaccumulation research using bibliometric analysis. COLLNET J Scientometr Inform Manage. 2018;12(2):327–41.
35. Ho YS, Kahn M. A bibliometric study of highly cited reviews in the science citation index expanded™. J Am Soc Inf Sci. 2014;65(2):372–85.
36. Hsuly Y-H, Ho Y-S. Highly cited articles in health care sciences and services field in science citation index expanded a bibliometric analysis for 1958–2012. Methods Inf Med. 2014;53(6):446–58.
37. Ming HW, Hui ZF, Yuh SH. Comparison of universities'scientific performance using bibliometric indicators. Malays J Libr Inf Sci. 2011;16(2):1–19.
38. Brandt JS, Downing AC, Howard DL, Kofinas JD, Chasen ST. Citation classics in obstetrics and gynecology: the 100 most frequently cited journal articles in the last 50 years. Am J obstetr gynecol. 2010;203(4):355.
39. Robinson JK, Callen JP. The best of the best: a new section led by Henry W. Lim, MD. Arch Dermatol. 2010;146(5):554.
40. Wang M-H, Yu T-C, Ho Y-S. A bibliometric analysis of the performance of water research. Scientometrics. 2010;84(3):813–20.
41. Dunn S, johe. Hydrogen futures: toward a sustainable energy system. Int J Hydrog Energy. 2002;27(3):235–64.
42. Zhang L, Xu CC, Champagne P. Overview of recent advances in thermo-chemical conversion of biomass. Energy Convers Manage. 2010;51(5):969–82.
43. Juan Carlos S-R. Catalytic routes for the conversion of biomass into liquid hydrocarbon transportation fuels. Energy Environ Sci. 2010;4(1):83.
44. Rubin ES, Chen C, Rao AB. Cost and performance of fossil fuel power plants with $CO_2$ capture and storage. Energy Policy. 2007;35(9):4444–54.
45. Davison J. Performance and costs of power plants with capture and storage of $CO_2$. Energy. 2007;32(7):1163–76.
46. Elvidge C, Ziskin D, Baugh K, Tuttle B, Ghosh T, Pack D, Zhizhin M. A fifteen year record of global natural gas flaring derived from satellite data. Energies. 2009;2:595.

47. Makogon YF, Holditch S, Makogon TY. Natural gas-hydrates—a potential energy source for the 21st century. J Petrol Sci Eng. 2007;56(1–3):14–31.
48. Luabach S, Marrett R, Olsen J, Scott A. Characteristics and origins of coal cleats: a review. Int J Coal Geol. 1998;35:175–207.
49. Huang Z, Zhang Y, Zeng K, Liu B, Wang Q, Jiang D. Measurements of laminar burning velocities for natural gas–hydrogen–air mixtures. Combust Flame. 2006;146(1–2):302–11.
50. Rufford TE, Smart S, Watson GC, Graham B, Boxall J, Da Costa JD, et al. The removal of $CO_2$ and $N_2$ from natural gas: a review of conventional and emerging process technologies. J Petrol Sci Eng. 2012;94:123–54.
51. Brown LF. A comparative study of fuels for on-board hydrogen production for fuel-cell-powered automobiles. Int J Hydrog Energy. 2001;26(4):381–97.
52. Keith DW, Holmes G, Angelo DS, Heidel K. A process for capturing $CO_2$ from the atmosphere. Joule. 2018;2(8):1573–94.
53. Comesaña-Gándara B, Chen J, Bezzu CG, Carta M, Rose I, Ferrari M-C, et al. Redefining the Robeson upper bounds for $CO_2/CH_4$ and $CO_2/N_2$ separations using a series of ultrapermeable benzotriptycene-based polymers of intrinsic microporosity. Energy Environ Sci. 2019;12(9):2733–40.
54. Dicks AL. Hydrogen generation from natural gas for the fuel cell systems of tomorrow. J Power Sour. 1996;61(1–2):113–24.
55. Verykios XE. Catalytic dry reforming of natural gas for the production of chemicals and hydrogen. Int J Hydrog Energy. 2003;28(10):1045–63.
56. Akansu SO, Dulger Z, Kahraman N, Veziroğlu TN. Internal combustion engines fueled by natural gas—hydrogen mixtures. Int J Hydrog Energy. 2004;29(14):1527–39.
57. Bharadwaj S, Schmidt LD. Catalytic partial oxidation of natural gas to syngas. Fuel Process Technol. 1995;42(2–3):109–27.
58. Wang C-C, Ho Y-S. Research trend of metal–organic frameworks: a bibliometric analysis. Scientometrics. 2016;109(1):481–513.
59. Ge Y, Han J, Ma Q, Feng J. Optimal configuration and operation analysis of solar-assisted natural gas distributed energy system with energy storage. Energy. 2022;246:123429.
60. Davoodi V, Kazemiani-Najafabadi P, Rad EA. Presenting a power and cascade cooling cycle driven using solar energy and natural gas. Renew Energy. 2022;186:802–13.
61. Zou X, Qiu R, Yuan M, Liao Q, Yan Y, Liang Y, et al. Sustainable offshore oil and gas fields development: techno-economic feasibility analysis of wind–hydrogen–natural gas nexus. Energy Rep. 2021;7:4470–82.
62. Ansari M, Zadsar M, Sebtahmadi SS, Ansari M. Optimal sizing of supporting facilities for a wind farm considering natural gas and electricity networks and markets constraints. Int J Electr Power Energy Syst. 2020;118:105816.
63. Yang S, Chen Q, Liu Z, Wang Y, Tang Z, Sun Y. Performance analysis of the wind energy integrated with a natural-gas-to-methanol process. Energy Convers Manage. 2018;173:735–42.
64. Qiao Z, Guo Q, Sun H, Pan Z, Liu Y, Xiong W. An interval gas flow analysis in natural gas and electricity coupled networks considering the uncertainty of wind power. Appl Energy. 2017;201:343–53.
65. Freund P. Making deep reductions in CO2 emissions from coal-fired power plant using capture and storage of CO2. Proc Ins Mech Eng, Part A: J Power Energy. 2003;217(1):1–7.
66. Sreedhar I, Nahar T, Venugopal A, Srinivas B. Carbon capture by absorption–path covered and ahead. Renew Sustain Energy Rev. 2017;76:1080–107.
67. Biliyok C, Yeung H. Evaluation of natural gas combined cycle power plant for post-combustion $CO_2$ capture integration. Int J Greenh Gas Control. 2013;19:396–405.
68. Zohrabian A, Majoumerd MM, Soltanieh M, Sattari S. Techno-economic evaluation of an integrated hydrogen and power co-generation system with $CO_2$ capture. Int J Greenh Gas Control. 2016;44:94–103.
69. Wassie SA, Gallucci F, Zaabout A, Cloete S, Amini S, van Sint AM. Hydrogen production with integrated $CO_2$ capture in a novel gas switching reforming reactor: proof-of-concept. Int J Hydrog Energy. 2017;42(21):14367–79.
70. Nord LO, Anantharaman R, Bolland O. Design and off-design analyses of a pre-combustion $CO_2$ capture process in a natural gas combined cycle power plant. Int J Greenh Gas Control. 2009;3(4):385–92.
71. Ghorbani B, Mehrpooya M, Omid E. Hybrid solar liquefied natural gas, post combustion carbon dioxide capture and liquefaction. Energy Convers Manage. 2020;207:112512.
72. Wang D, Li S, Liu F, Gao L, Sui J. Post combustion $CO_2$ capture in power plant using low temperature steam upgraded by double absorption heat transformer. Appl Energy. 2018;227:603–12.
73. Kanbur BB, Xiang L, Dubey S, Choo FH, Duan F. Thermoeconomic analysis and optimization of the small scale power generation and carbon dioxide capture system from liquefied natural gas. Energy Convers Manage. 2019;181:507–18.
74. Xie W, Chen X, Ma J, Liu D, Cai T, Wu Y. Energy analyses and process integration of coal-fired power plant with $CO_2$ capture using sodium-based dry sorbents. Appl Energy. 2019;252:113434.
75. Hashemi M, Pourfayaz F, Mehrpooya M. Simulation, equipment performance evaluation and sensitivity analysis as a comprehensive parametric study of sulfur recovery unit. Asia-Pac J Chem Eng. 2020;15(2):e2427.
76. Abedi B, Castano EPM, Heidaryan E, Shadloo MS. Pore-scale visualization on polymer flooding: application of singular value decomposition-based image analysis method. J Porous Media. 2020;23(6):531.
77. Mehrpooya M, Mousavi SA, Asadnia M, Zaitsev A, Sanavbarov R. Conceptual design and evaluation of an innovative hydrogen purification process applying diffusion-absorption refrigeration cycle (exergoeconomic and exergy analyses). J Clean Prod. 2021;316:128271.
78. Heidaryan E, de Alcântara Pessôa Filho P, Fuentes MDR. Molecular dynamic simulations of clathrate hydrate structures I: lattice constant and thermal expansion. J Low Temp Phys. 2022;207(5–6):227–40.
79. Pham TN, Long NVD, Lee S, Lee M. Enhancement of single mixed refrigerant natural gas liquefaction process through process knowledge inspired optimization and modification. Appl Therm Eng. 2017;110:1230–9.
80. Martino M, Ruocco C, Meloni E, Pullumbi P, Palma V. Main hydrogen production processes: an overview. Catalysts. 2021;11(5):547.
81. Mejía-Saucedo C, Buitrón G, León-Galván MF, Carrillo-Reyes J. Biomass purge strategies to control the bacterial community and reactor stability for biohydrogen production from winery wastewater. Int J Hydrog Energy. 2022;47(9):5891–900.
82. Cao Y, Zhang H, Liu X, Jiang Q, Hong H. A strategy of mid-temperature natural gas based chemical looping reforming for hydrogen production. Int J Hydrog Energy. 2022;47(24):12052–66.
83. Sorgulu F, Dincer I. Analysis and techno-economic assessment of renewable hydrogen production and blending into natural gas for better sustainability. Int J Hydrog Energy. 2022;47(46):19977–88.
84. Ozturk M, Dincer I. Development of a combined flash and binary geothermal system integrated with hydrogen production for blending into natural gas in daily applications. Energy Convers Manage. 2021;227:113501.
85. Chehade AMEH, Daher EA, Assaf JC, Riachi B, Hamd W. Simulation and optimization of hydrogen production by steam

reforming of natural gas for refining and petrochemical demands in Lebanon. Int J Hydrog Energy. 2020;45(58):33235–47.
86. Bargiacchi E, Candelaresi D, Valente A, Spazzafumo G, Frigo S. Life cycle assessment of substitute natural gas production from biomass and electrolytic hydrogen. Int J Hydrog Energy. 2021;46(72):35974–84.
87. Boretti A. Production of hydrogen for export from wind and solar energy, natural gas, and coal in Australia. Int J Hydrog Energy. 2020;45(7):3899–904.
88. Chisalita D-A, Cormos C-C. Techno-economic assessment of hydrogen production processes based on various natural gas chemical looping systems with carbon capture. Energy. 2019;181:331–44.
89. Szima S, Cormos C-C. Techno–economic assessment of flexible decarbonized hydrogen and power co-production based on natural gas dry reforming. Int J Hydrog Energy. 2019;44(60):31712–23.
90. Mehdizadeh-Fard M, Pourfayaz F. A simple method for estimating the irreversibly in heat exchanger networks. Energy. 2018;144:633–46.
91. Mehdizadeh-Fard M, Pourfayaz F, Maleki A. Exergy analysis of multiple heat exchanger networks: an approach based on the irreversibility distribution ratio. Energy Rep. 2021;7:174–93.
92. Ghorbani B, Hamedi M-H, Amidpour M. Development and optimization of an integrated process configuration for natural gas liquefaction (LNG) and natural gas liquids (NGL) recovery with a nitrogen rejection unit (NRU). J Nat Gas Sci Eng. 2016;34:590–603.
93. Ghorbani B, Salehi G, Ghaemmaleki H, Amidpour M, Hamedi M. Simulation and optimization of refrigeration cycle in NGL recovery plants with exergy-pinch analysis. J Nat Gas Sci Eng. 2012;7:35–43.
94. Niasar MS, Ghorbani B, Amidpour M, Hayati R. Developing a hybrid integrated structure of natural gas conversion to liquid fuels, absorption refrigeration cycle and multi effect desalination (exergy and economic analysis). Energy. 2019;189:116162.
95. Ghorbani B, Mehrpooya M, Hamedi M-H, Amidpour M. Exergoeconomic analysis of integrated natural gas liquids (NGL) and liquefied natural gas (LNG) processes. Appl Therm Eng. 2017;113:1483–95.
96. Özen DN, Koçak B. Advanced exergy and exergo-economic analyses of a novel combined power system using the cold energy of liquefied natural gas. Energy. 2022;248:123531.
97. Mehdizadeh-Fard M, Pourfayaz F. Advanced exergy analysis of heat exchanger network in a complex natural gas refinery. J Clean Prod. 2019;206:670–87.
98. Mehdizadeh-Fard M, Pourfayaz F, Mehrpooya M, Kasaeian A. Improving energy efficiency in a complex natural gas refinery using combined pinch and advanced exergy analyses. Appl Therm Eng. 2018;137:341–55.
99. Mehrpooya M, Sharifzadeh MMM, Mousavi SA. Evaluation of an optimal integrated design multi-fuel multi-product electrical power plant by energy and exergy analyses. Energy. 2019;169:61–78.
100. Ghaebi H, Parikhani T, Rostamzadeh H. A novel trigeneration system using geothermal heat source and liquefied natural gas cold energy recovery: energy, exergy and exergoeconomic analysis. Renew Energy. 2018;119:513–27.
101. Palizdar A, Ramezani T, Nargessi Z, AmirAfshar S, Abbasi M, Vatani A. Thermodynamic evaluation of three mini-scale nitrogen single expansion processes for liquefaction of natural gas using advanced exergy analysis. Energy Convers Manage. 2017;150:637–50.
102. Klöpffer W. Life cycle assessment. Environ Sci Pollut Res. 1997;4(4):223–8.
103. Petrakopoulou F, Tsatsaronis G, Morosuk T, Paitazoglou C. Environmental evaluation of a power plant using conventional and advanced exergy-based methods. Energy. 2012;45(1):23–30.
104. Lerner A, Brear MJ, Lacey JS, Gordon RL, Webley PA. Life cycle analysis (LCA) of low emission methanol and di-methyl ether (DME) derived from natural gas. Fuel. 2018;220:871–8.
105. San Miguel G, Corona B. Hybridizing concentrated solar power (CSP) with biogas and biomethane as an alternative to natural gas: analysis of environmental performance using LCA. Renew Energy. 2014;66:580–7.
106. Sutar DD, Jadhav SV. Life cycle assessment of methanol production by natural gas route. Materi Today: Proc. 2022;57:1559–66.
107. Cavalcanti EJ, Ribeiro TJ, Carvalho M. Exergoenvironmental analysis of a combined cycle power plant fueled by natural gas from an offshore platform. Sustain Energy Technol Assess. 2021;46:101245.
108. Blumberg T, Lee YD, Morosuk T, Tsatsaronis G. Exergoenvironmental analysis of methanol production by steam reforming and autothermal reforming of natural gas. Energy. 2019;181:1273–84.
109. Açıkkalp E, Aras H, Hepbasli A. Advanced exergoenvironmental assessment of a natural gas-fired electricity generating facility. Energy Convers Manage. 2014;81:112–9.
110. Li J, Ma X, Liu H, Zhang X. Life cycle assessment and economic analysis of methanol production from coke oven gas compared with coal and natural gas routes. J Clean Prod. 2018;185:299–308.
111. Jalili M, Ghasempour R, Ahmadi MH, Chitsaz A, Ghazanfari HS. Exergetic, exergo-economic, and exergo-environmental analyses of a trigeneration system driven by biomass and natural gas. J Therm Anal Calorim. 2022;147(6):4303–23.
112. Azar A. Reserve base lending and the outlook for shale oil and gas finance. Columbia Center on Global Energy Policy working paper. 2017.
113. Conrad CL, Yin YB, Hanna T, Atkinson AJ, Alvarez PJ, Tekavec TN, et al. Fit-for-purpose treatment goals for produced waters in shale oil and gas fields. Water Res. 2020;173:115467.
114. Hu H, Wei W, Chang C-P. The relationship between shale gas production and natural gas prices: an environmental investigation using structural breaks. Sci Total Environ. 2020;713:136545.
115. Zeng S, Gu J, Yang S, Zhou H, Qian Y. Comparison of techno-economic performance and environmental impacts between shale gas and coal-based synthetic natural gas (SNG) in China. J Clean Prod. 2019;215:544–56.
116. Sun H, Yao J, Gao S-h, Fan D-y, Wang C-c, Sun Z-x. Numerical study of $CO_2$ enhanced natural gas recovery and sequestration in shale gas reservoirs. Int J Greenh Gas Control. 2013;19:406–19.
117. Liang H-B, Zhang L-H, Zhao Y-L, He X, Wu J-F, Zhang J, et al. Techno-economic and sensitivity analysis of shale gas development based on life cycle assessment. J Nat Gas Sci Eng. 2021;95:104183.
118. Singh H. Hydrogen storage in inactive horizontal shale gas wells: techno-economic analysis for Haynesville shale. Appl Energy. 2022;313:118862.
119. Mevawala C, Jiang Y, Bhattacharyya D. Techno-economic optimization of shale gas to dimethyl ether production processes via direct and indirect synthesis routes. Appl Energy. 2019;238:119–34.
120. Ortiz-Espinoza AP, Noureldin MM, El-Halwagi MM, Jiménez-Gutiérrez A. Design, simulation and techno-economic analysis of two processes for the conversion of shale gas to ethylene. Comput Chem Eng. 2017;107:237–46.
121. Zhou H, Yang S, Xiao H, Yang Q, Qian Y, Gao L. Modeling and techno-economic analysis of shale-to-liquid and coal-to-liquid fuels processes. Energy. 2016;109:201–10.

122. Yang Q, Yang Q, Xu S, Zhang D, Liu C, Zhou H. Optimal design, exergy and economic analyses of coal-to-ethylene glycol process coupling different shale gas reforming technologies. Energy. 2021;228:120535.
123. Onishi VC, Manesh MHK, Salcedo-Díaz R, Ruiz-Femenia R, Labarta JA, Caballero JA. Thermo-economic and environmental optimization of a solar-driven zero-liquid discharge system for shale gas wastewater desalination. Desalination. 2021;511:115098.



## Authors and Affiliations

**Mehdi Mehrpooya[1] · Chia-Ming Chang[2] · Seyed Ali Mousavi[1] · Mohammad Reza Ganjali[3,4] · Yuh-Shan Ho[5]**

✉ Mehdi Mehrpooya
mehrpoya@ut.ac.ir

✉ Yuh-Shan Ho
ysho@asia.edu.tw

1 Faculty of New Sciences and Technologies, University of Tehran, Tehran, Iran

2 CPC Corporation Taiwan, No. 98, Mingwu, Touwu Township 362004, Miaoli County, Taiwan

3 Center of Excellence in Electrochemistry, School of Chemistry, College of Science, University of Tehran, Tehran, Iran

4 National Institute of Genetic Engineering and Biotechnology (NIGEB), Tehran, Iran

5 Trend Research Centre, Asia University, No. 500, Lioufeng Road, Wufeng, Taichung 41354, Taiwan