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A review of heavy industries

Golmohamadi, Hessam

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Demand-side management in industrial sector: A review of heavy industries

Hessam Golmohamadi

Department of Computer Science, Aalborg University, 9220, Aalborg, Denmark

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ABSTRACT

The penetration of renewable energies is increasing in power systems all over the world. The volatility and intermittency of renewable energies pose real challenges to energy systems. To overcome the problem, demand-side flexibility is a practical solution in all demand sectors, including residential, commercial, agricultural, and industrial sectors. This paper provides a comprehensive review of industrial demand response opportunities in energy-intensive industries. Flexibility potentials are discussed from (1) viewpoints of power flexibility for cement manufacturing and aluminum smelting plants (2) viewpoints of joint power-heat flexibility for oil refinery industries. The flexibility potentials of industrial processes are classified based on their compatibility with time responses on long, mid, and short advance notices of different electricity market floors and ancillary service markets. Challenges and opportunities of industrial demand management are classified from viewpoints of power systems and industry owners. Software tools and solution methodologies of industrial energy models are surveyed for energy researchers. The studies show that cement manufacturing plants have great potentials in providing peak-shaving and valley-filling in crushers and cement mills with up to 10% and 16.9% reduction in energy consumption cost and power consumption, respectively. The aluminum smelting plants can provide up to 34.2% and 20.70% reduction in energy consumption cost and power consumption by turning down/off the variable voltage smelting pots.

1. Introduction

1.1. Background and motivation

In the last decade, the penetration of renewable energies, i.e. wind and solar, has increased considerably all over the world. For example, in the Danish sector of the Nordic Electricity Market, the share of wind energy increased from 44% in 2015 to 55% in 2020. This rate is scheduled to increase up to 60% in 2025. There is a similar pattern in the United States, Germany, and China which are investing heavily in renewable power generation [1]. Therefore, renewable energies are an essential and inevitable part of future power systems. Against thermal power, renewable power suffers from volatility and intermittency. Increasing the penetration of intermittent energy in future power systems, the stability and reliability of power systems are serious challenges. In this way, demand-side flexibility is a practical solution to hedge against uncertain renewable power. The energy consumptions of consumers, including residential, commercial, agricultural, and industrial sectors, have structural flexibilities that can meet the flexibility requirements of future power systems. To achieve the aim, the flexibility potentials should be extracted, aggregated, and finally integrated into the power system.

The flexibility potentials of the demand sectors are integrated into power systems to provide local and global system support. In the case of global support, the key aims can be stated as follows [2]:

1. Voltage compensation by reactive power management [3].
2. Power congestion management in weak lines of transmission and distribution networks [4].
3. Power loss reduction in transmission and distribution lines [5].
4. Power quality improvement in power grids, especially in critical buses [6].

Regarding the global power system support, the flexibility potentials fulfill the following underlying aims:

1. Providing power regulation during deficit and excess of renewable power generation [7].
2. Providing Power frequency control [8].
3. Preparing power reserves, including spinning, non-spinning, and supplemental reserves [9].
4. Increasing power system reliability and resiliency [10].
5. Reducing power system investment costs [11].

E-mail address: hessamgolmoh@cs.aau.dk.

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Acronyms

ADRA	Agricultural Demand Response Aggregator
CP	Clinker Production
CPP	Critical Peak Pricing
Cr	Crushing
CHP	Combined Heat and Power
DG	Distributed Generation
DR	Demand Response
DSM	Demand Side Management
FEMS	Factory Energy Management System
FG	Finish Grinding
FRP	Final Refining Process
GHG	Greenhouse Gas Emissions
HEMS	Home Energy Management Systems
HVAC	Heat Ventilation and Air Conditioning
IDR	Industrial Demand Response
KFP	Kiln Feed Preparation
ORI	Oil Refinery Industry
PEV	Plug-in Electric Vehicle
PLA	Parking Lot Aggregator
PRP	Primary Refining Process
RES	Renewable Energy Source
SRP	Secondary Refining Process
TOU	Time-of-Use
VSD	Variable Speed Drive

6. Increasing the penetration of distributed renewable generation [12].
7. Providing peak-shaving, valley-filling, and power factor correction [13].

In order to achieve the abovementioned aims, three major steps should be taken as follows:

1. Extraction of power flexibility from different demand sectors
2. Aggregation of power flexibility with different sectors
3. Integration of demand flexibility into upstream networks

First of all, to extract flexibility potations of demand sectors, expert knowledge is required. The power flexibility of the industrial sector needs technical knowledge about the industrial processes and limitations [14]. In the agricultural sector, the power consumption of the irrigation system is optimized not only with the purpose of power flexibility but also to meet the crops' water needs and evapotranspiration requirements [15]. In the residential sector, the flexibility potentials of the heating systems are extracted from the thermal dynamics of buildings, heat carrier of the district heating, and heat storage; therefore, thermodynamic and building knowledge are required [16]. As a result, expert knowledge is required in each demand sector not only to extract the flexibility potentials technically but also to motivate the consumers socially to participate in demand response programs.

The segregated demand flexibilities fail to meet power system requirements. To overcome this problem, the flexibility potentials of a demand sector should be aggregated by a professional intermediary agent, called Demand Response Provider (DRP) or Demand Response Aggregator (DRA) [17]. At the upper level, the DRA/DRP coordinates the power flexibility of four demand sectors according to the power system requirements. Therefore, flexibility aggregation is essential between (1) different consumers of the same demand sector and (2) the four demand sectors.

Finally, the flexibility potentials are integrated into power systems to fulfill the abovementioned key aims. In this way, the flexibility requirements for frequency control are completely different from the flexibility of power system reserve in terms of response time, duration, and intensity. As an example, in an industrial cement factory, the power consumption of raw crushers can be turned off for a few hours to provide peak-shaving in critical hours [18]. In the metal smelting factories, the power consumption of variable-voltage smelting pots can be turned down in few seconds to provide a fast power regulation or frequency control [19]. Therefore, technical knowledge is required to find out which industrial process is reasonably fitted with the flexibility requirements of the supply side.

Based on the background, the main motivation of this study is to look for flexibility potentials in different industrial processes of heavy industries. Moreover, the study aims to find out the compatibility of industrial demand flexibility with the flexibility requirements of the power system. In this way, it should be answered "which industrial process is compatible with peak-shaving and which one is appropriate for real-time frequency control" and "how much demand flexibility can be expected from a heavy industry". This is the main motivation of this study to find out compelling answers for these questions through a comprehensive review of the literature.

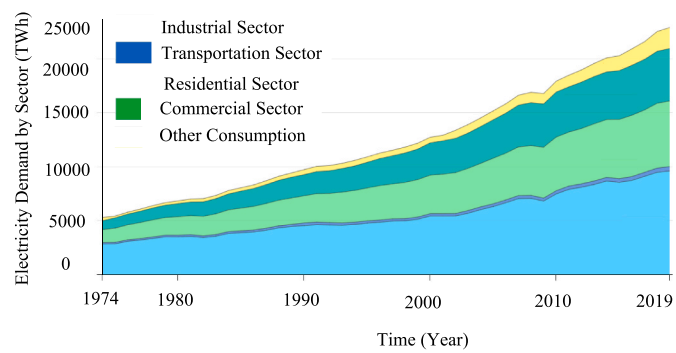

Fig. 1. Electricity demand in different sectors in the world from 1974 to 2019 [1].

Table 1
Total flexibility potentials of demand sectors in the world in 2018 (NA: Not Available). [1].

Demand Sector	Total Electricity Demand in 2018 (TWh)	Total Flexibility Potential in 2018 (TWh)	Percentage of Demand Flexibility (%)
Industrial	9362	847	9.04
Residential	6008	3071	51.11
Commercial	4799	NA	NA
Transportation	390	51	13.07
Other	1757	NA	NA

1.2. Literature review

In recent years, many research studies have been carried out to review the Demand Response (DR) opportunities in four demand sectors. i.e. residential, commercial, agricultural, and industrial. To have a general insight into the flexibility potentials of the demand sectors, Fig. 1 depicts the total electricity demand in the world from 1974 to 2019. Besides, Table 1 presents the percentage of total available flexibility potentials in 2018. Based on the table data, the residential buildings exhibit great flexibility potentials around 51.11%. In contrast, the flexibility potential of the industrial sector is relatively low, approximately 9.04%. It shows that further studies should be conducted in the

industrial sector to extract flexibility opportunities for industrial processes.

In the residential sector, flexibility potentials of thermostatically controlled appliances, e.g. refrigerators [20], water heaters [21], and heat pumps [22], are extensively studied. Besides, the flexibility opportunities of some appliances, e.g. vacuum cleaners [23], hairdryers [24], washing machines [25], Plug-in Electric Vehicles (PEV) [26], are investigated. Reference [27] reviews the latest information and communication technologies that support residential DR systems. A general overview of price-based residential DR programs is provided in Ref. [28]. This paper concludes that a price signal is an efficient tool for residential DR programs. Reference [29] conducted a literature review on central, distributed, and hybrid control of heating and cooling networks, especially for residential buildings. A comprehensive review of computational tools for the design, analysis and management of residential DR programs is presented in Ref. [30]. Renewable-based heat pumps and district heating have attracted much attention in the residential sector. In Ref. [31], a model predictive heat controller is proposed for residential heat pumps to optimize the energy consumption of the heating system in response to power availability in electricity markets with high penetration of renewable power. A mixing loop controller is suggested not only to extract flexibility potentials of the residential heating system but also to facilitate the integration of renewables into district heating [16].

Regarding the commercial sector, the DR programs can be implemented in a retail store or a large commercial building. Heat Ventilation and Air Conditioning (HVAC), lighting systems, and supermarket refrigerators are the main subject of commercial DR programs. Besides, the commercial parking lot is not only a practical solution to overcome the increased penetration of PEVs but also paves the way to make a profit from parked PEVs in commercial buildings. In recent years, a Parking Lot Aggregator (PLA) is suggested to integrate flexibility potentials of PEVs parked in shopping centers into power systems with high penetration of renewable power [32]. Besides, the commercial sector is proposed as a parking lot microgrid to provide peak-shaving and valley-filling for the electricity markets with power shortages [33]. Reference [34] reviews DR opportunities in a retail store to investigate retail stores' preferences of DR programs and stakeholders' engagement. Reference [35] provides a thorough review of DR programs in commercial and institutional buildings. This paper draws a strategy map as a pathway for achieving better building energy performance. In Ref. [36], a hybrid robust-stochastic approach is proposed to extract flexibility potentials of PEVs in presence of intermittent wind power generation. An optimal day-ahead charging framework is suggested for PEVs to provide power flexibility for electricity markets [37]. In addition to the power flexibility, the profit of PEV owners and power system operators are also optimized simultaneously.

Table 2
Histogram of review papers in the DR literature in four demand sectors (References in square brackets).

20	[62]			
19	[63]			
18	[64]			
17	[65]			
16	[66]			
15	[67]			
14	[68]			
13	[69]			
12	[70]			
11	[71]	[48]		
10	[72]	[49]		
9	[73]	[50]		
8	[74]	[51]		
7	[75]	[76]		
6	[77]	[73]	[15]	
5	[78]	[79]	[80]	
4	[81]	[52]	[82]	[83]
3	[84]	[85]	[43]	[86]
2	[28]	[87]	[39]	[51]
1	[27]	[46]	[38]	[52]
	Residential Flexibility	Industrial Flexibility	Agricultural Flexibility	Commercial Flexibility

In the case of the agricultural sector, the main research studies aim to optimize the water-energy nexus. In 2013 and 2015, comprehensive review studies were conducted by the US Department of Energy to investigate the opportunities/challenges of demand-side flexibility in farms [38,39]. The results showed that irrigation pumps have great potential to provide flexibility for power systems. In the next years, some scoping studies surveyed the issue in open-air farms [40] and greenhouses [41,42]. In continue, a review study proposed a restructuring in the agricultural industry to provide a great deal of flexibility for power grids [43]. The main concentration of the study is to facilitate the integration of renewable energies, e.g. wind and solar, in agricultural electricity consumption, especially irrigation systems. Recently, an Agricultural Demand Response Aggregator (ADRA) is proposed to integrate the flexibility potentials of the irrigation systems into three trading floors of the Danish Electricity Market [44]. In Ref. [13], a farm greenhouse is suggested with on-site solar sites and thermal generation units to provide peak-shaving for power systems when the highest crop evapotranspiration coincides with the peak demand of the power system.

In contrast to the three sectors, heavy industries are energy-intensive consumers which consist of different industrial sub-processes. In the residential, commercial, and agricultural sectors, the aggregation of a significant number of responsive demands provides considerable flexibility for the power system. In heavy industries, due to energy-intensive processes, the flexibility potentials of a factory may be equal to or higher than a significant number of responsive commercial, residential or agricultural demands. In manufacturing plants, some industrial processes are interdependent critically and may not be allowed to interrupt. In some others, the industrial processes can be interrupted on advance notice; the "advance notice" is critical to prevent serious damage to the costly equipment. For this reason, the Industrial Demand Response (IDR) programs are quite complex and need knowledge experts.

In the literature, some scoping studies have reviewed the IDR potentials. First of all, the US Department of Energy provided a general overview of IDR opportunities in 2008 [45]. The study suggested a strategic roadmap for IDR programs in the US. In 2016, cement manufacturing and metal smelting industries are investigated in the review study [46]. In 2018, a scoping study was carried out in the UK to increase energy efficiency in the industrial sector [47]. Metal, food, and drink industries are the main scopes of this study. Demand response opportunities in the energy systems and industrial processes of wastewater plants are reviewed in the study [48]. A comprehensive review is carried out on the demand response of internet data centers [49]. In this study, load models, load regulation operations, and economic aspects of demand-side flexibility are surveyed. Technical characteristics of demand response opportunities for industrial parks are reviewed [50]. The study addresses different technical aspects of demand flexibility in a multi-energy sector, including gas and power networks simultaneously. Recent advances in the demand response opportunities of industrial and commercial sectors as well as the limitations and barriers are reviewed in the study [51]. A broad overview of industrial demand response technologies is provided in the United States to describe standards and end uses of industrial demand flexibility [52].

In addition to the review studies, many research studies are carried out to investigate flexibility potentials in light and heavy industries, including cement plants, metal/steel/aluminum smelting factories, textile industries, glass furnaces, oil refinery plants, pulp and paper mills, and food industries. In Ref. [53], a hygro-thermal model is presented to estimate demand response opportunities of refrigerated display cabinets in food industries. Industrial demand side management is conducted in cement manufacturing plants to reduce the electricity

Table 3
The bibliographic features of review studies in the four demand sectors from 2010 to 2020 with key contribution(s).

No.		Reference	First Author	Year	Journal	Main Contribution(s)
1	Residential	[27]	H.T. Haider	2016	Renewable and Sustainable Energy Reviews	Information and communication technologies in residential DR programs
2		[28]	XingYan	2018	Renewable and Sustainable Energy Reviews	Survey of price-based DR programs in the residential sector
3		[69]	J.V. Canteli	2019	Applied Energy	Algorithms of reinforcement learning for residential DR programs
4		[70]	P. Kohlhepp	2019	Renewable and Sustainable Energy Reviews	Integration of residential HVAC as flexible demand into power systems
5		[71]	P. Rajendhar	2019	IET Generation, Transmission & Distribution	Interaction of HEMS, smart grids, and renewable generation
6		[72]	H.Sharee	2018	IEEE Access	Review of HEMS with various DR programs, smart technologies, and load controllers
7		[73]	Lennart Söder	2018	Renewable and Sustainable Energy Reviews	Estimate flexibility potentials in Northern European countries
8		[74]	M. H. J. Weck	2016	International Journal of Energy Research	Review barriers of residential DR programs in the Netherlands
9		[75]	B. Priya Esther	2016	Renewable and Sustainable Energy Reviews	Review of architecture, approaches, optimization models, and methods of residential DR
10		[77]	Aftab Khan	2015	Renewable and Sustainable Energy Reviews	Review HEMS with various DR architectures and models
11		[78]	M. Murator	2014	Renewable and Sustainable Energy Reviews	Review techno-economic challenges of residential DR in modern electricity markets
12		[81]	S. Gyamfi	2013	Renewable and Sustainable Energy Reviews	Review of challenges in voluntary demand reduction in the residential sector
13		[84]	Geoff Kelly	2012	Renewable and Sustainable Energy Reviews	Review of energy efficiency in household appliances
14	Industrial	[46]	M. H.Shoreh	2016	Electric Power Systems Research	A comprehensive review of DR opportunities in the industrial sector
15		[48]	D. Kirchem	2020	Applied Energy	Review of DR programs in energy systems and industrial processes
16		[49]	Min Chen	2020	Renewable and Sustainable Energy Reviews	Review of DR opportunities in data centers
17		[73]	L. Söder	2018	Renewable and Sustainable Energy Reviews	Estimate flexibility of responsive industries in Northern European countries
18		[50]	Z. Chen	2019	Modern Power Systems and Clean Energy	Review of integrated flexibility potentials in industrial parks
19		[51]	M.Shafiekhah	2019	IEEE Transactions on Industrial Informatics	Survey of most recent advances on industrial and commercial DR
20		[76]	T. L. Vasques	2019	Energy Efficiency	Literature review of energy efficiency and DR opportunities of data centers
21		[79]	Qin Wang	2017	IEEE Transactions on Industrial Informatics	In-depth review of flexible ramping products in industrial processes
22		[52]	Sila Kiliccote	2015	WIREs, Energy and Environment	Overview of DR technologies in the United States
23		[85]	Kaile Zhou	2015	Renewable and Sustainable Energy Reviews	A comprehensive review of DR programs in China's power industry
24		[87]	Tom Maes	2011	Renewable and Sustainable Energy Reviews	Literature on industrial energy management, industrial symbiosis, and eco-industrial parks
25	Agricultural	[38]	Daniel Olsen	2015	Lawrence Berkeley National Laboratory	DR opportunities for automated irrigation systems in California
26		[39]	Daniel Olsen	2013	Lawrence Berkeley National Laboratory	Review of water-energy nexus in agricultural farms of California
27		[43]	Aghajanzadeh	2019	Journal of Cleaner Production	Agricultural DR programs to decarbonize power grids and facilitate RES
28		[15]	Golmohamadi	2020	Technology and Economics of Smart Grids and Sustainable Energy	Review of challenges, barriers, opportunities of DR programs in the agricultural sector
29		[80]	Amir Vadiee	2012	Renewable and Sustainable Energy Reviews	Review of energy management in horticultural applications and closed greenhouse
30		[82]	V. Skoulou	2011	Renewable and Sustainable Energy Reviews	Assessment of the sustainability and integrated management of energy crops in Greece
31	Commercial	[51]	M. Shafiekhah	2019	IEEE Transactions on Industrial Informatics	Review of the interaction of commercial DR and electricity markets
32		[52]	Sila Kiliccote	2015	WIREs, Energy and Environment	Overview of DR technologies, standards and end uses, in the U.S. commercial sector
33		[83]	Siiri Söyrinki	2018	Sustainability	Application of DR in a grocery store with refrigeration and photovoltaics panels.
34		[86]	Tariq Samad	2016	Proceedings of the IEEE	Review of motivation for DR in commercial buildings

consumption cost and carbon emission by 4.2% and 4%, respectively [54]. In aluminum smelting plants, a hierarchical model predictive control is suggested for smelting pots to provide ancillary services for the power system [55]. The flexibility potentials of two energy-intensive industries, including chloralkali process and wood pulp production, are evaluated in Ref. [56]. Pulp and paper mills with electric boilers can provide primary frequency reserve for power systems. The simulation results show that the pulp and paper industry not only provides frequency response to the supply side but also reduces the energy consumption cost between 7.4% in summer and 2.3% in winter [57]. Dynamic optimization is addressed in the study [58] to make a balance between natural gas and power consumption of glass furnaces under electricity price fluctuations. Oil refinery plants are investigated to extract joint heat-power flexibilities of refinery processes, steam boilers, and Combined Heat and Power (CHP) units [59]. In Ref. [60], mathematical formulations are presented for cement, steel, and aluminum factories to integrate industrial power flexibilities into the energy and ancillary service markets. In the literature, some studies investigated the flexibility opportunities of industries in response to dynamic electricity prices. In fact, time-varying electricity price is one of the most important approaches to study the behavior of flexible demands in response to dynamic electricity prices [61].

To give the readers a general insight into the scoping studies in the four demand sectors, Table 2 illustrates some distinguished review studies in the last decade, from 2011 to 2020. As the table reveals, most scoping studies have concentrated on the residential sector. The number of review studies on the industrial, agricultural, and commercial sectors is relatively lower than the residential ones. Therefore, more review studies should be conducted in the industrial sector to clarify the technical challenges of industrial demand flexibility.

Table 4
Characteristics of review papers in the industrial DR literature with main objectives, challenges, and opportunities.

Reference	Opportunities/Challenges	Main Target Industry(s)	Surveyed Industries
[46]	Challenges: (1) Financial barriers. (1-1) Lack of persuasive incentives. (1–2) Lack of exact evaluations for DR benefits. (2) Regulatory barriers. (2–1) Utility reconstruction issues. (2-2) Program requirements and aggregation. (2–3) Measurement and verification variety. (2–4) Limitations on market regulations. (2–5) Inclusion in energy efficiency programs. (3) Knowledge-based barriers. (3–1) Lack of knowledge and resource availability. (3–2) Interoperability and open standards limitations. (3-3) Administrative burden.	(1) Cement Manufacturing Plants (2) Metal: aluminum and steel (3) Refrigeration	(1) Oxygen Manufacturing (2) Chloride Manufacturing (3) Oil refinery industry (4) Data centers
[51]	Challenges: (1) Market Barriers. (1-1) Collecting and processing data. (1–2) Hidden costs and market power. (1–3) Increase the standardization: (2) Barriers of Social and customer behavior. (2–1) Trust level among parties. (2-2) Widespread adoption of DR programs. (3) Technological barrier. (3–1) Sensing, computing, and communication. (3–2) Technological skills. (4) Regulatory barriers. (4–1) Lack of regulation for DR. (4–2) Various regulations in different countries.	(1) Aluminum Smelting Factory (2) Steel Manufacturing Plant (3) Cement plant (4) Pulp and paper mill	
[50]	Opportunities: (1) Inhibiting demand. (2) Adjusting the load curve. (3) Allowing operators to control the load directly. (4) Improving customer satisfaction. (5) Guiding customer behaviors depending on the price. Challenges: (1) Market mechanism is not perfect. (2) Industrial DR is not used widely yet.	Industrial Multi-Energy Systems	Industrial Parks/ Zones
[48]	Challenges: (1) Neglect of the interaction between power system operation and industrial process operation. (2) Abstraction from critical physical process constraints. affecting the DR potential. Opportunities: (1) Energy-water nexus as a great source of industrial DR. (2) Integration of water-energy flexibility to power system.	Wastewater treatment plants	(1) Steel plant (2) Refinery industrial plant (3) Biscuit production (4) Vehicle cockpit (5) Manufacturing (6) Paper industry (7) Colliery process (8) Chlor-alkali plant (9) Air-separation process (10) Pulp and paper mill
[76]	Challenges: (1) Regulation and market maturity. (2) Risk management. (3) Market complexity. (4) Load control approaches.	(1) Computing Data Centers including: (1-1) Small-scale Data Centers (1–2) Medium-scale Data Centers (1–3) Hyper-scale Data Centers	Components of datacenters: (1) Computing unit (2) Lighting (3) UPS (4) Cooling system
[49]	Challenges: (1) Suitable load models of the internet data center for power system operations. (2) Expansion of load regulation potential for internet data center. (3) Design of targeted DR mechanisms for spatial-coupling loads. Opportunities: (1) Have a potential of temporal and spatial load regulation. (2) Significant impact on the cost savings. (3) Improved efficiency in energy systems.	Internet Data Centers	Components of datacenters: (1) IT equipment Components of datacenters: (2) Cooling system (3) Auxiliary energy systems
[73]	Challenges: (1) Industrial DR imposes a challenge as industrial processes need to be run continuously. Opportunity: (1) The industry's flexibility is higher in heavy industries, e.g. cement and metal. (2) The biggest flexibility can be achieved in industries where the production has thermal inertia or a buffer capacity in the production.	Industries in North European countries	(1) Iron foundry (2) Cement manufacturer (3) Pulp and paper industry (4) Arc furnaces and rolling mills (5) Chemical industry (6) Wood processing plants
[85]	Challenges: (1) Customer understanding and participation. (2) Advanced metering infrastructure (AMI) and ICT. (3) Pricing mechanisms and optimal scheduling. (4) Big data analytics-based decision support. (5) Government regulations and market policies.	China's power industry	(1) Hydroelectric power (2) Thermal power (3) Nuclear power (4) Wind power
[87]	Challenges: (1) Technical and spatial, e.g. lack of matching	(1) Industrial Park (1-1) Green industry parks	(1) Food and beverage (2) Textiles

(*continued on next page*)

Table 4 (*continued*)

Reference	Opportunities/Challenges	Main Target Industry(s)	Surveyed Industries
	energy profiles. (2) Financial, e.g, capital accessibility and preconditions of companies and third parties. (3) Organizational, e.g. lack of information about potential companies, energy consumption. (4) Social, e.g. trust, openness, clarity between parties, reciprocal relations. (5) Legal, permits (energy production, linking to distribution net, environmental permits, spatial permits, safety issues)	(1–2) Integrated eco-industry parks	(3) Wearing apparel leather (4) Wood and cork (5) Pulp and paper (6) Chemical products (7) Plastic products (8) Non-metallic mineral (9) Basic metals (10) Manufacture of machinery (11) Manufacture of furniture (12) Manufacture of motor vehicles
[79]	Challenges: (1) Market design: the emergence of renewable power and storage devices. (2) Model improvement and validation: despite robust optimization and stochastic programming, some recent advances on this topic include data-driven are needed. (3) Implementation issues: implementation of flexibility management is a complex action in industries practically.	General flexible ramping products	

The main contributions of the review studies are stated in Table 3 for the four demand sectors. Based on the table, the most scoping studies in the residential sector have concentrated on Home Energy Management Systems (HEMS) and heating systems, e.g. Heat Ventilation and Air Conditioning (HVAC). In the industrial sector, the flexibility opportunities of industrial processes are discussed in different industrial plants. In the agricultural sector, most scoping studies survey demand response opportunities of water-energy systems, e.g. water irrigation pumps. Regarding the commercial sector, supermarket refrigerators and commercial buildings are heeded.

Table 4 surveys the main characteristics of some distinguished review papers in the industrial sector. In this table, the main opportunities and challenges of industrial DR programs are illustrated. Besides, the target industries are stated.

1.3. Paper contributions and organization

Based on the literature review and to the best of the authors' knowledge, none of the scoping studies provided a comprehensive review of the demand response potentials for joint heat-power flexibility, e.g. oil refinery plants. Besides, the compatibility of flexibility potentials of industrial processes of heavy industries with different electricity market floors is not discussed. None of the studies elaborated on the time response of industrial processes in response to long, mid and short advance notices of flexibility requests. Also, the simulation software, objective functions, and optimization solutions are not classified. To narrow these gaps, this paper reviews industrial demand-side flexibility in energy-intensive industries from the viewpoints of (1) power flexibility in cement manufactories and aluminum smelting and (2) joint power-heat flexibility in oil refinery plants. The flexibility potentials of the industries are classified based on their compatibility with the response time of electricity market floors. Afterward, the main challenges and opportunities of industrial demand flexibilities are classified. The main software tools, mathematical models, and metaheuristic approaches are surveyed to provide a general insight for the researchers. Finally, bibliographic data are stated to show the role of industrial energy management in the past and today's research environment. To sum up, the main contributions of the study can be stated as follows:

1. Investigation of power and joint heat-power flexibility potentials in industrial processes of heavy industries, including cement manufacturing, aluminum smelting, and oil refinery plants.
2. Classification of the industrial demand flexibility with long, mid, and short advance notices of demand response programs in the normal operation of electricity markets and contingency modes.
3. Surveying the simulation software, optimization algorithms, challenges, and opportunities of industrial energy management.

Fig. 2 sketches the graphical abstract of the raised issues. Besides, Fig. 3 describes the different steps of the current study. Based on the graphs, in sections 2, 3, and 4, the flexibility potentials of three energy-intensive industries are elaborated. In section 5, the main electricity market floors and ancillary services are stated in normal and contingency operational modes. Section 6 classifies the key challenges and opportunities of energy management in heavy industries. Section 7 explains the diversity of software tools, mathematical programming, and nature-inspired optimization solutions. In section 8, the bibliographic information of industrial energy management is stated. Finally, section 9 concludes the scoping study.

2. Cement manufacturing plants

Cement manufacturing plants are comprised of several industrial processes that transform raw material, including limestone, clay, and shale, into cement powder. Generally, the industrial process of a cement plant can be divided into four main industrial sub-processes as follows [88]:

(1) Crushing (Cr)
(2) Kiln Feed Preparation (KFP)
(3) Clinker Production (CP)
(4) Finish Grinding (FG)

Crushing is the first industrial sub-process that crushes the limestone and pre homogenize the raw materials [89]. The raw material, e.g. limestone, clay, shale, is transferred by large dump trucks and/or conveyors. The crushers are normally comprised of primary and secondary crushers. The energy intensity of the crushers varies between 5 and 20 kWh/ton of feedstock [18]. Due to stockpiling of the production in the silos, the crushers are normally operated during off-peak hours (low electricity prices). Therefore, the crushers are exploited for a few hours a day, and the silos' stockpile supplies the KFP. It is worthy to note that as the size of limestone silos increases, the flexibility potential of the crushers increases.

The output of crushing, i.e. homogenized raw materials, supplies the kiln feed preparation. The KFP includes raw mills to grind and blend the raw materials to prepare them for clinker production (CP) [90]. Similar to the crushers, the KFP mills have great potential to operate during off-peak hours. The Cr and KFP are interruptible processes whose electricity consumption can be shifted to off-peak hours (low price hours) not only to provide peak-shaving and/or valley-filling for the power system but also to reduce the electricity consumption cost of the factory. Stockpiling of the raw mix in the KFP silos plays a key role in the flexibility potentials of the KFP. Consequently, it can supply the feedstock of the CP without causing an interruption in the whole procedure.

The CP includes a preheater tower and kiln which are operated uninterruptedly receiving feedstock from the KFP [91]. In this way, two

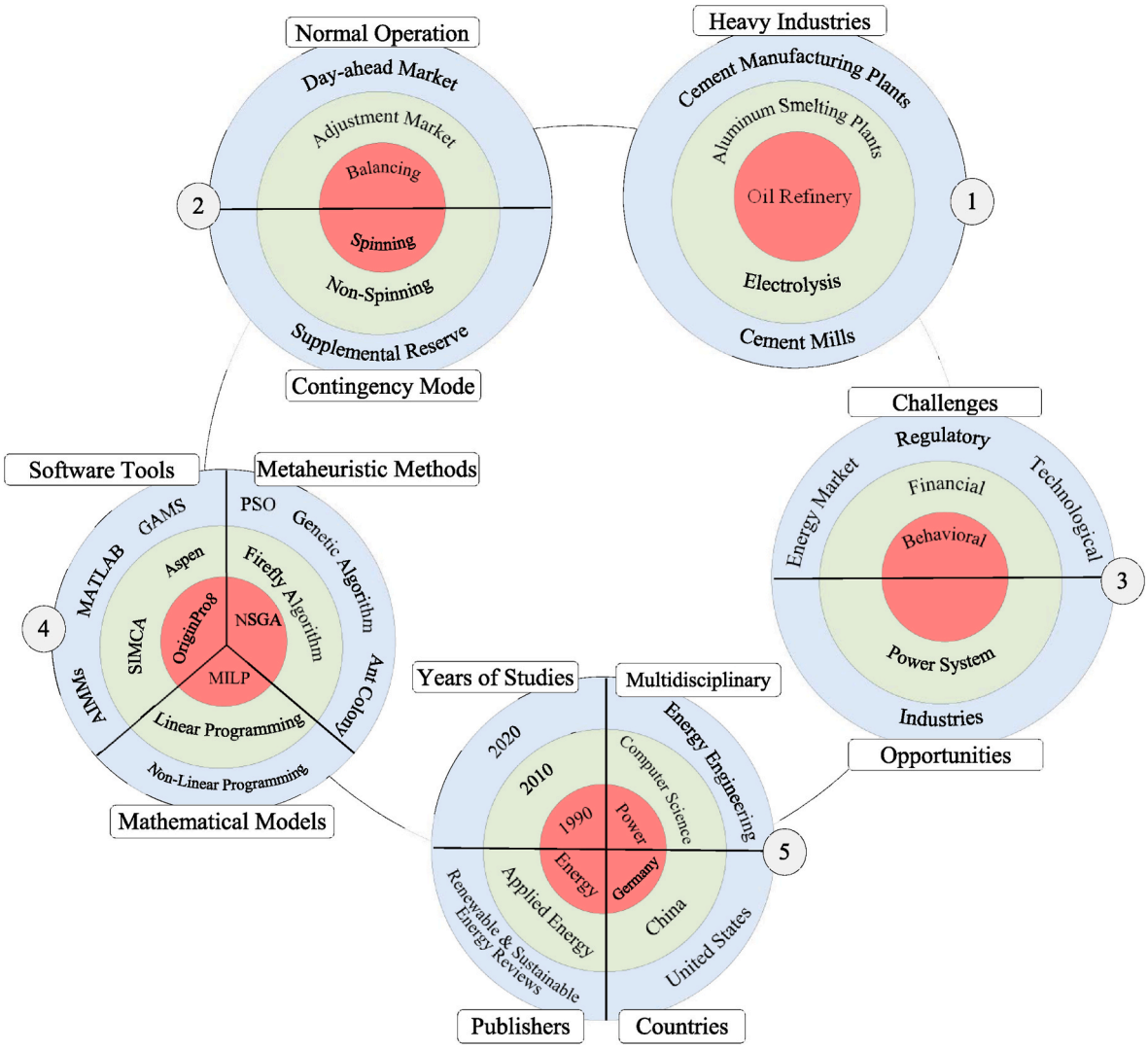

Fig. 2. Graphical abstract of the suggested methodology of industrial flexibility in the current study.

points should be stated. Firstly, the CP is normally a continuous duty process without long interruption. The reason is that an unscheduled interruption may impose a high cost on the kiln's envelope and equipment. Besides, the kiln is mainly supplied by fossil fuels, e.g. coal and natural gas. Therefore, the flexibility potential of the CP is relatively low.

The output material of the CP is hot clinker. The clinker is cooled down in the clinker cooler and then is imported to the FG [92]. The FG includes cement mills to transform the clinker into cement powder. Although the cement mill is an interruptible industrial process, the flexibility potential of the FG is lower than the crushers and KFP at least for two reasons. Firstly, the previous process, i.e. the CP, is a critical process without any interruption. Therefore, the FG must be operated to prevent over-stockpiling of the clinker. Besides, the FG is the final process in which the cement production is loaded by trucks, ships, etc. As a result, it is under pressure to meet the consumers' delivery constraints. The flexibility potentials of the industrial processes of the cement plants can be surveyed as follow:

(1) Turning on/off the interruptible industrial processes [93].
(2) Turning up/down the smart variable speed mills [19].

The former refers to a scheduled interruption in the crushers, and mills of KFP, and FG. In this way, the whole process is turned off/on in response to the DR requests. Therefore, great flexibility potential is unlocked for the power system. In contrast, the latter reflects a minor increase/decrease in the power consumption of smart mills run by Variable Speed Drive (VSD) [94]. The VSD makes it possible to turn up/down the power consumption of mills on short advance notice without any interruption in the industrial process. While the former provides demand flexibility for power systems on long advance notice, e.g. the day-ahead markets [14], the latter provides up-/down-power regulation on short notice, e.g. real-time markets [19], especially in electricity markets with high penetration of Renewable Energy Source (RES).

Fig. 4 describes the schematic diagram of the industrial processes of the modern cement industry. Based on the graph, the cement plant is comprised of four main subprocesses with storage for the feedstocks. The processes can be turned off/on in response to power availability on the supply side. Moreover, the processes can be turned up/down on short notice to provide down-/up-regulations for the power systems. In this way, the storages play a key role in providing power flexibility to the electricity market. The energy management system of the cement factory includes storage stock management and production line management. The energy management system aims to control the production lines as well as the silos not only to provide demand flexibility for the power system but also to reduce the electricity consumption cost of the factory. Note that the daily production of cement is a key factor to meet

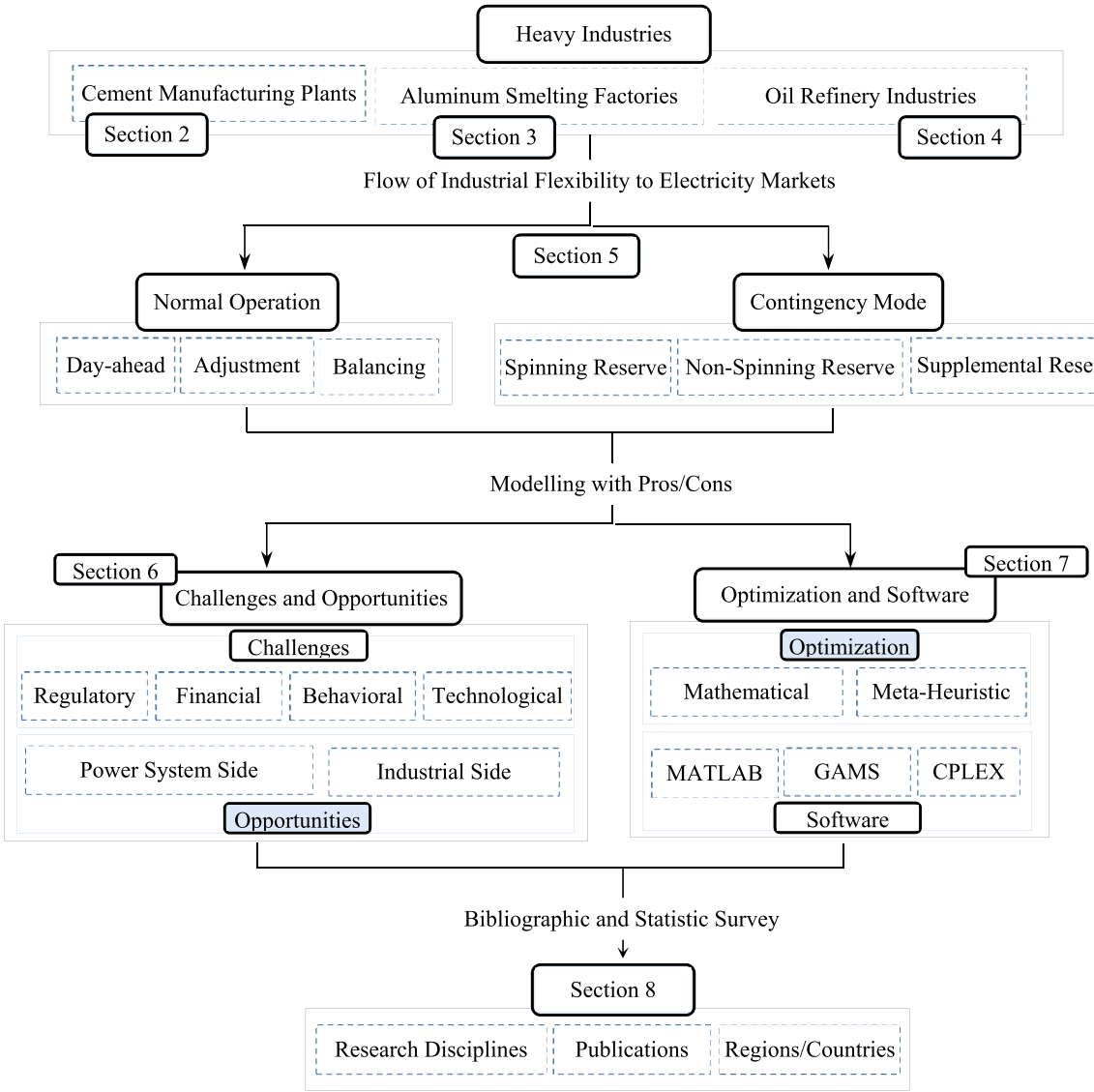

Fig. 3. Diagram of the suggested steps in the current study.

the consumers' delivery preferences.

Table 5 illustrates the energy intensities of four industrial processes of the cement plants. Moreover, the flexibility potentials are surveyed. Based on the table, the KFP and FG have high flexibility potentials both in terms of energy intensity and time response to advance notices. The crusher can respond to long, mid, and short notices effectively. The CP is an uninterruptible subprocess due to technical limitations. In the CP, the majority of energy is consumed by the kiln which is the heart of cement plants. The temperature of the kiln must meet a standard bound. Unexpected temperature deviations can cause heavy financial loss to the kiln's envelope and insulation. For this reason, the flexibility potential of the CP is relatively low.

In the literature on the cement plants, the principal aims of demand-side management can be stated as follows:

(1) Peak-shaving and/or valley-filling for power systems [54].
(2) Reduction of energy consumption cost [96].
(3) Facilitation of RES integration into power systems [97].
(4) Providing up-/down-power regulation in near real-time [98].
(5) Reduction of carbon footprint [99].

In [54], a new production scheduling is developed to minimize electricity consumption costs and electricity-derived CO_2 emissions in the UK. The study proposes a rescheduling of the production plan without loss of overall production. The research study [18] is conducted to provide peak power shaving for Iran Electricity Market. The study uses robust optimization to determine the optimized flexibility operations of cement plants in the worst-case realization of the uncertain electricity price. Besides, feedstock storage is offered as a workable solution to turn off the interruptible processes when a power shortage occurs. In Ref. [19], three-stage stochastic programming is suggested to unlock the flexibility potentials of the cement industry hierarchically in three trading floors of the Danish Electricity Market. The main aim of the study is to provide near real-time regulation for power systems with high penetration of renewable power. The research study [100] suggests a model predictive control to provide ancillary service and power regulation. This study proposes onsite energy storage as a practical solution to overcome the discrete power change of industrial processes. In Ref. [101], various strategies of energy consumption reduction are examined on cement plants. The study proposes industrial practices to increase energy efficiency in the industrial processes of the cement plants.

Table 6 surveys the main studies from 1976 to 2020 focusing on demand-side flexibility in the cement industries. Based on the table,

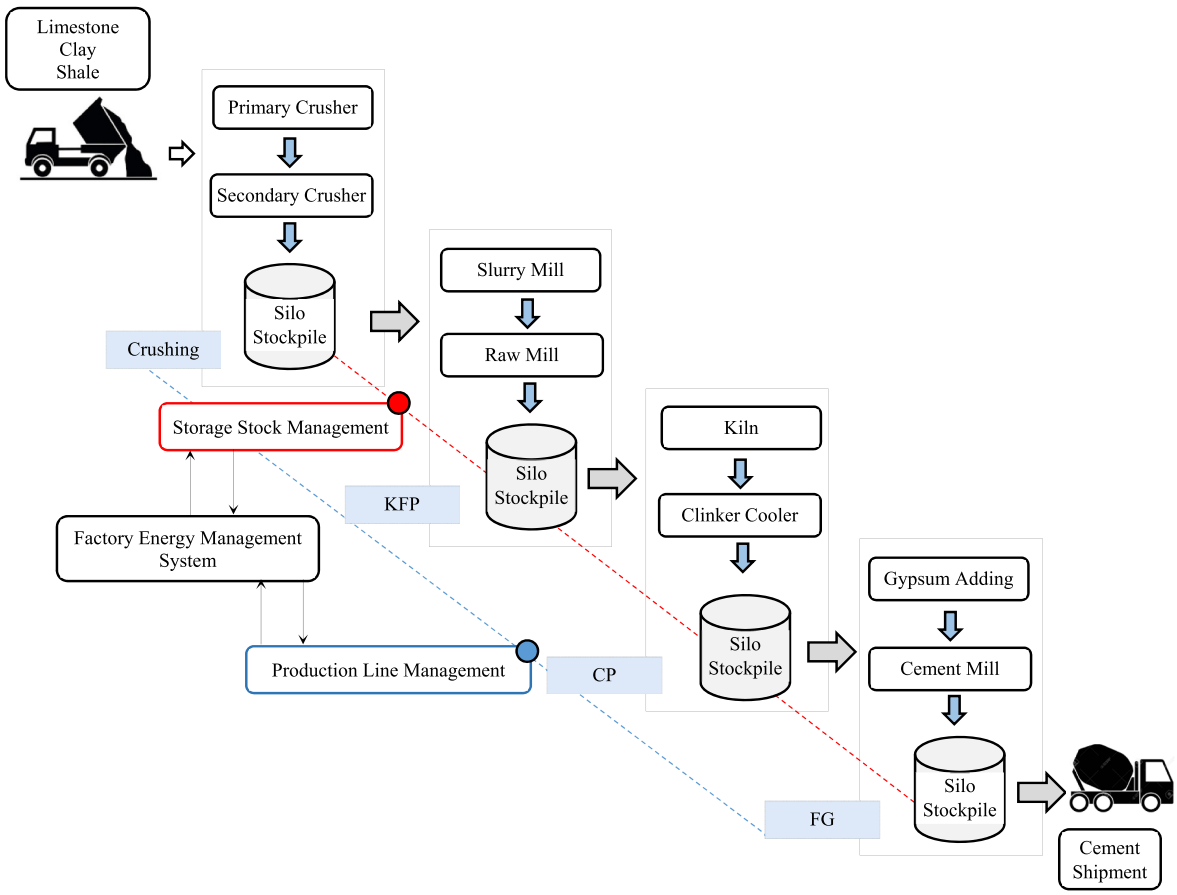

Fig. 4. Four industrial processes in a modern cement manufacturing plant from viewpoint of demand side management [18].

Table 5
Energy intensity, flexibility potentials, and electricity market compatibility for industrial processes of cement plants.

Process	Energy Intensity [95] [a]		Interruption	Flexibility Potential		
	Electrical (kWh/ton)	Fuel (MBtu/ton)		Long Notice	Mid Notice	Short Notice
C	5–20	≈0	Interruptible	High	High	High
KFP	27–38	≈0	Interruptible	High	High	High
CP	39–45	4–6	Uninterruptible	Low	Very Low	Very Low
FG	52–57	≈0	Interruptible	High	Medium	Medium
Total	123–160	4–6				

[a] The data is extracted to provide general insight into the energy intensity of different sub-processes in a modern cement plant. However, the data may vary based on different technologies and process types, e.g. wet or dry, etc.

some key features can be recognized. First of all, most studies use deterministic approaches to optimize energy management in the cement industry [102]. Increasing the penetration of renewable power, uncertain variables should be addressed to overcome the intermittency of the supply side. To overcome this problem, two non-deterministic approaches, including stochastic programming [19] and robust optimization [18], are suggested recently. In the electricity market, the power flexibilities of the cement industries are normally integrated into energy markets, e.g. the day-ahead market, on long advance notice [54]. In this way, few studies have investigated the role of cement industries in ancillary service and near real-time markets. Besides, most studies have concentrated on the demand-flexibility of crushing and cement mills. Except [18], barely any study can be seen to address the flexibility potentials of the whole industrial processes of the cement plants.

Table 7 quantifies the energy management plans in the cement industries. As the table reveals, different DR programs can cause a reduction in electricity consumption from 4% to 25%. On the other hand, the industries have reported a 6%–10% reduction in energy consumption costs. A comprehensive study on 84 aggregated cement plants in Iran shows that the cement plants can decrease the peak demand up to 37% in critical hours of power system operation [18].

3. Aluminum smelting industries

Aluminum smelting plants are one of the key energy-intensive industries. The energy intensity of aluminum plants is relatively between 13 and 14 kWh/kg Al [115]. Generally, in aluminum smelting plants, the aluminum oxide is turned into aluminum using chemical reduction [116]. The electrolysis takes place in smelting pots supplied by DC electric current. The smelting pots are operated in high currents, i.e. hundreds of thousand ampers, and a very low voltage, i.e. less than then volt. The smelting process takes place in several pots, the so-called potline. A potline may be comprised of tens of single pots. In large-scale smelting plants, more than one potline is operated. To manage the power consumption of the potlines, the input voltage of the pots is controlled [117]. Therefore, the direct current and power

Table 6
A survey of DR studies on cement plants with main contribution(s). "NA: Not Addressed, FOR: Forced Outage Rate, PSO: Particle Swarm Optimization, LP: Linear Programming, MILP: Mixed Integer Linear Programming".

Ref.	Year	Principal Aim	Electricity Market	Uncertainty(s)	Mathematical Structure	Software	Main Contribution(s)
[101]	1976	Energy consumption reduction	NA	Deterministic	Experimental	NA	Practicable reductions in energy use.
[103]	1986	Energy consumption reduction	NA	Deterministic	Experimental	NA	Important energy waste sources are identified.
[104]	2000	Increasing energy efficiency	NA	Deterministic	Experimental	NA	Practical solution to potential energy saving.
[105]	2010	Increasing energy efficiency	NA	Deterministic	Experimental	NA	Implementation of Energy Conservation Supply Curves to identify cost-effective energy efficiency potentials.
[106]	2012	Increasing profit of industry	Day-ahead Real-time	Electricity price	Fuzzy model	NA	Optimization of operation of risk-taker/-averse industry in uncertain electricity market.
[107]	2013	Reducing operational cost	Wholesale market	(1) Electricity price (2) FOR of units	Stochastic Programming	GAMS/ CPLEX	Optimization of industry load profile with uncertain self-generation facilities.
[108]	2015	Peak shaving of power system	Retail market	Deterministic	PSO	NA	Proposing time-based DR according to behavioral classification of industries.
[102]	2016	Reducing operational cost	Day-ahead Reserve	Deterministic	LP	GAMS/ CPLEX	Modify power consumption in response to electricity price.
[54]	2017	Reducing operational cost	Wholesale Market	Deterministic	LP	NA	Rescheduling the milling to minimize operation cost.
[100]	2018	Provide regulation and ancillary service to power system	Day-ahead Real-time	Deterministic	MILP	CPLEX	Providing regulation and load following by adjusting power consumption.
[19]	2019	Overcome RES intermittency	Day-ahead Adjustment Balancing	Electricity price	Stochastic programming	GAMS MATLAB	Integration of smart variable speed milling to power system.
[18]	2020	Peak shaving of power system	Day-ahead Bilateral	Electricity price	Robust Optimization	GAMS MATLAB	Optimization of operation of responsive industry in worst-case realization of electricity price.

Table 7
The quantification of energy management plans in cement industries worldwide.

Reference	Country/ Region	Cost Reduction (%)	Electricity Consumption reduction (%)	Peak Reduction (%)
[109]	Portugal	6	×	×
[110]	Global	×	15	×
[54]	The UK	4.2	×	×
[105]	China	×	16	×
[111]	Ethiopia	×	16	×
[112]	Turkey	×	6.7	×
[18]	Iran	10	×	37.5
[113]	Taiwan	×	25	×
[114]	Thailand	×	16.9	×
[89]	Bangladesh	×	4–5	×

consumption are changed. In smelting pots, the volume of aluminum oxide has a strong correlation with power consumption. Therefore, the Factory Energy Management System (FEMS) controls the feedstock of aluminum oxide to manage the power consumption of the potlines. To unlock the demand flexibility of the potlines, the smelting pots are subject to the following measures:

(1) Turning the whole pots (potline) on/off
(2) Turning the pots (potline) up/down

The former refers to load shifting/interruption. In this case, the whole pot is turned off/on in response to power shortage/excess in the power system. The off/on states are normally rotated among different pots not only to satisfy the daily production level but also to maintain the pots in service. The main advantage is that the DR scheme integrates high values of demand flexibility into the power systems. The negative point is that the DR requests should be sent to the FEMS hours before loading the pots. Therefore, it can participate in DR programs on long and mid advance notices, e.g. the day-ahead [118] and intraday markets [119].

The latter shows the partial power control (increase/decrease) without smelting interruption. In this case, the input voltage and/or the feedstock aluminum oxide are controlled [120]. The value of demand flexibility is lower than the first DR program. However, the main advantage is that the power consumption can be changed in real-time in response to the availability of intermittent renewable energies [121]. When a power deficit/excess occurs in the electricity market, the smart pots decrease/increase the input voltage to provide up-/down-regulation for the supply side. Consequently, this type of DR program is appropriate for flexibility requests on short advance notice, e.g. regulation [122] and balancing markets [123].

In both cases, the thermal balance of the smelting pots is a key limiting factor. The pots envelope is made of carbon. The electrolysis takes place in a cryolite bath which contains aluminum oxide and some mineral combinations. When normal electrolysis is processed, the cryolite is frozen near the envelope and molten near the anode. In order to maintain this feature, thermal balance is required to prevent melting cryolite near the envelopes and solidating near the anode. Therefore, the time and duration of pot interruption must meet the thermal balance. It means that the interruption requests have to be sent to the FEMS hours ahead. Moreover, the duration of the interruption is limited. In smelting plants, the smelting processes are normally uninterrupted with discrete loading-unloading cycles. It means that once the smelting started, the process continues without interruption. After finishing the smelting cycle, the next smelting cycle can be interrupted in response to flexibility requirements. Note that short interruption may be allowed by the FEMS during the smelting process. The interruption may happen from a few minutes to hours depending on the characteristics of the pots, the volume of aluminum oxide, and ambient temperature. In this way, power loss and lost aluminum production are the first repercussions. Fig. 5 depicts the schematic diagram of an aluminum smelting plant. Based on the figure, the FEMS receives the flexibility requirements from the power system operator. Then, the FEMS uses three leverages, including feedstock control, switch control, and voltage control, to unlock the flexibility potentials of the potlines in response to the power system requirements.

In the literature on the aluminum industries, some research studies have been conducted to unlock the flexibility potentials of the plants. Among them, minimizing the energy consumption cost [124],

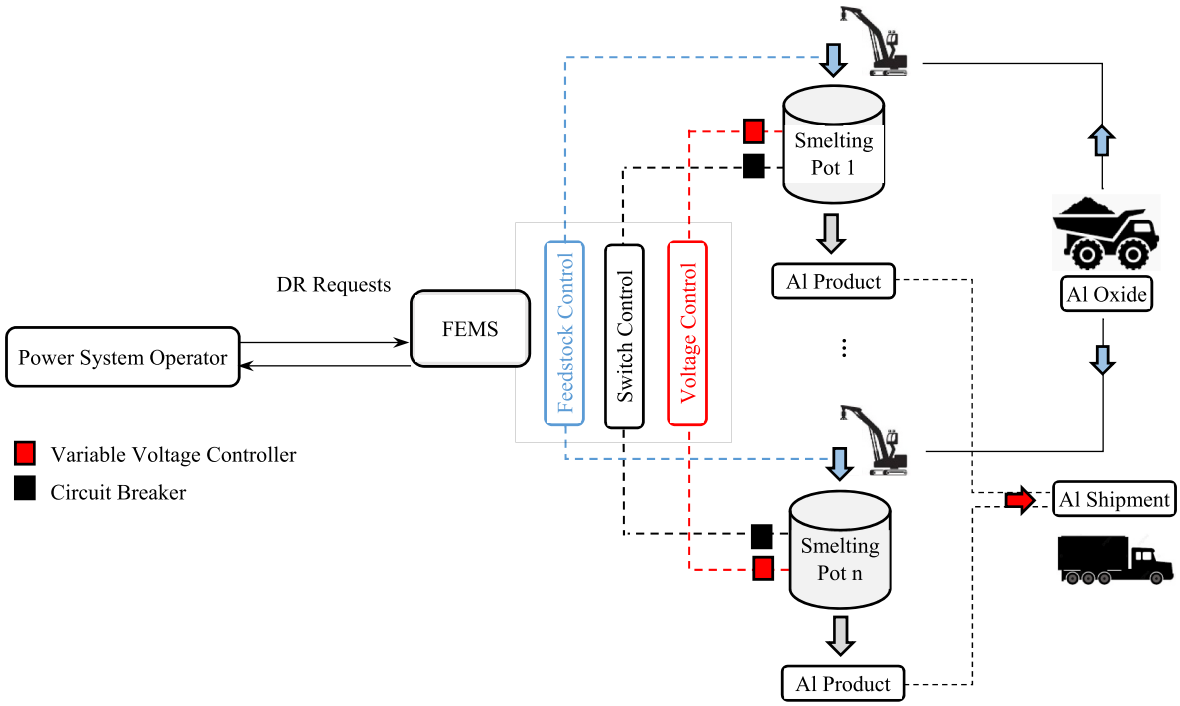

Fig. 5. Implementation of DR programs in an aluminum smelting plant with n pots.

Table 8
A survey of DR studies on aluminum/metal/steel plants with distinctive characteristics.

Ref.	Year	Principal Aim	Electricity Market	Uncertainty(s)	Mathematical Structure	Software	Main Contribution(s)
[136]	1994	Minimizing energy consumption cost	NA	Deterministic	Experimental	SPMS	Cost savings and improved plant reliability with no production downtime.
[137]	1999	Minimizing Energy Consumption	NA	Deterministic	NA	NA	Cascade use of waste heat in industries to save energy
[138]	2009	DR opportunities of aluminum plants	(1) Ancillary (2) Regulation	Deterministic	NA	NA	Comprehensive flexibility potentials of aluminum smelters in the US.
[139]	2011	Price-based flexibility of aluminum industries	European markets	Electricity price	NA	TSP	Flexibility potentials of aluminum smelters in response to variable electricity price
[129]	2012	Energy management in smart grid	(1) Retail market (2) Ancillary service	Deterministic	NA	NA	Potentials of energy management and demand flexibility in smart grids
[140]	2013	Minimizing energy consumption cost	(1) Day-ahead (2) Intraday (3) Real-time	Deterministic	MILP problems	GAMS CPLEX	Providing flexibility to energy system considering energy constraints of the industrial processes
[141]	2014	Increasing energy efficiency and decreasing the energy cost	NA	Deterministic	Linear Optimization	GAMS	Provide strategies to manage production structures, production costs, energy use, and emission reduction in steel making.
[142]	2015	Maximizing profit	Wholesale market	Deterministic	MILP	CPLEX	Energy flexibility, co-optimizing energy usage, and material flow
[143]	2016	Energy/exergy analysis of aluminum smelters	NA	Deterministic	LP	NA	Waste heat recovery/thermal integration of aluminum smelters
[144]	2017	Minimizing energy consumption cost	Wholesale market	Deterministic	MIP	Matlab TOMLABCPLEX	Using smart melting to provide demand flexibility
[145]	2018	Cost minimization Providing near-real-time flexibility to power system	(1) Day-ahead (2) Ancillary	Deterministic	MILP	Gurobi	Provide ancillary and real-time flexibility to power system
[19]	2019	Using demand response to facilitate the integration of renewable energies	(1) Day-ahead (2) Adjustment (3) Balancing	Non-deterministic Electricity price Wind power	Three-stage stochastic programming	GAMS MATLAB	Integration of smart variable voltage smelting pots to power system
[146]	2020	Theoretical DR potential for Brazilian industries	Brazilian market	Deterministic	LP/NLP	NA	Industrial DR potentials to overcome RES intermittency
[127]	2021	DR and flexibility potentials of industries	NA	Deterministic	LP	NA	Electrolyzers show great potential in transition to 100% renewable energy supply

Table 9
The quantification of energy management plans in metal/steel/aluminum smelting industries.

Reference	Energy Consumption Cost Reduction (%)	Demand Flexibility and/or Efficiency Improvement (%)	CO_2/Emission Reduction (%)
[147]	×	5.69%	×
[148]	7.5%	×	×
[149]	×	14.07%	6.65%
[150]	29.7%	×	×
[151]	×	(2.95–6.99) %	×
[152]	×	2.66%	×
[153]	×	2%	×
[154]	34.2%	16.5%	16.5%
[155]	×	(11.98–20.70) %	×
[156]	×	4.92%	6.85%

increasing energy efficiency [125], minimizing the carbon footprint [126], facilitating the integration of RES into power systems [127], and providing peak-shaving and valley-filling for the power systems [128] are the main objectives. Considering the most important research studies in the last decade, first of all, in 2011, the economic and technical potentials of aluminum industries were investigated to provide demand-side flexibility for balancing markets [56]. This study made projections on the extent to which flexibility potentials and/or DR programs from aluminum plants can provide economic benefits in electricity markets with high RES penetration. In 2012, the aluminum industries are investigated to determine flexibility potentials as well as automated DR programs in the smart grid [129]. In 2013, the energy strategies of aluminum industries were surveyed to increase the energy efficiency of the industrial processes [130]. Moreover, the economic and technical evaluations were conducted for energy self-generation in aluminum plants. In 2014, a research study addressed the voltage control of aluminum smelters as a workable solution to overcome frequency stability issues in power systems [121]. In 2015, aluminum electrolysis was suggested as a practical solution to provide frequency balance in isolated power systems with high wind power penetration [131]. Besides, a model predictive control was designed in aluminum industries to provide frequency regulation for the power system during wind power fluctuation [132]. In 2016, an energy audit was carried out in China to determine the role of aluminum industries on overall greenhouse gas emissions [133]. The study concluded that further energy efficiency improvement reduces the carbon footprint in aluminum industries.

In 2018, a comprehensive scoping study was conducted to propose energy efficiency measures in aluminum industries [125]. Based on this study, the aluminum plants are subject to halved greenhouse gas emissions by 2050, while the demand for aluminum will increase up to three times in the same duration. Therefore, energy efficiency measures not only meet the carbon footprint goals but also reduce pressure on power systems. In 2019, three-stage stochastic programming was suggested to integrate the flexibility potential of aluminum smelting plants into the Danish Electricity Market [19]. In this study, three market floors, including day-ahead, intraday, and balancing markets were addressed. The on/off states of the smelting pots were scheduled in the day-ahead market. The input voltage of the smart pots was controlled in the balancing market to provide up-/down-regulation in the opposite direction of the power system imbalance. In 2020, a dynamic model for aluminum smelter loads was derived to provide a hierarchical frequency control [55]. This study designed a model predictive control for the smelters current with lower control cost. In Ref. [134], the research study extracted an electrothermal characteristic model of aluminum smelter load to investigate the interaction between input power and electrolyte temperature. This model helps FEMS to employ the direct load control on the smelters satisfying the thermal balance constraints. The review study [135] surveyed different energy conservation technologies and heat recovery technologies for iron and steel industries. Case studies and practical projects are addressed all over the world and a general guideline is provided for energy optimization in the iron and steel industries.

Finally, Table 8 summarizes the key characteristics of some research studies in the last decade about energy management in aluminum industries. In this table, the main aims, uncertain variables, and target electricity markets are also surveyed.

Table 9 quantifies the demand side management in the metal, steel, and aluminum industries. The data are stated in terms of energy cost reduction, amount of demand flexibility, and contribution to emission reduction. As the table reveals, the energy cost reduction varies from 7.5% up to 34.2%. For the energy consumption, the industries have experienced between 2% and 20.70% demand flexibility or energy efficiency improvement. Regarding the emission reduction, the energy management plans cause a 6.65%–16.5% reduction in emission production. Note that the values of demand flexibility, energy efficiency, and emission reduction are strongly dependent on the case studies, energy management plans, and the strength of demand side management.

4. Oil refinery plants

The Oil Refinery Industries (ORI) are energy-intensive plants that refine the crude oil into petro production like petroleum naphtha, gasoline, diesel fuel, asphalt base, heating oil, kerosene, liquefied petroleum gas, jet fuel, and fuel oils [157]. The refinery processes consume a large amount of energy in terms of power, heat, and steam. Due to the importance and criticality of the ORI, the industrial processes are normally supplied by self-generation facilities, e.g. gas turbines and CHP [158]. In this way, the waste heat of the generation units mainly supplies the heat/steam demand of the refinery processes. Besides, industrial boilers are operated to compensate for the lack of heat/steam generation by the CHP units [159]. Considering the strong correlation between heat and power generation (consumption) in CHP units (refinery processes), the energy management of the ORI is a complex problem.

The ORI is also connected to the power grid to exchange power. Therefore, from the viewpoint of energy management, the ORI is an industrial microgrid that can be exploited in both grid-connected and stand-alone. The microgrid structure makes it possible to inject the overgeneration of self-generation units into the main grid when a power shortage occurs on the supply side or draw power from the upstream network when an unscheduled failure causes a power deficit in the ORI. In addition, the ORI is connected to the gas network to supply the fossil fuel generation units. As a result, the ORI is considered a multi-carrier microgrid with power and gas flexibility potentials.

Without loss of generality, the whole refinery processes of a typical ORI can be split into three main sub-sections as follows [160,163]:

(1) Refinery Process 1: Primary Refining Processes (PRP). This process is comprised of the Crude Distillation Unit (CDU). In the CDU, the crude oil is fractionated into wet gas, kerosene, naphtha, diesel, gas oil, and residual fractions. The output of this unit provides the feedstock to the next refinery process.
(2) Refinery Process 2: Secondary Refining Processes (SRP). This process is comprised of four main sub-processes. In the Gas Recovery Unit (GRU), the wet gas is refined into Liquefied Petroleum Gas (LPG), naphtha, and fuel gas. In the Hydrogen Treatment Unit (HTU), the kerosene and naphtha are hydrotreated to meet clean fuel requirements. In Fluid Catalytic Cracking (FCC), the heavy oil gas is converted into gasoline and some byproducts. Finally, the Vacuum Distillation Unit (VDU) produces three or four waxy distillate side cuts.
(3) Refinery Process 3: Final Refining Process (FRP) is comprised of six further refinery sub-processes. Firstly, in the Catalytic Reforming Unit (CRU), the naphtha is transformed into gasoline through isomerization and alkylation. In the Distillate

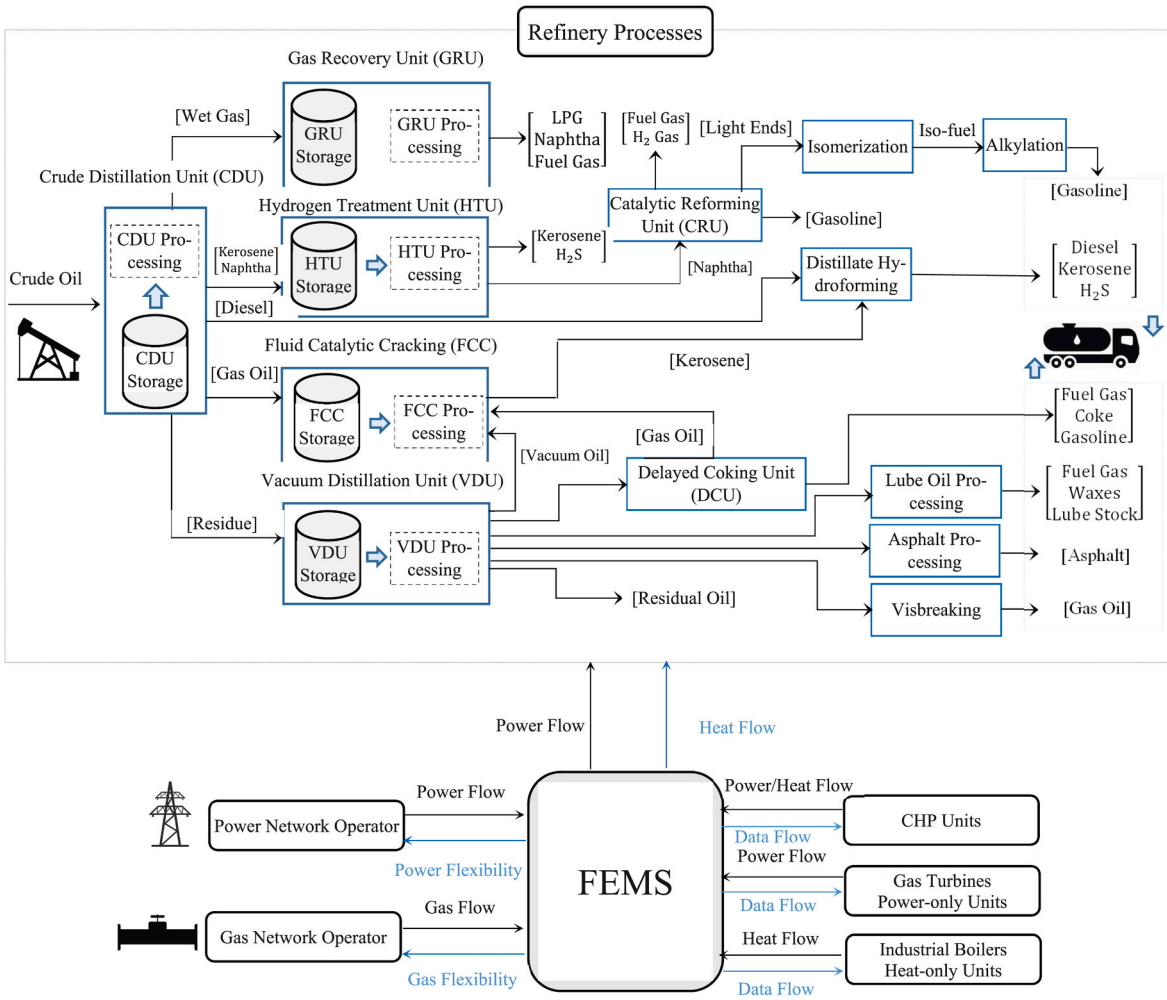

Fig. 6. Interaction of ORI units with multi-carrier girds to provide demand-side flexibility [163].

Hydroforming Unit (DHU), the diesel and kerosene are refined to reduce the Sulphur content. In the Delayed Coking Unit (DCU), fuel gas, coke, and gasoline are produced from the residual oil. In the Lube Oil Processing Unit (LPU), the physicochemical properties of the petrochemical products are improved to produce fuel gas, waxes, and lube oil. The Asphalt Processing Unit (APU) produces asphalt for road coating objectives. Finally, Visbreaking improves the quality of the residual oil by fractioning the large hydrocarbon molecules.

The three main refinery processes show that the ORI is comprised of various refinery sub-processes with different energy intensities. Besides, the products and byproducts of the processes are stockpiled in the downstream storages to provide the feedstock of the further processes. In this way, two flexibility potentials can be unlocked. First of all, the energy consumption, i.e. power and heat, of the refinery processes are dependent on the feedstock flow. Therefore, the variable mass flow model makes it possible to unlock the flexibility potentials of the processes in response to DR requests [59]. The flexibility opportunities are integrated into the power and gas networks through power and heat demand flexibilities, respectively. Besides, the feedstock storages play a key role in providing flexibility for the energy networks. The storage makes it possible to supply the downstream refinery processes without interruption in the daily production. Therefore, an energy-intensive process may be turned down in response to flexibility requirements while the downstream processes are supplied by the storage uninterruptedly. All in all, the flexibility opportunities of the ORI can be classified as follows:

1. Turn up/down the power and heat consumption of the refinery processes through the variable mass model.
2. Supply the downstream refinery processes by the upstream storage.
3. Generation scheduling of self-generation facilities, including CHP and industrial boilers.

In the literature on the ORI, to the best of authors' knowledge, there are a few studies focused on flexibility potential. The main reason is the complexity of energy management in refinery processes. Firstly, in 2003, a research study proposed a general framework to determine the optimal operational strategies of industrial cogeneration including both electrical and thermal systems [161]. The study showed that how self-generation facilities, including steam turbines, gas turbines, diesel generators, steam boilers, waste heat recovery boilers, and steam header configuration with grid connection, can be exploited in the petrochemical industry to provide peak-shaving for the power system. In 2013, a decision-making procedure was proposed to optimize load control in the ORI [162]. The study developed mathematical models to unlock demand flexibility in operational sequences of refinery processes in a smart grid. In 2019, an energy management system was suggested for ORI to unlock the flexibility potentials of refinery industries in response to dynamic energy prices [59]. The study addressed the variable mass flow model to integrate the demand flexibility of the ORI into power grids. Besides, it optimized the operating strategies of the self-generation facilities including CHP, industrial boilers, and on-site

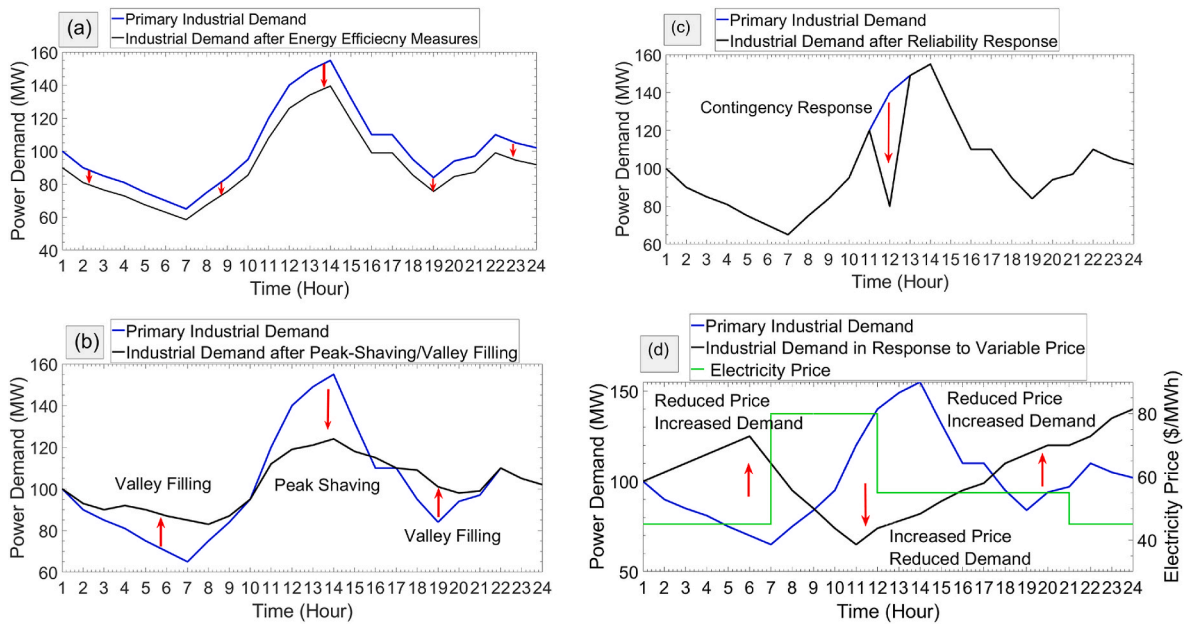

Fig. 7. Impact of energy management in load profile of an industrial plant (a) Energy efficiency measures (b) Peak-shaving and valley-filling (c) Reliability enhancement (d) Price responsive.

solar power generation units. In 2020, the energy consumption of the ORI is modeled mathematically to unlock the flexibility of the ORI when a power shortage occurs in the power grid [163]. The study modeled the industrial boiler and CHP to supply the power and heat demand of the refinery processes. A robust optimization approach was addressed to integrate the joint heat-power flexibility into the power system under electricity price uncertainty. The study concluded that the ORI can provide peak-shaving for power systems when a power shortage occurs.

Although there are few studies in the case of flexibility management in the ORI, the energy efficiency measures are heeded in many studies. Most of these studies focused on increasing the energy efficiency of refinery equipment and restoring the waste heat of refinery processes. In 2013, a research study was conducted to evaluate the impacts of four heat supply alternatives, including natural gas combined cycle, natural gas boiler, biomass boiler, and excess heat, on the carbon footprint of the ORI [164]. In 2016, an eco-technical study was done to investigate the role of the heat recovery systems of refinery processes on the cash flow and greenhouse gas emissions [165]. In 2017, a research study showed that waste gases from oil refinery plants can be retrieved for electric power generation [166]. In 2019, a practical study analyzed energy recovery solutions based on the pump-as-turbine technology in the ORI [167]. Moreover, a research study proposed energy efficiency measures as a pathway for greenhouse gas emissions reductions in the ORI [168]. In 2020, a practical study was conducted to show the impacts of solar-based systems in increasing the energy and cost efficiencies of refinery processes [169]. In 2021, a comprehensive study was carried out to investigate the interaction of water-energy-environment nexus in a hybrid system including an ORI, a thermal power plant, and a heat recovery steam generator. The hybrid system aimed to meet the electrical and gas demand of the residential and industrial sectors [170].

To sum up the demand-side management in the ORI, Fig. 6 depicts the general structure of energy management in a modern ORI. Based on the figure, the FEMS optimizes the energy generation of the self-generation facilities, i.e. CHP units, steam boilers, and power-only units, as well as the power/heat consumption of the refinery processes to provide demand flexibility for the upstream power and gas networks.

5. Main objectives and market floors

In power system studies, demand side management is implemented in the industrial sector to fulfill the key following aims:

1. Increasing energy efficiency of industrial processes
2. Providing peak-shaving and/or valley-filing for power system
3. Enhancing power system reliability
4. Providing up-/down-regulation for intermittent power systems
5. Provoking price responses

First of all, many technical measures have been introduced to improve energy efficiency in industrial processes. Besides, due to increased environmental concerns and global warming, the energy efficiency measures are more heeded to reduce greenhouse gas emissions. In Ref. [171], an extensive survey is conducted to introduce energy efficiency approaches and technologies in different industrial processes of cement manufacturing plants, from crushing to cement mills. The study concluded that the largest recorded values of energy savings are 3.4 GJ/t and 35 kW h/t for thermal and electrical energies, respectively. Moreover, the highest emission reduction in this industry is 212.54 kgCO2/t to date. In the aluminum industry, a research study proposed 52 energy efficiency measures [125]. Based on the study, the energy consumption of electrolysis and recycling processes are highly affected by the measures. In the US, a comprehensive study suggested a framework to improve energy efficiency in the pulp and paper industries [172]. In this study, the energy efficiency measures are evaluated quantitatively in key processes including raw material preparation, chemical pulping, mechanical pulping, and papermaking. In Ref. [173], the energy-saving opportunities of oil refinery plants are presented. In this way, practical solutions are offered for industrial motors, pumps, compressors, and fans in different refinery processes. Meanwhile, the energy management of self-generation facilities, including CHP, gas turbines, and industrial boilers, are investigated. Regarding peak-shaving and valley-filling, the industrial sector shifts the power consumption of energy-intensive processes from peak hours to off-peak hours. In Ref. [14], an incentive-based DR program is suggested to encourage the heavy industries, including 8 cement plants, 9 metal industries, and 1 automaking factory, to reduce the power consumption during peak hours of

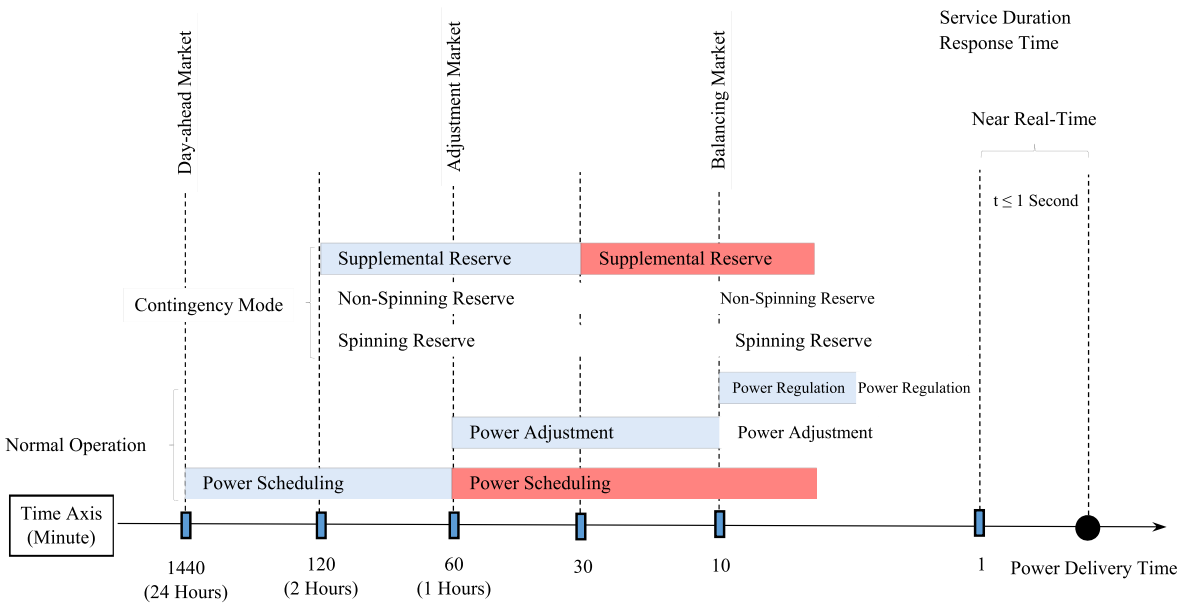

Fig. 8. Time response and duration of short-term market floors and ancillary services in a graphical presentation.

summer days when Iran Power Grid faces a surge in power consumption of residential and commercial cooling systems. With the development of the smart grid, research study [98] proposed flexible industrial processes of cement and metal smelting plants to maintain power system reliability and to provide power regulation in ancillary service markets. The research study [174] provides a theoretic framework and practice-oriented survey of industrial demand flexibility in response to different pricing schemes. To give a general overview, Fig. 7 describes how the key objectives affect the load profile of an industrial plant.

To fulfill the abovementioned aims, the flexibility potentials of the industrial plants are integrated into the trading floors of electricity markets. The market floors are so designed to meet the flexibility requirements of the supply-side from hours before energy delivery time until near real-time. In power systems with high RES penetration, the daily electricity markets are normally comprised of three market floors, including the day-ahead, adjustment, and balancing markets. In the normal operation, the main energy consumption of heavy industries is scheduled in the day-ahead market 24 h before power delivery time [175]. For example, a cement plant can make a decision about the main power consumption of energy-intensive processes, e.g. crushers and mills, in the day-ahead market [176]. Approaching the power delivery time, the adjustment market is performed 60 to 10 min before power delivery time. In the case of flexibility requests by the power system operator, the cement plant can turn off/on the interruptible processes, e.g. crushers, and supply the feedstock from the silos [19]. Finally, the balancing market is cleared a few seconds before power delivery time. Consequently, the factory may turn up/down the power consumption of the VSD mills in response to power system imbalance to provide down-/up-regulation at the opposite side of power system imbalances [177]. Therefore, the flexibility potentials of the factories are integrated into the three successive market floors hierarchically on long, mid, and short advance notices.

In addition to the normal operation, ancillary service markets provide required flexibility in a contingency operation. In this way, generally, three types of reserve services are considered, including spinning reserve, non-spinning reserve, and supplemental (replacement) reserve [46]. The spinning reserve is an online power generation capacity that is extracted from the running generators connected to the power system. The spinning reserve is normally provided within a few seconds up to 10 min. In the industrial sector, some industrial processes can turn down the energy consumption in few minutes in response to flexibility requirements. The contingency state may be due to a renewable power shortage or a failure in power system facilities. For example, in aluminum smelting plants, the variable voltage controller of the pots can provide power flexibility within a few minutes without imposing interruption to the whole pot [117]. The non-spinning reserve is the generation capacity of offline generators that can be connected to the power system on short notice, i.e. fast-run generators. In industrial plants, the power consumption of some processes, e.g. crushers and cement mills, can be turned off within a few minutes. Meanwhile, the self-power generation facilities of industries, e.g. gas turbines and diesel generators, can be synchronized with the power system to support the non-spinning reserve market [178]. The supplemental reserve is normally used to restore the spinning and non-spinning reserve to a pre-contingency operational state. In contrast to the spinning and non-spinning reserves, the time response of the supplemental reserve is more than half an hour and may take up to 2 h. Some industrial loads with 0.5–2 h time response can integrate power flexibility to this market service. As an example, the operation time of a running smelting pot takes around 45–60 min. Therefore, the running pots can respond to flexibility requirements as the supplemental reserve without

Table 10
Quantitative characteristics of time response and time duration for short term market floors and ancillary services.

Power System State	Service Type	Response Speed	Duration	Cycle Time
Normal Operation	Long Notice Power Scheduling	≈1 Hour	Hours	Hours
	Mid Notice Power Adjustment	10 Minutes ≤ t ≤ 60 Minutes	10 Minutes to Hours	10 Minutes to Hours
	Short Notice Power Regulation	≈1 Minute	Minutes	Minutes
Contingency State	Spinning Reserve	Seconds ≤ t ≤ 10 Minutes	10 Minutes ≤ t ≤ 120 Minutes	Hours to Days
	Non-spinning Reserve	t ≤ 10 Minutes	10 Minutes ≤ t ≤ 120 Minutes	Hours to Days
	Supplemental Reserve	t ≤ 30 Minutes	≈120 Minutes	Hours to Days

interruption. Completing the operation of the running pot, the next operation cycle of the pot is postponed to provide power flexibility for the supplemental reserve market. Fig. 8 and Table 10 explain the characteristics of the market floors and ancillary services in the normal operation and contingency mode. The data are extracted from Refs. [138,179].

6. Challenges and opportunities

Industrial demand flexibility is a necessity, especially for future power systems with high intermittent power penetration. Although both the power system and industry owners take advantage of the Demand Side Management (DSM), some challenges may discourage the industries to participate in DR programs.

In the energy markets, data availability, including energy price and demand level, is a challenging issue. In power systems with high RES penetration, there is a strong correlation between electricity price and renewable power availability [180]. The intermittency of the RES, as well as the uncertain nature of demand level, impose a great deal of uncertainty on the industrial DR programs [181].

Market power and economic withholding is a critical issue that is performed by heavy industries, especially large-scale ones. In metal smelting plants, the nominal power consumption of a smelting pot is up to 100 MW. Therefore, such heavy industries may bid high prices (or request high financial incentives) surpassing the conventional incentive for small- and mid-scale industries. In this way, economic withholding [182] emerges, especially when the power system balance depends heavily on the operation of heavy industries.

To encourage the industries to participate in DR programs, the industries are normally offered price-based [58] or incentive-based programs [183]. The uniform incentive or price schemes are not satisfactory for different industries. The reason is that the revenue of shifting/curtailing energy consumption is not the same for various industries. Therefore, to compensate for the lack of financial losses, the DR incentives should be offered based on the financial characteristics of the target industries individually. As an example, the incentive for textile industries should be different from the metal smelting plants.

The responsive plants are not allowed to participate directly in the electricity market. As a result, an intermediary agent is required between the power system and industrial plants. The third party is called the industrial demand response aggregator and industrial demand response provider in the literature [184]. The basic structure and protocols of such agents are still under investigation in many studies [185]. The intermediary agent is responsible for informing the contracted industries of the DR programs and provide them with compelling incentives to encourage them. Widespread adoption is a challenge for the third parties to raise consciousness in the industrial sector and attract more industrial plants to join the DR programs.

Shifting the operational strategies of industries to off-peak hours, the working hours of the industries' crew need to be extended. Besides, the working load of the crew in the production line increases/decreases in off-peak/peak hours of the power system [186]. It may impose a challenge to the industries and affects crew availability. The crew availability and the associated cost should be taken into account before deciding on participation in DR programs.

The key feature of the smart grid is the two-way communication between supply and demand sectors which makes it possible to unlock power flexibility [187]. In the industrial sector, technical data play a key role in operational scheduling and flexibility management. The data includes the supply side, e.g. electricity price, incentive plans, flexibility requirements, and the demand side, e.g. production line limitations and operational strategies. A data lake is required to store, manage and preprocess the raw data to be tailored for industrial demand flexibility [188]. In this way, data collecting, communicating, storing, and processing are still controversial issues.

Implementation of DR programs in industries needs technical skills

Table 11
Classification of main challenges and opportunities of industrial demand side management.

Challenge/ Opportunity	Type	Description		Discussed References
Challenges	Energy Markets	Data Availability, e.g. energy price, demand level.		[51,200,201]
		Market Power by Large-scale Industries		[51]
		Pricing mechanisms and optimal scheduling		[73,85]
	Behavioral Interaction	Lack of trustworthy parties		[51]
		Widespread adoption of DR programs		[50,51,202]
		Customer understanding and participation		[85,203]
	Technological	Data and IoT	Data Collection Data Process Data Communication	[204,205]
		Technical Skills		[206,207]
		Non-interruptible industrial processes		[73]
		Big data analytics-based decision support.		[85]
		The emergence of RES and storage devices		[79]
		Implementation issues: implementation of flexibility management is a complex action in industries practically		[79]
	Regulatory	Lack of regulation for flexible industries	Tax GHG Emission	[208–210] [211–213]
		Utility reconstruction issues		[46,214]
		Program requirements and aggregation		
		Measurement and verification variety		
		Limitations on market regulations.		
		Inclusion in energy efficiency programs.		[46,215]
		Various regulations in different countries		[51,184,216]
		The market mechanism is not perfect		[50]
	Financial	Lack of persuasive incentives		[46]
		Lack of exact evaluations for DR benefits		[46]
		Capital accessibility and preconditions of third parties		[87]
Opportunities	Power System	Power frequency regulation		[217–219]
		RES facilitation		[220–222]
		Reduction in power system operation cost/emission production		[223–225]
		Flatten the load profile (Peak-shaving and/or Valley-filling)		[226–228]
		Improving power system reliability/security/resilience		
		Congestion mitigation and voltage improvement		[196,229,230]
		Unlocking DG/CHP capacity of industries		[231–233]
	Industries	Incentive financial plans		[234–236]
		Reduction in electricity bills		[237–239]
		Effective maintenance scheduling		[240–242]
		Improved power quality and decelerate aging		[243–245]
		Prevent power interruption/ Sustainable power supply		[246–248]
		Decreasing in energy intensity		[249–251]

and expert knowledge. Otherwise, imposing interruption/curtailment on industrial processes may cause financial losses. Due to a lack of technical skills, many industries are reluctant to respond to DR programs and prefer to follow conventional operational strategies. Technical knowledge contributes to the acceptance of industrial DR [189]. Therefore, it is crucial to educate the industrial energy experts and production planning departments about DR skills.

The challenges are not limited to financial and technical issues. The regulatory problems are stated in many studies in recent years. Energy tax [190] and Greenhouse Gas Emissions (GHG), also known as the carbon tax [191], are two critical regulatory issues. Tax issues may be used as leverage to persuade the industries to participate in DR programs. The GHG emission is a barrier for some industries to shift the operational strategies, especially for industries close to urban areas. In this case, the industries are not allowed to produce GHG emissions in some seasons and even some hours a day depending on local emission constraints [192]. Such regulatory rules are quite localized in countries and do not follow the same pattern worldwide.

Despite the surveyed challenges, industrial demand flexibility provides perfect opportunities for both power systems and industries. Power frequency regulation [193] and facilitation of RES integration [194] are two key opportunities especially for power systems with high intermittent power penetration. For a power system with distinct peak demand, the industrial flexibility not only flattens the demand profile but also reduces the operational cost of the power system due to avoid investing in fast-run power plants [18]. In addition to the normal operation of the power system, the responsive plants can provide the required flexibility when an unforeseen failure affects power system reliability. The opportunities of responsive industries are not limited to the global power balance. Besides, the flexible industries contribute to the local congestion mitigation in weak power lines [195] and voltage regulation in connected buses and substations [196]. Meanwhile, there is a significant amount of unused thermal distributed generation capacity in industries that can be connected to the power system within a few minutes when a power shortage occurs. Most thermal Distributed Generations (DG) are normally used for emergency power system backup. The aggregated DG capacity offers a great flexibility potential for power systems during critical hours.

On the other hand, the industries benefit from the DR programs. The industries are offered financial incentives in response to DR programs [197]. Moreover, they take advantage of reduced electricity bills by participating in price-based DR programs, e.g. Time-of-Use (TOU) and Critical Peak Pricing (CPP) [198]. Many industries schedule the minor maintenance and overhaul of the production lines in time durations when a considerable power reduction is required on the supply side [14]. In this way, the industries take advantage of financial incentives to reduce the annual maintenance cost. In some power grids with seasonal power shortages, if the industries do not participate in DR programs, the unscheduled power outage is possible. Therefore, the active flexible industries not only help power systems to provide a sustainable power supply but also improve the power quality in industrial zones. The low power quality and unscheduled power outage impose significant financial losses to the industries [199]. To sum it up, Table 11 classifies the key challenges and opportunities associated with industrial DSM.

7. Optimization algorithms and software

To model energy structures of industries, different technical models are suggested in the literature. In the model-based approaches, generally, two types of solution methodologies are used to optimize the energy consumption of the industries. The solution approaches include mathematical programming and nature-inspired (metaheuristic) algorithms. The mathematical programming uses mathematical approaches, e.g. Newton, quasi-Newton, steepest descent, and the Simplex methods to optimize the solution. These methods are capable to optimize simple mathematical energy models, normally in form of linear and convex, e.g. Linear Programming (LP). Increasing the dimension of the physical energy model, the computational burden of the optimization algorithms increases considerably. In the real world, the energy model of many industrial processes follows nonlinear and/or nonconvex structures. Although it is difficult to solve severe nonlinear models using mathematical approaches, some advanced methods, e.g. branch-and-bound [252] and benders decomposition [253], facilitate the optimization of nonlinear energy models. In the case of large-scale nonlinear models, heuristic and metaheuristic approaches are useful techniques to optimize the energy models. The main advantage of heuristic and metaheuristic approaches is that the optimized solution can be found easily with low time and computation burden. In contrast to the mathematical approaches, the optimized solution is an approximate answer instead of the exact solution found by mathematical approaches.

7.1. Linear programming

Linear programming shows a simple form of physical models with linear objective functions and constraints. The mathematical programming approaches can optimize the LP models easily in a low computational burden. In the industrial sector, some research studies have proposed LP models for the energy equations of the industrial processes. In Ref. [254], an LP is addressed to model the energy system of a textile industry while minimizing the annual operation cost of the plant. In aluminum smelting plants, the LP is used to maximize the integration of intermittent renewable energy into the industry [255]. This method is used in industrial microgrids to minimize the energy consumption cost of the industrial demands [256].

7.2. Mixed-integer linear programming

Mixed-integer linear programming (MILP) includes linear objective functions and constraints with at least one integer variable. In industrial demand management, the MILP is addressed to optimize the energy model of oil palm-based industrial parks [257]. The study aims to maximize the economic performance of the industrial units. A generic MILP model is suggested for industrial hubs to minimize energy and production costs, rewards, and penalties due to not meeting the production plan of industrial processes [258]. Regarding industrial microgrids, a MILP approach is presented to minimize the expected cost of industrial prosumers in battery manufacturing plants, including power procurement cost and operation cost of self-generation facilities [259]. In the steel milling industry, the MILP is adopted to optimize the operation of on-site power plants with the purpose of peak-shaving for the upstream network [260]. The research study [261] uses the MILP to determine the optimum operation of the refinery process in an ethanol biorefinery plant.

7.3. Mixed-integer non-linear programming

In Mixed-integer non-linear programming (MINLP), the objective function and/or constraints are nonlinear and at least one of the decision variables is an integer. In the research study [262], an MINLP is suggested to maximize the profit of smart power grids in presence of responsive industrial demands. In a large-scale ethylene plant, the MINLP is addressed to minimize the total energy consumption of the industrial processes [263]. This approach is addressed in Alberta's oil sands industry to facilitate the integration of renewables into the plant [264]. In Ref. [265], an MINLP model is proposed to maximize the profit of the industrial microgrid and minimize the industrial load shedding.

7.4. Metaheuristic approaches

In severe nonlinear models, the mathematical programming approaches may fail to find the optimum solution. In such a situation, the time and computational burden of the problem increase significantly

Table 12
Metaheuristic algorithms to optimize industrial energy models.

No.	Reference	Algorithm	Target Industry
1	[266]	Non-dominated Sorting Genetic Algorithm (NSGA-III)	Iron And Steel Industry
2	[277]	Genetic Algorithm	Oil Industry
3	[267]	Particle Swarm Optimization (PSO)	Pulp And Paper Industry
4	[268]	Simulated Annealing (SA)	Smart Grid For Industry
5	[269]	Ant Colony Optimization (ACO)	Pulping Industry
6	[270]	Firefly Algorithm (FA)	Food Industry
7	[278]	Differential Evolution (DE)	Multi-Energy Industrial Network
8	[271]	Teaching Learning Based optimization (TLBO)	Foundry Industry
9	[272]	Gravitational Search Algorithm (GSA)	Chemical Industrial Processes
10	[273]	Cuckoo Search (CS)	Textile Industry
11	[274]	Grey Wolf Optimization (GWO)	Maritime Industry
12	[275]	Harmony Search Algorithm (HSA)	General Manufacturing Plants
13	[276]	Krill Herd (KH)	Liquefied Natural Gas Industry

and make the problem intractable. Nature-inspire optimization approaches are practical solutions to find a fast optimum point. Although the optimum point may be approximate, the tractability and low computational burden may overweigh the mathematical methods. In the iron and steel industry, a Non-dominated Sorting Genetic Algorithm (NSGA) is addressed to optimize the objective function which is comprised of three terms including (1) minimization of energy consumption, (2) minimization of pollutant emission, and (3) minimization of total energy conservation and emission reduction cost [266]. In the paper milling industry, Particle Swarm Optimization (PSO) is suggested to minimize the energy consumption cost of the industrial processes [267]. In an industrial smart grid, the Simulated Annealing (SA) is proposed to minimize energy and production costs of industrial companies [268]. In the pulping industry, the Ant Colony Optimization (ACO), as well as the GA, PSO, Differential Evolution (DE), and Biogeography-based Optimization Algorithm (BBO), are addressed to increase the accuracy of energy management models [269]. Firefly Algorithm (FA) combined with PSO is addressed in the sugar industry to model industrial clarifying processes of the plant [270]. In the foundry industry, Teaching Learning Based Optimization (TLBO) is used to optimize the industrial operation of furnaces [271]. Gravitational Search Algorithm (GSA) is addressed in a research study [272] to minimize ignition energy of industrial processes of chemical industries. In a woolen mill plant, Cuckoo Search (CS) and Bio-Inspired Optimization Algorithms are suggested to optimize the objective function of the energy management system including minimization of the energy consumption cost, peak-to-average power ratio, and waiting time of customers due to production rescheduling [273]. In maritime industries, the Grey Wolf Optimization (GWO) is proposed to minimze the energy consumption of the self-generation facilities and electric ferries [274]. A holistic approach is presnted in study [275] to minimize the total energy consumption of production processes of industrial plants while fulfilling the customers' requirements by using Harmony Search Algorithm (HSA). In liquefied natural gas industries, Krill-Herd-Based investigation algorithm is addressed to minimize the required shaft work of industrial compressors [276].

Table 12 describes the metaheuristic approaches used in industrial energy management. In this table, 13 nature-inspired algorithms are stated. To the best of the authors' knowledge, some well-known algorithms, including Group Search Optimizer (GSO), Bee Colony, Invasive Weed Optimization (IWO), Artificial Immune System (AIS), Crisscross Optimization (CSO), Line-up competition algorithm (LCA), and Exchange Market Algorithm (EMA) are not examined in the industrial sector. It may provide an opportunity for energy researchers to investigate the functionality of the suggested algorithms in industrial energy management.

Table 13
Software tools addressed in industrial energy management studies.

No.	Reference	Software	Target Industry	Homepage of Software Developer
1	[254]	AIMMs 4.32	Textile	https://www.aimms.com/
2	[279]	DIgSILENT	Industrial Energy Hubs	https://www.digsilent.de/
		GAMS		https://www.gams.com/
3	[299]	COMSOL Multiphysics 5.3	Metal Hydride Hydrogen Compressors	https://www.comsol.dk/
4	[300]	Aspen Plus	Cement	https://www.aspentech.com
5	[280]	Aspen Plus	Cement	https://www.aspentech.com
6	[281]	Fortran	Cement	https://fortran-lang.org/
7	[286]	HOMER Pro-3.2	Cement	https://www.homerenergy.com/
8	[301]	GE Intelligent Platform	Paper Mill	https://www.ge.com/
9	[287]	Simprosys 2.1	Paper Industry	http://www.simprotek.com/
10	[302]	reMIND	Pulp And Paper Industry	NA
11	[288]	SIMCA 14.1	Pulp And Paper Industry	https://www.sartorius.com/
12	[303]	Aspen Plus	Steel Industry	https://www.aspentech.com
13	[304]	Termolog EPIX 10	Wine Industry	www.logical.it/software-per-la-termotecnica
14	[282]	MATLAB	Pulp And Paper Industry	https://www.mathworks.com
15	[283]	Python	Industrial Manufacturing Systems	https://www.python.org/
20	[305]	OriginPro8.0	Drilling Industries	https://www.originlab.com/
21	[285]	SPSS	Cement, Steel, Pulp And Paper, Textile	https://www.ibm.com/products/spss-statistics/
22	[284]	LEAP	Iron And Steel Industry	https://leap.sei.org/
23	[306]	Computational Fluid Dynamics (CFD)	Ceramics Industry	https://www.simscale.com/
24	[289]	Vensim	Textile Industry	https://vensim.com/
25	[307]	DOE-2.2	IT Industries	https://www.doe2.com/
26	[308]	MATLAB	Agrifood Industries	https://www.mathworks.com
27	[309]	System Advisor Model (SAM) Aspen HYSYS	Oil & Gas Industries	https://sam.nrel.gov/ https://www.aspentech.com/en/products/engineering/aspen-hysys
28	[310]	Superdecisions	Fuel-Oil, Coal, LPG, Natural Gas	http://www.superdecisions.com/
29	[311]	REFPROP	Steel Industry	https://www.nist.gov/srd/refprop
30	[312]	GAMS	Chemical Industry	https://www.gams.com/

7.5. Software and solvers

In order to make a mathematical model for industrial processes,

Table 14
Software tools addressed in industrial energy management studies.

Solver	LP	MILP	NLP	MINLP	Target Industry	Reference
ANTIGONE			✔	✔	Power Industry	[292]
BARON	✔	✔	✔	✔	Power Industry	[292]
CONOPT	✔		✔		Industrial furnace	[295]
CPLEX	✔	✔			Glass Container Industry	[290]
DICOPT				✔	Process Industries	[293]
GUROBI	✔	✔			Refining furnaces	[291]
IPOPT	✔		✔		Process Industries	[296]
LINDO	✔	✔	✔	✔	Biodiesel industry	[297]
MOSEK	✔	✔	✔	✔	General Industries	[294]
XPRESS	✔	✔	✔	✔	Oil industry	[298]

programming languages and simulation software are used. In simulation software, the mathematical model of energy systems, industrial processes, and objective functions with associated constraints are coded. In this way, the physical model is translated into machine language. The machine language makes it possible to optimize the target variables of the energy experts and production planners. In contrast to the simulation software, the solvers are optimization approaches to find the optimum point of the simulated problem. The type of solvers depends on the type of the objective functions and constraints in terms of linearity, nonlinearity, and problem dimensions.

Regarding the simulation software, AIMMs [254], GAMS [279], Aspen Plus [280], Fortran [281], MATLAB [282], Phyton [283], LEAP [284], SPSS [285], HOMER [286], Simprosys [287], SIMCA [288], Vensim [289] are used in cement manufacturing, metal and aluminum smelting, textile, wood and paper mills, and oil refinery industries.

For linear energy models, the LP and MILP are the most efficient solution methods offered by mathematical solvers, e.g. CPLEX [290], and GUROBI [291]. Regarding the non-linear energy models, the solution algorithm depends mainly on the non-linear strength of the problem. In this case, many mathematical solvers are addressed in industrial energy management including ANTIGONE [292], DICOPT [293], MOSEK [294], CONOPT [295], IPOPT [296], LINDO [297] BARON [292], and XPRESS [298]. To sum up, Table 13 illustrates some important software tools in industrial energy management. Besides, Table 14 describes some features of the used solvers in industrial energy management studies. Note that the table aims to show the software diversity instead of the software intensity. The official homepages of the software are also provided to help energy researchers accessing the software.

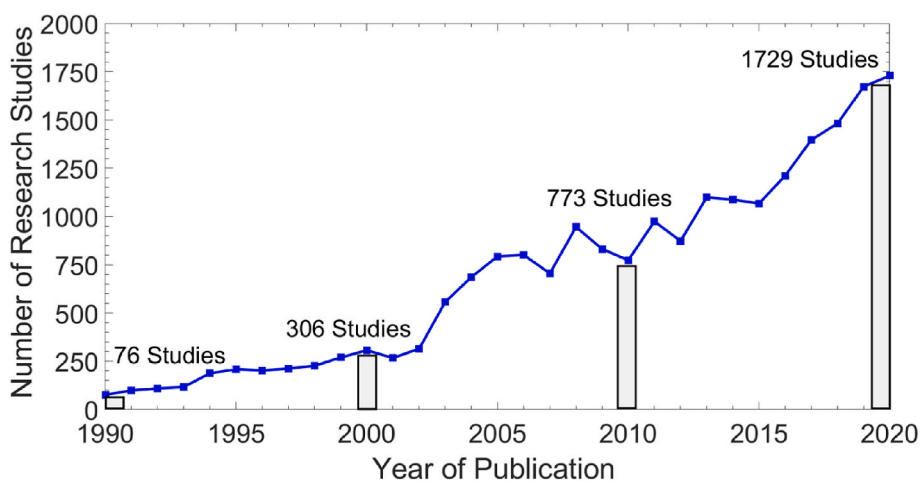

Fig. 9. The annual number of research studies from 1990 to 2020 in the field of industrial energy management.

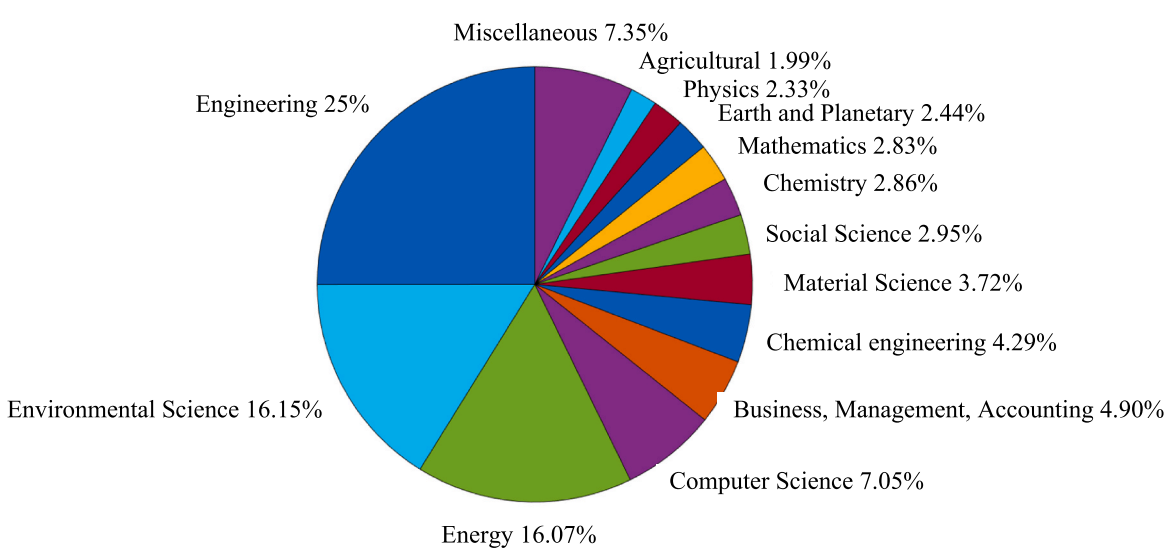

Fig. 10. Contribution of research studies to scientific disciplines in the field of industrial energy management.

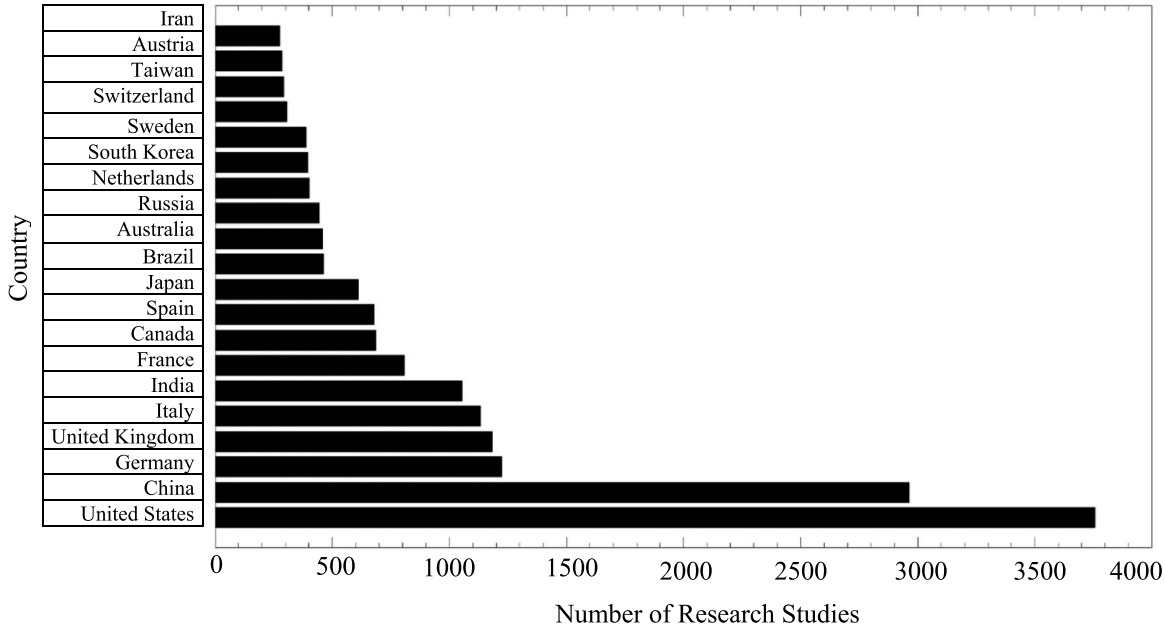

Fig. 11. Number of research studies in the field of industrial energy management in top 20 countries.

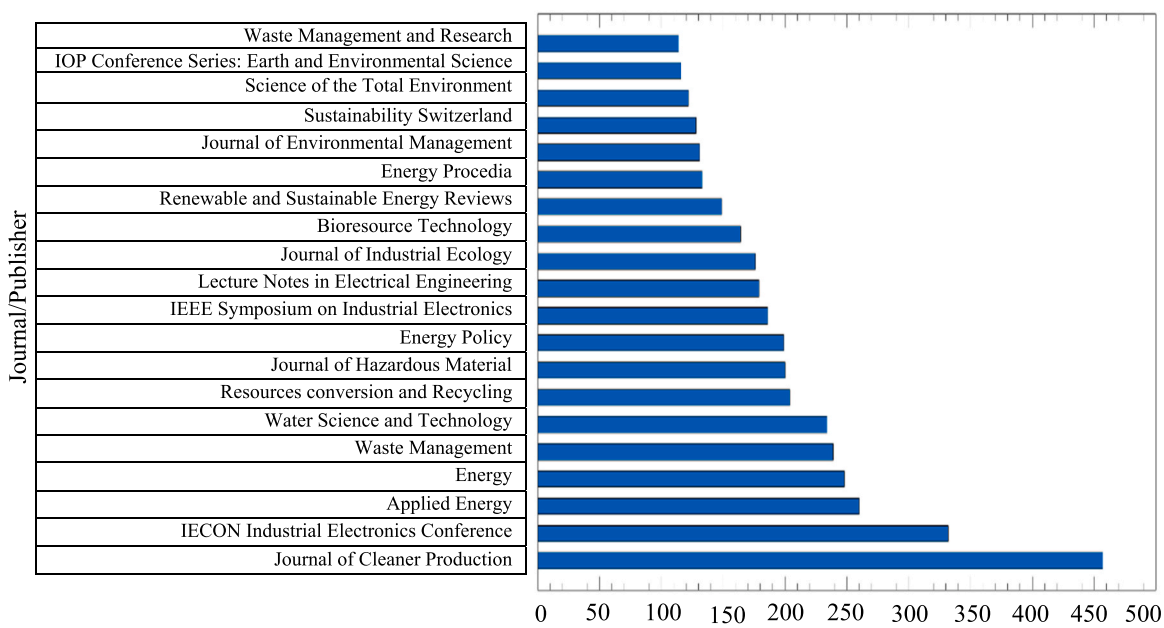

Fig. 12. Number of research studies in the field of industrial energy management in top 20 journal publishers.

8. Bibliographic and statistic survey

In this section, a bibliographic survey is presented to show the increasing importance of industrial energy management in the literature. The statistic data are extracted from Scopus [313] between 1990 and 2020. First of all, Fig. 9 describes the total number of research studies during the last three decades. As can be seen, the number of research studies in the field of industrial energy management increased from 76 in 1990 to 1729 in 2020. It shows that industrial energy management has attracted much attention in energy optimization, especially after 2000.

Fig. 10 illustrates the share of scientific disciplines in industrial energy management. Based on the pie chart, engineering, environmental science, and energy are the most top priorities for industrial energy management.

Fig. 11 explains the country-of-origin researches. As the bar graph reveals, the United States, China, and Germany published the most industrial research studies during the past thirty years.

Finally, Fig. 12 describes the distribution of the industrial publications in different journal publishers. As can be seen, the Journal of Cleaner Production, IECON Industrial Electronic Conference, and Applied Energy have published the most research studies in the last three decades.

9. Conclusion

Industrial demand management is a workable solution to meet the flexibility requirements of future power systems with high penetration

of intermittent power. In the industrial sector, the heavy industries provide great flexibility potentials for power systems by scheduling/adjusting/regulating the energy consumption of energy-intensive processes. Cement manufacturing plants, aluminum smelting factories, and oil refinery industries show considerable potentials in providing power flexibility from 24 h prior to energy delivery time until real-time. In this way, the power consumption of industrial processes can be scheduled in the day-ahead market on long notice, then is adjusted in the intraday market on mid notice, and finally is regulated in the balancing market.

In heavy industries, some industrial processes are interruptible. Therefore, they can be turned on/off on short advance notice without imposing financial loss/damage to the factories. They can offer considerable flexibility values to the power systems in the day-ahead and intraday markets. In contrast, some industrial processes are uninterruptible; therefore, they can turn down/up the power consumption on short advance notice without causing interruption to the production line of the factory. Such processes are functional for real-time and ancillary service markets.

The simulation studies of industrial demand management show that cement manufacturing plants can provide up to 10% and 16.9% reduction in energy consumption cost and energy demand, respectively. The aluminum smelting factories can benefit from up to 34.2%, 20.70%, and 16.5% reduction in energy cost, energy demand, and emission production. The industrial processes of oil refinery industries exhibit great potentials for joint power and heat flexibility depending on the size of self-generation facilities, i.e. power generators and steam boilers.

The industrial demand response programs are beneficial for both the power system and industries. The power system mainly takes advantage of peak shaving and valley filling, frequency regulation, reduction in carbon footprint, and reduction in operational cost. In addition to the global support, the industries provide local power system support, e.g. congestion mitigation in power lines and voltage improvement in power substations. In response, the industries benefit from reduced energy consumption costs, financial incentives, improved power quality, and sustainable energy supply.

Although the supply and demand sides benefit from the DR programs, some challenges may discourage industries from participating in the DR programs. Regulatory barriers, data communication/storing/processing, and lack of financial incentives are the most important barriers reported in the studies. Moreover, the implementation of DR programs in heavy industries needs expert knowledge. As a result, education of technological skills raises consciousness and improves the acceptability of DR programs among industry owners. Finally, the regulation of the intermediary agent, i.e. the industrial demand response aggregators, is still a controversial issue that needs further investigation.

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Declaration of competing interest

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

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References

[1] International energy agency, IEA. https://www.iea.org/data-and-statistics/charts/world-electricity-final-consumption-by-sector-1974-2019; 2021.
[2] Golmohamadi Hessam. Virtual storage plants in parking lots of electric Vehicles providing local/global power system supports. *Energy Storage*; 2021.
[3] Kazemi-Razi SM, Askarian Abyaneh H, Nafisi H, Ali Z, Marzband M. Enhancement of flexibility in multi-energy microgrids considering voltage and congestion improvement: robust thermal comfort against reserve calls. Sustain. Cities Soc. 2021;74:103160. https://doi.org/10.1016/j.scs.2021.103160.
[4] Yan X, Gu C, Zhang X, Li F. Robust optimization-based energy storage operation for system congestion management. IEEE Syst. J. 2020;14(2):2694–702. https://doi.org/10.1109/JSYST.2019.2932897.
[5] Ahmadi M, Adewuyi OB, Danish MSS, Mandal P, Yona A, Senjyu T. Optimum coordination of centralized and distributed renewable power generation incorporating battery storage system into the electric distribution network. Int J Electr Power Energy Syst 2021;125:106458. https://doi.org/10.1016/j.ijepes.2020.106458.
[6] Mahela OP, Shaik AG. Power quality improvement in distribution network using DSTATCOM with battery energy storage system. Int J Electr Power Energy Syst 2016;83:229–40. https://doi.org/10.1016/j.ijepes.2016.04.011.
[7] Goebel C, Callaway DS, Jacobsen H. The impact of state of charge management when providing regulation power with energy storage. IEEE Trans Power Syst 2014;29(3):1433–4. https://doi.org/10.1109/TPWRS.2013.2292434.
[8] Zhao H, Hong M, Lin W, Loparo KA. Voltage and frequency regulation of microgrid with battery energy storage systems. IEEE Trans. Smart Grid 2019;10(1):414–24. https://doi.org/10.1109/TSG.2017.2741668.
[9] He G, Chen Q, Kang C, Xia Q. Optimal offering strategy for concentrating solar power plants in joint energy, reserve and regulation markets. IEEE Trans. Sustain. Energy 2016;7(3):1245–54. https://doi.org/10.1109/TSTE.2016.2533637.
[10] Parvini Z, Abbaspour A, Fotuhi-Firuzabad M, Moeini-Aghtaie M. Operational reliability studies of power systems in the presence of energy storage systems. IEEE Trans Power Syst 2018;33(4):3691–700. https://doi.org/10.1109/TPWRS.2017.2771521.
[11] Zhao T, Ceseña EAM, Parisio A, Panteli M, V Milanović J. Towards optimal management and control of virtual storage plants for flexible operation in future power networks. In: 2019 IEEE PES GTD grand international conference and exposition asia. GTD Asia); 2019. p. 583–8. https://doi.org/10.1109/GTDAsia.2019.8715913.
[12] Dahash A, Ochs F, Tosatto A, Streicher W. Toward efficient numerical modeling and analysis of large-scale thermal energy storage for renewable district heating. Appl Energy 2020;279:115840. https://doi.org/10.1016/j.apenergy.2020.115840.
[13] H. Golmohamadi, "Operational scheduling of responsive prosumer farms for day-ahead peak shaving by agricultural demand response aggregators," Int J Energy Res, vol. n/a, no. n/a, doi: 10.1002/er.6017.
[14] Aras Nejad M, Golmohamadi H, Bashian A, Mahmoodi H, Hammami M. Application of demand response programs to heavy industries: a case study on a regional electric company. Int. J. Smart Electr. Eng. 2017;6(3):93–9 [Online]. Available: http://ijsee.iauctb.ac.ir/article_537456.html.
[15] Golmohamadi H. Agricultural demand response aggregators in electricity markets: structure, challenges and practical solutions- a tutorial for energy experts. Technol. Econ. Smart Grids Sustain. Energy 2020;5(1):17. https://doi.org/10.1007/s40866-020-00091-7.
[16] H. Golmohamadi and K. G. Larsen, "Economic heat control of mixing loop for residential buildings supplied by low-temperature district heating," J. Build. Eng., p. 103286, 2021, doi: https://doi.org/10.1016/j.jobe.2021.103286.
[17] Rashidizadeh-Kermani H, Vahedipour-Dahraie M, Shafie-khah M, Catalão JPS. Stochastic programming model for scheduling demand response aggregators considering uncertain market prices and demands. Int J Electr Power Energy Syst 2019;113:528–38. https://doi.org/10.1016/j.ijepes.2019.05.072.
[18] Golmohamadi H, Keypour R, Bak-Jensen B, Pillai JR, Khooban MH. Robust self-scheduling of operational processes for industrial demand response aggregators. IEEE Trans Ind Electron Feb. 2020;67(2):1387–95. https://doi.org/10.1109/TIE.2019.2899562.
[19] Golmohamadi H, Keypour R, Bak-Jensen B, Pillai JR. A multi-agent based optimization of residential and industrial demand response aggregators. Int J Electr Power Energy Syst 2019;107:472–85. https://doi.org/10.1016/j.ijepes.2018.12.020.
[20] Fischer D, Surmann A, Biener W, Selinger-Lutz O. From residential electric load profiles to flexibility profiles – a stochastic bottom-up approach. Energy Build 2020;224:110133. https://doi.org/10.1016/j.enbuild.2020.110133.
[21] Golmohamadi H, Keypour R, Bak-Jensen B, Radhakrishna Pillai J. Optimization of household energy consumption towards day-ahead retail electricity price in home energy management systems. Sustain. Cities Soc. 2019;47:101468. https://doi.org/10.1016/j.scs.2019.101468.
[22] Golmohamadi H, Guldstrand Larsen K, Gjøl Jensen P, Riaz Hasrat I. Optimization of power-to-heat flexibility for residential buildings in response to day-ahead electricity price. Energy Build 2021;232:110665. https://doi.org/10.1016/j.enbuild.2020.110665.
[23] Walker I, Hope A. Householders' readiness for demand-side response: a qualitative study of how domestic tasks might be shifted in time. Energy Build 2020;215:109888. https://doi.org/10.1016/j.enbuild.2020.109888.
[24] Lee S, et al. Optimal power management for nanogrids based on technical information of electric appliances. Energy Build 2019;191:174–86. https://doi.org/10.1016/j.enbuild.2019.03.026.
[25] Vellei M, Le Dréau J, Abdelouadoud SY. Predicting the demand flexibility of wet appliances at national level: the case of France. Energy Build 2020;214:109900. https://doi.org/10.1016/j.enbuild.2020.109900.
[26] Gan L, Chen X, Yu K, Zheng J, Du W. A probabilistic evaluation method of household EVs dispatching potential considering users' multiple travel needs.

IEEE Trans Ind Appl 2020;56(5):5858–67. https://doi.org/10.1109/TIA.2020.2989690.
[27] Haider HT, See OH, Elmenreich W. A review of residential demand response of smart grid. Renew Sustain Energy Rev 2016;59:166–78. https://doi.org/10.1016/j.rser.2016.01.016.
[28] Yan X, Ozturk Y, Hu Z, Song Y. A review on price-driven residential demand response. Renew Sustain Energy Rev 2018;96:411–9. https://doi.org/10.1016/j.rser.2018.08.003.
[29] Vandermeulen A, van der Heijde B, Helsen L. Controlling district heating and cooling networks to unlock flexibility: a review. Energy 2018;151:103–15. https://doi.org/10.1016/j.energy.2018.03.034.
[30] Mahmud K, Amin U, Hossain MJ, Ravishankar J. Computational tools for design, analysis, and management of residential energy systems. Appl Energy 2018;221:535–56. https://doi.org/10.1016/j.apenergy.2018.03.111.
[31] Golmohamadi H. Stochastic energy optimization of residential heat pumps in uncertain electricity markets. Appl Energy 2021;303:117629. https://doi.org/10.1016/j.apenergy.2021.117629.
[32] Daryabari MK, Keypour R, Golmohamadi H. Stochastic energy management of responsive plug-in electric vehicles characterizing parking lot aggregators. Appl Energy 2020;279:115751. https://doi.org/10.1016/j.apenergy.2020.115751.
[33] Daryabari MK, Keypour R, Golmohamadi H. Robust self-scheduling of parking lot microgrids leveraging responsive electric vehicles. Appl Energy 2021;290:116802. https://doi.org/10.1016/j.apenergy.2021.116802.
[34] Ma Z, Kuusinen K, Kjærgaard MB. A survey of demand response adoption in retail stores DR control preferences, stakeholder engagement, and cross-national differences. Energy Informatics 2019;2(1):8. https://doi.org/10.1186/s42162-019-0073-3.
[35] Ruparathna R, Hewage K, Sadiq R. Improving the energy efficiency of the existing building stock: a critical review of commercial and institutional buildings. Renew Sustain Energy Rev 2016;53:1032–45. https://doi.org/10.1016/j.rser.2015.09.084.
[36] Zeynali S, Nasiri N, Marzband M, Ravadanegh SN. A hybrid robust-stochastic framework for strategic scheduling of integrated wind farm and plug-in hybrid electric vehicle fleets. Appl Energy 2021;300:117432. https://doi.org/10.1016/j.apenergy.2021.117432.
[37] Shahkamrani A, Askarian-abyaneh H, Nafisi H, Marzband M. A framework for day-ahead optimal charging scheduling of electric vehicles providing route mapping: kowloon case study. J Clean Prod 2021;307:127297. https://doi.org/10.1016/j.jclepro.2021.127297.
[38] Daniel Olsen ATM. Arian aghajanzadeh, "opportunities for automated demand response in California agricultural irrigation,". California; 2015.
[39] Marks G, Wilcox E, Olsen D, Goli S. Opportunities for demand response in California agricultural irrigation: a scoping study. 2013.
[40] Meschede H. Increased utilisation of renewable energies through demand response in the water supply sector – a case study. Energy 2019;175:810–7. https://doi.org/10.1016/j.energy.2019.03.137.
[41] Iddio E, Wang L, Thomas Y, McMorrow G, Denzer A. Energy efficient operation and modeling for greenhouses: a literature review. Renew Sustain Energy Rev 2020;117:109480. https://doi.org/10.1016/j.rser.2019.109480.
[42] Golzar F, Heeren N, Hellweg S, Roshandel R. A novel integrated framework to evaluate greenhouse energy demand and crop yield production. Renew Sustain Energy Rev 2018;96:487–501. https://doi.org/10.1016/j.rser.2018.06.046.
[43] Aghajanzadeh A, Therkelsen P. Agricultural demand response for decarbonizing the electricity grid. J Clean Prod 2019;220:827–35. https://doi.org/10.1016/j.jclepro.2019.02.207.
[44] Golmohamadi H, Asadi A. A multi-stage stochastic energy management of responsive irrigation pumps in dynamic electricity markets. Appl Energy 2020;265:114804. https://doi.org/10.1016/j.apenergy.2020.114804.
[45] McKane G, , A.T., Piette MA, Faulkner D, Ghatikar. Opportunities, barriers and actions for industrial demand response in California. California; 2008.
[46] Shoreh MH, Siano P, Shafie-khah M, Loia V, Catalão JPS. A survey of industrial applications of Demand Response. Elec Power Syst Res 2016;141:31–49. https://doi.org/10.1016/j.epsr.2016.07.008.
[47] Chowdhury JI, Hu Y, Haltas I, Balta-Ozkan N, Matthew GJ, Varga L. Reducing industrial energy demand in the UK: a review of energy efficiency technologies and energy saving potential in selected sectors. Renew Sustain Energy Rev 2018;94:1153–78. https://doi.org/10.1016/j.rser.2018.06.040.
[48] Kirchem D, Lynch MÁ, Bertsch V, Casey E. Modelling demand response with process models and energy systems models: potential applications for wastewater treatment within the energy-water nexus. Appl Energy 2020;260:114321. https://doi.org/10.1016/j.apenergy.2019.114321.
[49] Chen M, Gao C, Song M, Chen S, Li D, Liu Q. Internet data centers participating in demand response: a comprehensive review. Renew Sustain Energy Rev 2020;117:109466. https://doi.org/10.1016/j.rser.2019.109466.
[50] Chen Z, Sun Y, Ai X, Malik SM, Yang L. Integrated demand response characteristics of industrial park: a review. J. Mod. Power Syst. Clean Energy Jan. 2020;8(1):15–26. https://doi.org/10.35833/MPCE.2018.000776.
[51] Shafie-khah M, Siano P, Aghaei J, Masoum MAS, Li F, Catalão JPS. Comprehensive review of the recent advances in industrial and commercial DR. IEEE Trans. Ind. Informatics Jul. 2019;15(7):3757–71. https://doi.org/10.1109/TII.2019.2909276.
[52] Kiliccote S, Olsen D, Sohn MD, Piette MA. Characterization of demand response in the commercial, industrial, and residential sectors in the United States. In: Advances in energy systems. John Wiley & Sons, Ltd; 2019. p. 425–43.
[53] Månsson T, Sasic Kalagasidis A, Ostermeyer Y. Hygro-thermal model for estimation of demand response flexibility of closed refrigerated display cabinets. Appl Energy 2021;284:116381. https://doi.org/10.1016/j.apenergy.2020.116381.
[54] Summerbell DL, Khripko D, Barlow C, Hesselbach J. Cost and carbon reductions from industrial demand-side management: study of potential savings at a cement plant. Appl Energy 2017;197:100–13. https://doi.org/10.1016/j.apenergy.2017.03.083.
[55] Bao P, Zhang W, Cheng D, Liu M. Hierarchical control of aluminum smelter loads for primary frequency support considering control cost. Int J Electr Power Energy Syst 2020;122:106202. https://doi.org/10.1016/j.ijepes.2020.106202.
[56] Paulus M, Borggrefe F. The potential of demand-side management in energy-intensive industries for electricity markets in Germany. Appl Energy 2011;88(2):432–41. https://doi.org/10.1016/j.apenergy.2010.03.017.
[57] Herre L, Tomasini F, Paridari K, Söder L, Nordström L. Simplified model of integrated paper mill for optimal bidding in energy and reserve markets. Appl Energy 2020;279:115857. https://doi.org/10.1016/j.apenergy.2020.115857.
[58] Seo K, Edgar TF, Baldea M. Optimal demand response operation of electric boosting glass furnaces. Appl Energy 2020;269:115077. https://doi.org/10.1016/j.apenergy.2020.115077.
[59] Alarfaj O, Bhattacharya K. Material flow based power demand modeling of an oil refinery process for optimal energy management. IEEE Trans Power Syst May 2019;34(3):2312–21. https://doi.org/10.1109/TPWRS.2018.2889773.
[60] Gerami N, Ghasemi A, Lotfi A, Kaigutha LG, Marzband M. Energy consumption modeling of production process for industrial factories in a day ahead scheduling with demand response. Sustain. Energy, Grids Networks 2021;25:100420. https://doi.org/10.1016/j.segan.2020.100420.
[61] Ghasemi A, Jamshidi Monfared H, Loni A, Marzband M. CVaR-based retail electricity pricing in day-ahead scheduling of microgrids. Energy 2021;227:120529. https://doi.org/10.1016/j.energy.2021.120529.
[62] Jean-Paul P, Lie T-T, Anderson TN, Vallès B. A generalized economic model for optimally selecting forecasted load profiles for measuring demand response in residential energy management system. Int J Energy Res May 2021;n/a(n/a). https://doi.org/10.1002/er.6857.
[63] Chen Y, Xu P, Gu J, Schmidt F, Li W. Measures to improve energy demand flexibility in buildings for demand response (DR): a review. Energy Build 2018;177:125–39. https://doi.org/10.1016/j.enbuild.2018.08.003.
[64] Soares A, Gomes Á, Antunes CH. Categorization of residential electricity consumption as a basis for the assessment of the impacts of demand response actions. Renew Sustain Energy Rev 2014;30:490–503. https://doi.org/10.1016/j.rser.2013.10.019.
[65] Dusparic I, Taylor A, Marinescu A, Golpayegani F, Clarke S. Residential demand response: experimental evaluation and comparison of self-organizing techniques. Renew Sustain Energy Rev 2017;80:1528–36. https://doi.org/10.1016/j.rser.2017.07.033.
[66] Pallonetto F, De Rosa M, D'Ettorre F, Finn DP. On the assessment and control optimisation of demand response programs in residential buildings. Renew Sustain Energy Rev 2020;127:109861. https://doi.org/10.1016/j.rser.2020.109861.
[67] Carmichael R, Gross R, Hanna R, Rhodes A, Green T. The Demand Response Technology Cluster: accelerating UK residential consumer engagement with time-of-use tariffs, electric vehicles and smart meters via digital comparison tools. Renew Sustain Energy Rev 2021;139:110701. https://doi.org/10.1016/j.rser.2020.110701.
[68] Davarzani S, Pisica I, Taylor GA, Munisami KJ. Residential demand response strategies and applications in active distribution network management. Renew Sustain Energy Rev 2021;138:110567. https://doi.org/10.1016/j.rser.2020.110567.
[69] Vázquez-Canteli JR, Nagy Z. Reinforcement learning for demand response: a review of algorithms and modeling techniques. Appl Energy 2019;235:1072–89. https://doi.org/10.1016/j.apenergy.2018.11.002.
[70] Kohlhepp P, Harb H, Wolisz H, Waczowicz S, Müller D, Hagenmeyer V. Large-scale grid integration of residential thermal energy storages as demand-side flexibility resource: a review of international field studies. Renew Sustain Energy Rev 2019;101:527–47. https://doi.org/10.1016/j.rser.2018.09.045.
[71] Rajendhar P, Jeyaraj BE. Application of DR and co-simulation approach for renewable integrated HEMS: a review. IET Gener Transm Distrib 2019;13(16):3501–12. https://doi.org/10.1049/iet-gtd.2018.5791.
[72] Shareef H, Ahmed MS, Mohamed A, Al Hassan E. Review on home energy management system considering demand responses, smart technologies, and intelligent controllers. IEEE Access 2018;6:24498–509. https://doi.org/10.1109/ACCESS.2018.2831917.
[73] Söder L, et al. A review of demand side flexibility potential in Northern Europe. Renew Sustain Energy Rev 2018;91:654–64. https://doi.org/10.1016/j.rser.2018.03.104.
[74] Weck MHJ, van Hooff J, W. G. J. H. M. van Sark. Review of barriers to the introduction of residential demand response: a case study in The Netherlands. Int J Energy Res 2017;41(6):790–816. https://doi.org/10.1002/er.3683.
[75] Esther BP, Kumar KS. A survey on residential Demand Side Management architecture, approaches, optimization models and methods. Renew Sustain Energy Rev 2016;59:342–51. https://doi.org/10.1016/j.rser.2015.12.282.
[76] Vasques TL, Moura P, de Almeida A. A review on energy efficiency and demand response with focus on small and medium data centers. Energy Effic. 2019;12(5):1399–428. https://doi.org/10.1007/s12053-018-9753-2.
[77] Khan AA, Razzaq S, Khan A, Khursheed F, Owais. HEMSs and enabled demand response in electricity market: an overview. Renew Sustain Energy Rev 2015;42:773–85. https://doi.org/10.1016/j.rser.2014.10.045.

[78] Muratori M, Schuelke-Leech B-A, Rizzoni G. Role of residential demand response in modern electricity markets. Renew Sustain Energy Rev 2014;33:546–53. https://doi.org/10.1016/j.rser.2014.02.027.
[79] Wang Q, Hodge B. Enhancing power system operational flexibility with flexible ramping products: a review. IEEE Trans. Ind. Informatics Aug. 2017;13(4): 1652–64. https://doi.org/10.1109/TII.2016.2637879.
[80] Vadiee A, Martin V. Energy management in horticultural applications through the closed greenhouse concept, state of the art. Renew Sustain Energy Rev 2012;16 (7):5087–100. https://doi.org/10.1016/j.rser.2012.04.022.
[81] Gyamfi S, Krumdieck S, Urmee T. Residential peak electricity demand response—highlights of some behavioural issues. Renew Sustain Energy Rev 2013;25:71–7. https://doi.org/10.1016/j.rser.2013.04.006.
[82] Skoulou V, Mariolis N, Zanakis G, Zabaniotou A. Sustainable management of energy crops for integrated biofuels and green energy production in Greece. Renew Sustain Energy Rev 2011;15(4):1928. https://doi.org/10.1016/j.rser.2010.12.019. 1936.
[83] Söyrinki S, Heiskanen E, Matschoss K. Piloting demand response in retailing: lessons learned in real-life context. Sustainability 2018;10:10. https://doi.org/10.3390/su10103790.
[84] Kelly G. Sustainability at home: policy measures for energy-efficient appliances. Renew Sustain Energy Rev 2012;16(9):6851–60. https://doi.org/10.1016/j.rser.2012.08.003.
[85] Zhou K, Yang S. Demand side management in China: the context of China's power industry reform. Renew Sustain Energy Rev 2015;47:954–65. https://doi.org/10.1016/j.rser.2015.03.036.
[86] Samad T, Koch E, Stluka P. Automated demand response for smart buildings and microgrids: the state of the practice and research challenges. Proc IEEE Apr. 2016; 104(4):726–44. https://doi.org/10.1109/JPROC.2016.2520639.
[87] Maes T, et al. Energy management on industrial parks in Flanders. Renew Sustain Energy Rev 2011;15(4):1988–2005. https://doi.org/10.1016/j.rser.2010.11.053.
[88] Olsen A, Daniel, Goli Sasank, Faulkner David, McKane. Opportunities for energy efficiency and demand response in the California cement industry. The US: California; 2010.
[89] Hossain SR, Ahmed I, Azad FS, Monjurul Hasan ASM. Empirical investigation of energy management practices in cement industries of Bangladesh. Energy 2020; 212:118741. https://doi.org/10.1016/j.energy.2020.118741.
[90] Ghalandari V, Majd MM, Golestanian A. Energy audit for pyro-processing unit of a new generation cement plant and feasibility study for recovering waste heat: a case study. Energy 2019;173:833–43. https://doi.org/10.1016/j.energy.2019.02.102.
[91] Mirhosseini M, Rezania A, Rosendahl L. Harvesting waste heat from cement kiln shell by thermoelectric system. Energy 2019;168:358–69. https://doi.org/10.1016/j.energy.2018.11.109.
[92] Fellaou S, Bounahmidi T. Analyzing thermodynamic improvement potential of a selected cement manufacturing process: advanced exergy analysis. Energy 2018; 154:190–200. https://doi.org/10.1016/j.energy.2018.04.121.
[93] Finch AC. A cement plant's experience in investigating power sags leads to a reduction in kiln outages by utilizing power hardening methods. IEEE Trans Ind Appl 2016;52(5):4435–41. https://doi.org/10.1109/TIA.2016.2570203.
[94] Ahrens M, Gonser J. Technical and commercial benefits of gearless mill drives for grinding applications. In: SME annual meeting; 2007.
[95] Worrell C. Ernst; galitsky, "energy efficiency improvement and cost saving opportunities for cement making. The US: " California; 2008.
[96] Mokhtar A, Nasooti M. A decision support tool for cement industry to select energy efficiency measures. Energy Strateg. Rev. 2020;28:100458. https://doi.org/10.1016/j.esr.2020.100458.
[97] Jamali DH, Noorpoor A. Optimization of a novel solar-based multi-generation system for waste heat recovery in a cement plant. J Clean Prod 2019;240:117825. https://doi.org/10.1016/j.jclepro.2019.117825.
[98] Yao M, Hu Z, Sifuentes F, Zhang N. Integrated power management of conventional units and industrial loads in China's ancillary services scheduling. Energies 2015;8(5). https://doi.org/10.3390/en8053955.
[99] Cadavid-Giraldo N, Velez-Gallego MC, Restrepo-Boland A. Carbon emissions reduction and financial effects of a cap and tax system on an operating supply chain in the cement sector. J Clean Prod 2020;275:122583. https://doi.org/10.1016/j.jclepro.2020.122583.
[100] Zhang X, Hug G, Kolter JZ, Harjunkoski I. Demand response of ancillary service from industrial loads coordinated with energy storage. IEEE Trans Power Syst Jan. 2018;33(1):951–61. https://doi.org/10.1109/TPWRS.2017.2704524.
[101] Wilson J, Iten HC. Optimizing energy utilization in cement plant operations. IEEE Trans Ind Appl 1976;IA-12(5):529–35. https://doi.org/10.1109/TIA.1976.349466.
[102] Xenos DP, Mohd Noor I, Matloubi M, Cicciotti M, Haugen T, Thornhill NF. Demand-side management and optimal operation of industrial electricity consumers: an example of an energy-intensive chemical plant. Appl Energy 2016; 182:418–33. https://doi.org/10.1016/j.apenergy.2016.08.084.
[103] Nilsson TR, Sinner B, V Volden O. Optimized production and energy conservation. IEEE Trans Ind Appl May 1986;IA-22(3):442–6. https://doi.org/10.1109/TIA.1986.4504740.
[104] Worrell E, Martin N, Price L. Potentials for energy efficiency improvement in the US cement industry. Energy 2000;25(12):1189–214. https://doi.org/10.1016/S0360-5442(00)00042-6.
[105] Hasanbeigi A, Price L, Lu H, Lan W. Analysis of energy-efficiency opportunities for the cement industry in Shandong Province, China: a case study of 16 cement plants. Energy 2010;35(8):3461–73. https://doi.org/10.1016/j.energy.2010.04.046.
[106] Zarif M, Javidi MH, Ghazizadeh MS. Self-scheduling approach for large consumers in competitive electricity markets based on a probabilistic fuzzy system. IET Gener Transm Distrib Jan. 2012;6(1):50–8. https://doi.org/10.1049/iet-gtd.2011.0308.
[107] Zarif M, Javidi MH, Ghazizadeh MS. Self-scheduling of large consumers with second-order stochastic dominance constraints. IEEE Trans Power Syst Feb. 2013; 28(1):289–99. https://doi.org/10.1109/TPWRS.2012.2197831.
[108] Xu FY, Lai LL. Novel active time-based demand response for industrial consumers in smart grid. IEEE Trans. Ind. Informatics Dec. 2015;11(6):1564–73. https://doi.org/10.1109/TII.2015.2446759.
[109] Barreiro A, Ferreira J, Abreu C, Blanck M. Energy management for rational electricity use-reducing cost and consumption at SECIL's Outao cement plant/Portugal. IEEE Trans Ind Appl May 1991;27(3):398–405. https://doi.org/10.1109/28.81819.
[110] Kermeli K, et al. The scope for better industry representation in long-term energy models: modeling the cement industry. Appl Energy 2019;240:964–85. https://doi.org/10.1016/j.apenergy.2019.01.252.
[111] Tesema G, Worrell E. Energy efficiency improvement potentials for the cement industry in Ethiopia. Energy 2015;93:2042–52. https://doi.org/10.1016/j.energy.2015.10.057.
[112] Atmaca A, Kanoglu M. Reducing energy consumption of a raw mill in cement industry. Energy 2012;42(1):261–9. https://doi.org/10.1016/j.energy.2012.03.060.
[113] Huang Y-H, Chang Y-L, Fleiter T. A critical analysis of energy efficiency improvement potentials in Taiwan's cement industry. Energy Pol 2016;96:14–26. https://doi.org/10.1016/j.enpol.2016.05.025.
[114] Hasanbeigi A, Menke C, Therdyothin A. The use of conservation supply curves in energy policy and economic analysis: the case study of Thai cement industry. Energy Pol 2010;38(1):392–405. https://doi.org/10.1016/j.enpol.2009.09.030.
[115] Tabereaux AT, Peterson RD, S. B. T.-T. on. Chapter 2.5 - aluminum production. In: Seetharaman PM, editor. Boston. Elsevier; 2014. p. 839–917.
[116] Taleghani ST, Sorin M, Gaboury S. Thermo-economic analysis of heat-driven ejector system for cooling smelting process exhaust gas. Energy 2021;220: 119661. https://doi.org/10.1016/j.energy.2020.119661.
[117] Zhang X, Hug G. Bidding strategy in energy and spinning reserve markets for aluminum smelters' demand response. In: In 2015 IEEE power & energy society innovative smart grid technologies conference. ISGT); 2015. p. 1–5. https://doi.org/10.1109/ISGT.2015.7131854.
[118] Chen R, Wang J, Sun H. Clearing and pricing for coordinated gas and electricity day-ahead markets considering wind power uncertainty. IEEE Trans Power Syst 2018;33(3):2496–508. https://doi.org/10.1109/TPWRS.2017.2756984.
[119] Nguyen HT, Le LB, Wang Z. A bidding strategy for virtual power plants with the intraday demand response exchange market using the stochastic programming. IEEE Trans Ind Appl 2018;54(4):3044–55. https://doi.org/10.1109/TIA.2018.2828379.
[120] Jiang H, Lin J, Song Y, Li X, Dong J. Frequency control by aluminum smelter load response in an isolated wind power system: a study for an industrial case. In: *2013* IEEE power & energy society general meeting; 2013. p. 1–5. https://doi.org/10.1109/PESMG.2013.6672664.
[121] Jiang H, et al. Demand side frequency control scheme in an isolated wind power system for industrial aluminum smelting production. In: 2014 IEEE PES general meeting | conference & exposition; 2014. p. 1. https://doi.org/10.1109/PESGM.2014.6939145.
[122] Alharbi H, Bhattacharya K. Participation of pumped hydro storage in energy and performance-based regulation markets. IEEE Trans Power Syst 2020;35(6): 4307–23. https://doi.org/10.1109/TPWRS.2020.2998490.
[123] Du Y, Li F. A hierarchical real-time balancing market considering multi-microgrids with distributed sustainable resources. IEEE Trans. Sustain. Energy 2020;11(1):72–83. https://doi.org/10.1109/TSTE.2018.2884223.
[124] Zhang Y, Li W, Yang J, Chai D, Qiu S, Li J. In: Suarez CE, editor. A techno-economic optimization model for aluminium electrolysis production BT - light metals 2012. Cham: Springer International Publishing; 2016. p. 709–14.
[125] Haraldsson J, Johansson MT. Review of measures for improved energy efficiency in production-related processes in the aluminium industry – from electrolysis to recycling. Renew Sustain Energy Rev 2018;93:525–48. https://doi.org/10.1016/j.rser.2018.05.043.
[126] Royo P, Ferreira VJ, López-Sabirón AM, García-Armingol T, Ferreira G. Retrofitting strategies for improving the energy and environmental efficiency in industrial furnaces: a case study in the aluminium sector. Renew Sustain Energy Rev 2018;82:1813–22. https://doi.org/10.1016/j.rser.2017.06.113.
[127] Bogdanov D, Gulagi A, Fasihi M, Breyer C. Full energy sector transition towards 100% renewable energy supply: integrating power, heat, transport and industry sectors including desalination. Appl Energy 2021;283:116273. https://doi.org/10.1016/j.apenergy.2020.116273.
[128] Gong F, et al. Review of electrolytic aluminum load participating in demand response to absorb new energy potential and methods. In: 2021 IEEE 2nd international Conference on big data, artificial Intelligence and Internet of things engineering. ICBAIE); 2021. p. 1015–9. https://doi.org/10.1109/ICBAIE52039.2021.9389999.
[129] Samad T, Kiliccote S. Smart grid technologies and applications for the industrial sector. Comput Chem Eng 2012;47:76–84. https://doi.org/10.1016/j.compchemeng.2012.07.006.
[130] Lucio NR, Lamas W de Q, de Camargo JR. Strategic energy management in the primary aluminium industry: self-generation as a competitive factor. Energy Pol 2013;59:182–8. https://doi.org/10.1016/j.enpol.2013.03.021.

[131] Xu J, et al. An isolated industrial power system driven by wind-coal power for aluminum productions: a case study of frequency control. IEEE Trans Power Syst 2015;30(1):471–83. https://doi.org/10.1109/TPWRS.2014.2322080.
[132] Jiang H, Lin J, Song Y, Hill DJ. MPC-based frequency control with demand-side participation: a case study in an isolated wind-aluminum power system. IEEE Trans Power Syst 2015;30(6):3327–37. https://doi.org/10.1109/TPWRS.2014.2375918.
[133] Hao H, Geng Y, Hang W. GHG emissions from primary aluminum production in China: regional disparity and policy implications. Appl Energy 2016;166:264–72. https://doi.org/10.1016/j.apenergy.2015.05.056.
[134] Liu M, et al. Electro-thermodynamics modeling of aluminum smelter load based on direct load control. In: 2020 IEEE/IAS Industrial and commercial power system Asia. I&CPS Asia); 2020. p. 1448–52. https://doi.org/10.1109/ICPSAsia48933.2020.9208620.
[135] Wang RQ, Jiang L, Wang YD, Roskilly AP. Energy saving technologies and mass-thermal network optimization for decarbonized iron and steel industry: a review. J Clean Prod 2020;274:122997. https://doi.org/10.1016/j.jclepro.2020.122997.
[136] Albaugh JR, Kornblit MJ. Updating a steel mill power system to improve reliability and decrease energy costs. IEEE Trans Ind Appl 1994;30(5):1317–20. https://doi.org/10.1109/28.315245.
[137] Hayajawam N, Wakazono Y, Kato T, Suzuoki Y, Kaya Y. Minimizing energy consumption in industries by cascade use of waste energy. IEEE Trans Energy Convers 1999;14(3):795–801. https://doi.org/10.1109/60.790953.
[138] Todd D, Caufield M, Helms B, Starke MR, Kirby BJ, Kueck JD. Providing reliability services through demand response: a preliminary evaluation of the demand response capabilities of alcoa inc. Jan. 2009.
[139] Blomberg J, Söderholm P. Factor demand flexibility in the primary aluminium industry: evidence from stagnating and expanding regions. Resour Pol 2011;36(3):238–48. https://doi.org/10.1016/j.resourpol.2011.03.002.
[140] Castro PM, Sun L, Harjunkoski I. Resource–task network formulations for industrial demand side management of a steel plant. Ind Eng Chem Res Sep. 2013;52(36):13046–58. https://doi.org/10.1021/ie401044q.
[141] Xu T, Karali N, Sathaye J. Undertaking high impact strategies: the role of national efficiency measures in long-term energy and emission reduction in steel making. Appl Energy 2014;122:179–88. https://doi.org/10.1016/j.apenergy.2014.01.094.
[142] Gholian A, Mohsenian-Rad H, Hua Y. Optimal industrial load control in smart grid. IEEE Trans. Smart Grid 2016;7(5):2305–16. https://doi.org/10.1109/TSG.2015.2468577.
[143] Zhao R, Nowicki C, Gosselin L, Duchesne C. Energy and exergy inventory in aluminum smelter from a thermal integration point-of-view. Int J Energy Res Aug. 2016;40(10):1321–38. https://doi.org/10.1002/er.3508.
[144] Zhang X, Hug G, Harjunkoski I. Cost-Effective scheduling of steel plants with flexible EAFs. IEEE Trans. Smart Grid 2017;8(1):239–49. https://doi.org/10.1109/TSG.2016.2575000.
[145] Ramin D, Spinelli S, Brusaferri A. Demand-side management via optimal production scheduling in power-intensive industries: the case of metal casting process. Appl Energy 2018;225:622–36. https://doi.org/10.1016/j.apenergy.2018.03.084.
[146] Dranka GG, Ferreira P. Load flexibility potential across residential, commercial and industrial sectors in Brazil. Energy 2020;201:117483. https://doi.org/10.1016/j.energy.2020.117483.
[147] Shen X, Chen L, Xia S, Xie Z, Qin X. Burdening proportion and new energy-saving technologies analysis and optimization for iron and steel production system. J Clean Prod 2018;172:2153–66. https://doi.org/10.1016/j.jclepro.2017.11.204.
[148] Kong H, Qi E, Li H, Li G, Zhang X. An MILP model for optimization of byproduct gases in the integrated iron and steel plant. Appl Energy 2010;87(7):2156–63. https://doi.org/10.1016/j.apenergy.2009.11.031.
[149] Zhang Q, Wei Z, Ma J, Qiu Z, Du T. Optimization of energy use with CO2 emission reducing in an integrated iron and steel plant. Appl Therm Eng 2019;157:113635. https://doi.org/10.1016/j.applthermaleng.2019.04.045.
[150] Zhao X, Bai H, Shi Q, Lu X, Zhang Z. Optimal scheduling of a byproduct gas system in a steel plant considering time-of-use electricity pricing. Appl Energy 2017;195:100–13. https://doi.org/10.1016/j.apenergy.2017.03.037.
[151] Liu C, Xie Z, Sun F, Chen L. Exergy analysis and optimization of coking process. Energy 2017;139:694–705. https://doi.org/10.1016/j.energy.2017.08.006.
[152] Xiong B, Chen L, Meng F, Sun F. Modeling and performance analysis of a two-stage thermoelectric energy harvesting system from blast furnace slag water waste heat. Energy 2014;77:562–9. https://doi.org/10.1016/j.energy.2014.09.037.
[153] Meng F, Chen L, Sun F, Yang B. Thermoelectric power generation driven by blast furnace slag flushing water. Energy 2014;66:965–72. https://doi.org/10.1016/j.energy.2014.02.018.
[154] Chen L, Yang B, Shen X, Xie Z, Sun F. Thermodynamic optimization opportunities for the recovery and utilization of residual energy and heat in China's iron and steel industry: a case study. Appl Therm Eng 2015;86:151–60. https://doi.org/10.1016/j.applthermaleng.2015.04.026.
[155] Zhang Z, Chen L, Yang B, Ge Y, Sun F. Thermodynamic analysis and optimization of an air Brayton cycle for recovering waste heat of blast furnace slag. Appl Therm Eng 2015;90:742–8. https://doi.org/10.1016/j.applthermaleng.2015.07.057.
[156] Liu C, Xie Z, Sun F, Chen L. Optimization for sintering proportioning based on energy value. Appl Therm Eng 2016;103:1087–94. https://doi.org/10.1016/j.applthermaleng.2016.04.158.
[157] Rossi M, Comodi G, Piacente N, Renzi M. Energy recovery in oil refineries by means of a Hydraulic Power Recovery Turbine (HPRT) handling viscous liquids. Appl Energy 2020;270:115097. https://doi.org/10.1016/j.apenergy.2020.115097.
[158] Nezhadfard M, Khalili-Garakani A. Power generation as a useful option for flare gas recovery: enviro-economic evaluation of different scenarios. Energy 2020;204:117940. https://doi.org/10.1016/j.energy.2020.117940.
[159] Aminmahalati A, Fazlali A, Safikhani H. Multi-objective optimization of CO boiler combustion chamber in the RFCC unit using NSGA II algorithm. Energy 2021;221:119859. https://doi.org/10.1016/j.energy.2021.119859.
[160] Parkash S, S. B. T.-R. P. H. Parkash. Chapter one - refinery distillation. In: Burlington. Gulf Professional Publishing; 2003. p. 1–28.
[161] Ashok S, Banerjee R. Optimal operation of industrial cogeneration for load management. IEEE Trans Power Syst May 2003;18(2):931–7. https://doi.org/10.1109/TPWRS.2003.811169.
[162] Gholian A, Mohsenian-Rad H, Hua Yingbo, Qin Joe. Optimal industrial load control in smart grid: a case study for oil refineries. In: 2013 IEEE power energy society general meeting; Jul. 2013. p. 1–5. https://doi.org/10.1109/PESMG.2013.6672710.
[163] Golmohamadi H, Asadi A. Integration of joint power-heat flexibility of oil refinery industries to uncertain energy markets. Energies 2020;13:18. https://doi.org/10.3390/en13184874.
[164] Johansson D, Franck P-Å, Berntsson T. CO2 capture in oil refineries: assessment of the capture avoidance costs associated with different heat supply options in a future energy market. Energy Convers Manag 2013;66:127–42. https://doi.org/10.1016/j.enconman.2012.09.026.
[165] Comodi G, Renzi M, Rossi M. Energy efficiency improvement in oil refineries through flare gas recovery technique to meet the emission trading targets. Energy 2016;109:1–12. https://doi.org/10.1016/j.energy.2016.04.080.
[166] Sharaf Eldean MA, Soliman AM. A novel study of using oil refinery plants waste gases for thermal desalination and electric power generation: energy, exergy & cost evaluations. Appl Energy 2017;195:453–77. https://doi.org/10.1016/j.apenergy.2017.03.052.
[167] Renzi M, Rudolf P, Štefan D, Nigro A, Rossi M. Installation of an axial Pump-as-Turbine (PaT) in a wastewater sewer of an oil refinery: a case study. Appl Energy 2019;250:665–76. https://doi.org/10.1016/j.apenergy.2019.05.052.
[168] Berghout N, Meerman H, van den Broek M, Faaij A. Assessing deployment pathways for greenhouse gas emissions reductions in an industrial plant – a case study for a complex oil refinery. Appl Energy 2019;236:354–78. https://doi.org/10.1016/j.apenergy.2018.11.074.
[169] Sadeghi S, Ghandehariun S, Rosen MA. Comparative economic and life cycle assessment of solar-based hydrogen production for oil and gas industries. Energy 2020;208:118347. https://doi.org/10.1016/j.energy.2020.118347.
[170] Tahmasebzadehbaie M, Sayyaadi H. Regional management of flare gas recovery based on water-energy-environment nexus considering the reliability of the downstream installations. Energy Convers Manag 2021;239:114189. https://doi.org/10.1016/j.enconman.2021.114189.
[171] Madlool NA, Saidur R, Rahim NA, Kamalisarvestani M. An overview of energy savings measures for cement industries. Renew Sustain Energy Rev 2013;19:18–29. https://doi.org/10.1016/j.rser.2012.10.046.
[172] Kramer EW, Jan Klaas, Masanet Eric R, Xu Tengfang T. Energy efficiency improvement and cost saving opportunities for the pulp and paper industry. 2009.
[173] Worrell C. ErnstGalitsky, "Energy efficiency improvement and cost saving opportunities for petroleum refineries,". 2005.
[174] Eid C, Koliou E, Valles M, Reneses J, Hakvoort R. Time-based pricing and electricity demand response: existing barriers and next steps. Util Pol 2016;40:15–25. https://doi.org/10.1016/j.jup.2016.04.001.
[175] Roesch M, et al. Harnessing the full potential of industrial demand-side flexibility: an end-to-end approach connecting machines with markets through service-oriented IT platforms. Appl Sci 2019;9:18. https://doi.org/10.3390/app9183796.
[176] Emir T, Güler MG, Environmental Dimensions. In: Dincer I, Colpan CO, Kizilkan Energetic OBT-E, editors. Chapter 1.9 - production planning using day-ahead prices in a cement plant. Academic Press; 2018. p. 149–66.
[177] Yao M, Hu Z, Zhang N, Duan W, Zhang J. Low-carbon benefits analysis of energy-intensive industrial demand response resources for ancillary services. J. Mod. Power Syst. Clean Energy 2015;3(1):131–8. https://doi.org/10.1007/s40565-015-0102-6.
[178] Nelson JR, Johnson NG. Model predictive control of microgrids for real-time ancillary service market participation. Appl Energy 2020;269:114963. https://doi.org/10.1016/j.apenergy.2020.114963.
[179] Conejo AJ, Carrión M, Morales JM. Pool trading for wind power producers BT - decision making under uncertainty in electricity markets. In: Conejo AJ, Carrión M, Morales JM, editors. Boston, MA. Springer US; 2010. p. 195–251.
[180] Suomalainen K, Pritchard G, Sharp B, Yuan Z, Zakeri G. Correlation analysis on wind and hydro resources with electricity demand and prices in New Zealand. Appl Energy 2015;137:445–62. https://doi.org/10.1016/j.apenergy.2014.10.015.
[181] Lu R, Bai R, Huang Y, Li Y, Jiang J, Ding Y. Data-driven real-time price-based demand response for industrial facilities energy management. Appl Energy 2021;283:116291. https://doi.org/10.1016/j.apenergy.2020.116291.
[182] Zhou H, Chen B, Han ZX, Zhang FQ. Study on economic withholding in electricity market of Zhejiang Province, China. Commun Nonlinear Sci Numer Simulat 2009;14(5):2495–501. https://doi.org/10.1016/j.cnsns.2008.05.016.
[183] Chai Y, Xiang Y, Liu J, Gu C, Zhang W, Xu W. Incentive-based demand response model for maximizing benefits of electricity retailers. J. Mod. Power Syst. Clean Energy 2019;7(6):1644–50. https://doi.org/10.1007/s40565-019-0504-y.

[184] Stede J, Arnold K, Dufter C, Holtz G, von Roon S, Richstein JC. The role of aggregators in facilitating industrial demand response: evidence from Germany. Energy Pol 2020;147:111893. https://doi.org/10.1016/j.enpol.2020.111893.
[185] Ponds KT, Arefi A, Sayigh A, Ledwich G. Aggregator of demand response for renewable integration and customer engagement: strengths, weaknesses, opportunities, and threats. Energies 2018;11(9). https://doi.org/10.3390/en11092391.
[186] Mohagheghi S, Raji N. Dynamic demand response solution for industrial customers. In: In *2013* IEEE industry applications society annual meeting; 2013. p. 1–9. https://doi.org/10.1109/IAS.2013.6682583.
[187] Babar M, et al. A secured data management scheme for smart societies in industrial internet of things environment. IEEE Access 2018;6:43088–99. https://doi.org/10.1109/ACCESS.2018.2861421.
[188] Zhang X. Big data analytics in smart grids: state-of-the-art, challenges, opportunities, and future directions. 13 IET Smart Grid Jun. 2019;2(2):141–54 [Online]. Available: https://digital-library.theiet.org/content/journals/10.1049/iet-stg.2018.0261.
[189] Salla Annala SH. Satu viljainen, jussi tuunanen, "does knowledge contribute to the acceptance of demand response? J. Sustain. Dev. Energy, Water Environ. Syst. 2014;2(1):51–60.
[190] Voulis N, van Etten MJJ, Chappin ÉJL, Warnier M, Brazier FMT. Rethinking European energy taxation to incentivise consumer demand response participation. Energy Pol 2019;124:156–68. https://doi.org/10.1016/j.enpol.2018.09.018.
[191] Lin B, Jia Z. Supply control vs. demand control: why is resource tax more effective than carbon tax in reducing emissions? Humanit. Soc. Sci. Commun. 2020;7(1):74. https://doi.org/10.1057/s41599-020-00569-w.
[192] Golmohamadi H, Keypour R, Mirzazade P. Multi-objective co-optimization of power and heat in urban areas considering local air pollution. Eng. Sci. Technol. an Int. J. 2020. https://doi.org/10.1016/j.jestch.2020.08.004.
[193] Bao Y, et al. Provision of secondary frequency regulation by coordinated dispatch of industrial loads and thermal power plants. Appl Energy 2019;241:302–12. https://doi.org/10.1016/j.apenergy.2019.03.025.
[194] Verzijlbergh RA, De Vries LJ, Dijkema GPJ, Herder PM. Institutional challenges caused by the integration of renewable energy sources in the European electricity sector. Renew Sustain Energy Rev 2017;75:660–7. https://doi.org/10.1016/j.rser.2016.11.039.
[195] Henni S, Staudt P, Kandiah B, Weinhardt C. Infrastructural coupling of the electricity and gas distribution grid to reduce renewable energy curtailment. Appl Energy 2021;288:116597. https://doi.org/10.1016/j.apenergy.2021.116597.
[196] Maharjan S, Sampath Kumar D, Khambadkone AM. Enhancing the voltage stability of distribution network during PV ramping conditions with variable speed drive loads. Appl Energy 2020;264:114733. https://doi.org/10.1016/j.apenergy.2020.114733.
[197] Yu M, Hong SH, Ding Y, Ye X. An incentive-based demand response (DR) model considering composited DR resources. IEEE Trans Ind Electron 2019;66(2):1488–98. https://doi.org/10.1109/TIE.2018.2826454.
[198] Asadinejad A, Tomsovic K. Optimal use of incentive and price based demand response to reduce costs and price volatility. Elec Power Syst Res 2017;144:215–23. https://doi.org/10.1016/j.epsr.2016.12.012.
[199] Bagdadee AH, Zhang L. Power quality impact on the industrial sector: a case study of Bangladesh. J. Electr. Eng. Technol. 2019;14(5):1841–57. https://doi.org/10.1007/s42835-019-00220-y.
[200] Heffron R, Körner M-F, Wagner J, Weibelzahl M, Fridgen G. Industrial demand-side flexibility: a key element of a just energy transition and industrial development. Appl Energy 2020;269:115026. https://doi.org/10.1016/j.apenergy.2020.115026.
[201] Sharifi R, Anvari-Moghaddam A, Fathi SH, Vahidinasab V. A flexible responsive load economic model for industrial demands. Processes 2019;7:3. https://doi.org/10.3390/pr7030147.
[202] Valdes J, Poque González AB, Ramirez Camargo L, Valin Fenández M, Masip Macia Y, Dorner W. Industry, flexibility, and demand response: applying German energy transition lessons in Chile. Energy Res. Soc. Sci. 2019;54:12–25. https://doi.org/10.1016/j.erss.2019.03.003.
[203] Darby SJ. Demand response and smart technology in theory and practice: customer experiences and system actors. Energy Pol 2020;143:111573. https://doi.org/10.1016/j.enpol.2020.111573.
[204] Schulz J, Popp RS-H, Scharmer VM, Zaeh MF. An IoT based approach for energy flexible control of production systems. Procedia CIRP 2018;69:650–5. https://doi.org/10.1016/j.procir.2017.11.097.
[205] Hossein Motlagh N, Mohammadrezaei M, Hunt J, Zakeri B. Internet of things (IoT) and the energy sector. Energies 2020;13(2). https://doi.org/10.3390/en13020494.
[206] Rowley P, Walker C. Adapt or perish: a new approach for industry needs-driven master's level low-carbon energy engineering education in the UK. Energies 2020;13(9). https://doi.org/10.3390/en13092246.
[207] Goulden M, Spence A, Wardman J, Leygue C. Differentiating 'the user' in DSR: developing demand side response in advanced economies. Energy Pol 2018;122:176–85. https://doi.org/10.1016/j.enpol.2018.07.013.
[208] Hájek M, Zimmermannová J, Helman K, Rozenský L. Analysis of carbon tax efficiency in energy industries of selected EU countries. Energy Pol 2019;134:110955. https://doi.org/10.1016/j.enpol.2019.110955.
[209] Mlecnik E, Parker J, Ma Z, Corchero C, Knotzer A, Pernetti R. Policy challenges for the development of energy flexibility services. Energy Pol 2020;137:111147. https://doi.org/10.1016/j.enpol.2019.111147.
[210] Albertsen LH, Andersen M, Boscán LR, Santos AQ. Implementing dynamic electricity taxation in Denmark. Energy Pol 2020;143:111543. https://doi.org/10.1016/j.enpol.2020.111543.
[211] Liobikienė G, Butkus M. Determinants of greenhouse gas emissions: a new multiplicative approach analysing the impact of energy efficiency, renewable energy, and sector mix. J Clean Prod 2021;309:127233. https://doi.org/10.1016/j.jclepro.2021.127233.
[212] Sovacool BK, Griffiths S, Kim J, Bazilian M. Climate change and industrial F-gases: a critical and systematic review of developments, sociotechnical systems and policy options for reducing synthetic greenhouse gas emissions. Renew Sustain Energy Rev 2021;141:110759. https://doi.org/10.1016/j.rser.2021.110759.
[213] Ouyang X, Fang X, Cao Y, Sun C. Factors behind CO2 emission reduction in Chinese heavy industries: do environmental regulations matter? Energy Pol 2020;145:111765. https://doi.org/10.1016/j.enpol.2020.111765.
[214] Lockwood M, Mitchell C, Hoggett R. Incumbent lobbying as a barrier to forward-looking regulation: the case of demand-side response in the GB capacity market for electricity. Energy Pol 2020;140:111426. https://doi.org/10.1016/j.enpol.2020.111426.
[215] Wohlfarth K, Worrell E, Eichhammer W. Energy efficiency and demand response – two sides of the same coin? Energy Pol 2020;137:111070. https://doi.org/10.1016/j.enpol.2019.111070.
[216] Zhang Y, Xiong Y, Li F, Cheng J, Yue X. Environmental regulation, capital output and energy efficiency in China: an empirical research based on integrated energy prices. Energy Pol 2020;146:111826. https://doi.org/10.1016/j.enpol.2020.111826.
[217] Otashu JI, Baldea M. Scheduling chemical processes for frequency regulation. Appl Energy 2020;260:114125. https://doi.org/10.1016/j.apenergy.2019.114125.
[218] Fu Y, Han X, Baker K, Zuo W. Assessments of data centers for provision of frequency regulation. Appl Energy 2020;277:115621. https://doi.org/10.1016/j.apenergy.2020.115621.
[219] Alaperä I, Honkapuro S, Paananen J. Data centers as a source of dynamic flexibility in smart girds. Appl Energy 2018;229:69–79. https://doi.org/10.1016/j.apenergy.2018.07.056.
[220] Ali SMH, Lenzen M, Sack F, Yousefzadeh M. Electricity generation and demand flexibility in wastewater treatment plants: benefits for 100% renewable electricity grids. Appl Energy 2020;268:114960. https://doi.org/10.1016/j.apenergy.2020.114960.
[221] Tsiligiannis A, Tsiliyannis C. Renewable energy in cement manufacturing: a quantitative assessment of energy and environmental efficiency of food residue biofuels. Renew Sustain Energy Rev 2019;107:568–86. https://doi.org/10.1016/j.rser.2019.03.009.
[222] Sgobba A, Meskell C. On-site renewable electricity production and self consumption for manufacturing industry in Ireland: sensitivity to techno-economic conditions. J Clean Prod 2019;207:894–907. https://doi.org/10.1016/j.jclepro.2018.09.260.
[223] Yue H, Worrell E, Crijns-Graus W. Modeling the multiple benefits of electricity savings for emissions reduction on power grid level: a case study of China's chemical industry. Appl Energy 2018;230:1603–32. https://doi.org/10.1016/j.apenergy.2018.09.078.
[224] Ren L, Zhou S, Peng T, Ou X. A review of CO2 emissions reduction technologies and low-carbon development in the iron and steel industry focusing on China. Renew Sustain Energy Rev 2021;143:110846. https://doi.org/10.1016/j.rser.2021.110846.
[225] Steinberg E, Daniel, Bielen Dave, Eichman Josh, Eurek Kelly, Logan Jeff, Mai Trieu, McMillan Colin, Parker Andrew, Vimmerstedt Laura, Wilson. Electrification and decarbonization: exploring U.S. Energy use and greenhouse gas emissions in scenarios with widespread electrification and power sector decarbonization. 2017. United States.
[226] Chapaloglou S, et al. Smart energy management algorithm for load smoothing and peak shaving based on load forecasting of an island's power system. Appl Energy 2019;238:627–42. https://doi.org/10.1016/j.apenergy.2019.01.102.
[227] Barsali S, Ciambellotti A, Giglioli R, Paganucci F, Pasini G. Hybrid power plant for energy storage and peak shaving by liquefied oxygen and natural gas. Appl Energy 2018;228:33–41. https://doi.org/10.1016/j.apenergy.2018.06.042.
[228] Åberg M, Lingfors D, Olauson J, Widén J. Can electricity market prices control power-to-heat production for peak shaving of renewable power generation? The case of Sweden. Energy 2019;176:1–14. https://doi.org/10.1016/j.energy.2019.03.156.
[229] van Blijswijk MJ, de Vries LJ. Evaluating congestion management in the Dutch electricity transmission grid. Energy Pol 2012;51:916–26. https://doi.org/10.1016/j.enpol.2012.09.051.
[230] Liu C, Hung K, Galicia ME, Lin S. Systematic integration guidance for alleviating substation congestion of steel mill power systems by distributed generation units. IEEE Trans Ind Appl 2014;50(5):3113–9. https://doi.org/10.1109/TIA.2014.2308361.
[231] Wang L, Hanna MA, Weller CL, Jones DD. Technical and economical analyses of combined heat and power generation from distillers grains and corn stover in ethanol plants. Energy Convers Manag 2009;50(7):1704–13. https://doi.org/10.1016/j.enconman.2009.03.025.
[232] Valdes J, Poque González AB, Masip Macia Y, Dorner W, Ramirez Camargo L. Unveiling the potential for combined heat and power in Chilean industry - a policy perspective. Energy Pol 2020;140:111331. https://doi.org/10.1016/j.enpol.2020.111331.

[233] Azhdari A, Ghadamian H, Ataei A, Yoo CK. A new approach for optimization of combined heat and power generation in edible oil plants. J Appl Sci 2009;9(21):3813–20. https://doi.org/10.3923/jas.2009.3813.3820.
[234] Mohandes B, El Moursi MS, Hatziargyriou ND, El Khatib S. Incentive based demand response program for power system flexibility enhancement. IEEE Trans. Smart Grid 2021;12(3):2212–23. https://doi.org/10.1109/TSG.2020.3042847.
[235] Molavi A, Lim GJ, Shi J. Stimulating sustainable energy at maritime ports by hybrid economic incentives: a bilevel optimization approach. Appl Energy 2020;272:115188. https://doi.org/10.1016/j.apenergy.2020.115188.
[236] Gu H, Li Y, Yu J, Wu C, Song T, Xu J. Bi-level optimal low-carbon economic dispatch for an industrial park with consideration of multi-energy price incentives. Appl Energy 2020;262:114276. https://doi.org/10.1016/j.apenergy.2019.114276.
[237] Richstein JC, Hosseinioun SS. Industrial demand response: how network tariffs and regulation (do not) impact flexibility provision in electricity markets and reserves. Appl Energy 2020;278:115431. https://doi.org/10.1016/j.apenergy.2020.115431.
[238] Serrano González J, Álvarez Alonso C. Industrial electricity prices in Spain: a discussion in the context of the European internal energy market. Energy Pol 2021;148:111930. https://doi.org/10.1016/j.enpol.2020.111930.
[239] Valdes J, Masip Macia Y, Dorner W, Ramirez Camargo L. Unsupervised grouping of industrial electricity demand profiles: synthetic profiles for demand-side management applications. Energy 2021;215:118962. https://doi.org/10.1016/j.energy.2020.118962.
[240] Sola AVH, Mota CMM. Influencing factors on energy management in industries. J Clean Prod 2020;248:119263. https://doi.org/10.1016/j.jclepro.2019.119263.
[241] Holler S, Winkelmann A, Pelda J, Salaymeh A. Feasibility study on solar thermal process heat in the beverage industry. *Energy*; 2021. p. 121153. https://doi.org/10.1016/j.energy.2021.121153.
[242] Herbert C, Phimister E. Private sector-owned mini-grids and rural electrification: a case study of wind-power in Kenya's tea industry. Energy Pol 2019;132:1288–97. https://doi.org/10.1016/j.enpol.2019.06.031.
[243] Muhamad MI, Mariun N, Radzi MAM. The effects of power quality to the industries. In: 2007 5th student Conference on Research and development; 2007. p. 1–4. https://doi.org/10.1109/SCORED.2007.4451410.
[244] Rea JA, Herring J, Sopoćko M, Dempsey P, Armstrong S. Survey on demand side sensitivity to power quality in Ireland. Int J Electr Power Energy Syst 2016;83:495–504. https://doi.org/10.1016/j.ijepes.2016.04.003.
[245] Yaghoobi J, Abdullah A, Kumar D, Zare F, Soltani H. Power quality issues of distorted and weak distribution networks in mining industry: a review. IEEE Access 2019;7:162500–18. https://doi.org/10.1109/ACCESS.2019.2950911.
[246] Küfeoğlu S, Lehtonen M. Interruption costs of service sector electricity customers, a hybrid approach. Int J Electr Power Energy Syst 2015;64:588–95. https://doi.org/10.1016/j.ijepes.2014.07.046.
[247] Yoshida Y, Matsuhashi R. Estimating power outage costs based on a survey of industrial customers. Electr Eng Jpn Dec. 2013;185(4):25–32. https://doi.org/10.1002/eej.22306.
[248] LaCommare KH, Eto JH, Dunn LN, Sohn MD. Improving the estimated cost of sustained power interruptions to electricity customers. Energy 2018;153:1038–47. https://doi.org/10.1016/j.energy.2018.04.082.
[249] Kesicki F, Yanagisawa A. Modelling the potential for industrial energy efficiency in IEA's World Energy Outlook. Energy Effic. 2015;8(1):155–69. https://doi.org/10.1007/s12053-014-9273-7.
[250] Millán G, Llano E, Globisch J, Durand A, Hettesheimer T, Alcalde E. Increasing energy efficiency in the food and beverage industry: a human-centered design approach. Sustainability 2020;12:17. https://doi.org/10.3390/su12177037.
[251] Liu K, Bai H, Wang J, Lin B. How to reduce energy intensity in China's heavy industry—evidence from a seemingly uncorrelated regression. J Clean Prod 2018;180:708–15. https://doi.org/10.1016/j.jclepro.2018.01.170.
[252] Huang C, Zhang H, Song Y, Wang L, Ahmad T, Luo X. Demand response for industrial micro-grid considering photovoltaic power uncertainty and battery operational cost. IEEE Trans. Smart Grid 2021;12(4):3043–55. https://doi.org/10.1109/TSG.2021.3052515.
[253] Soares J, Canizes B, Ghazvini MAF, Vale Z, Venayagamoorthy GK. Two-stage stochastic model using benders' decomposition for large-scale energy resource management in smart grids. IEEE Trans Ind Appl 2017;53(6):5905–14. https://doi.org/10.1109/TIA.2017.2723339.
[254] Abbas S, Chiang Hsieh L-H, Techato K. Supply chain integrated decision model in order to synergize the energy system of textile industry from its resource waste. Energy 2021;229:120754. https://doi.org/10.1016/j.energy.2021.120754.
[255] Sgouridis S, Ali M, Sleptchenko A, Bouabid A, Ospina G. Aluminum smelters in the energy transition: optimal configuration and operation for renewable energy integration in high insolation regions. Renew Energy 2021;180:937–53. https://doi.org/10.1016/j.renene.2021.08.080.
[256] Fedjaev J, Amamra SA, Francois B. Linear programming based optimization tool for day ahead energy management of a lithium-ion battery for an industrial microgrid. In: 2016 IEEE international power electronics and motion control conference. PEMC); 2016. p. 406–11. https://doi.org/10.1109/EPEPEMC.2016.7752032.
[257] Foong SZY, Ng DKS. Simultaneous design and integration of multiple processes for eco-industrial park development. J Clean Prod 2021;298:126797. https://doi.org/10.1016/j.jclepro.2021.126797.
[258] Halmschlager V, Hofmann R. Assessing the potential of combined production and energy management in Industrial Energy Hubs – analysis of a chipboard production plant. Energy 2021;226:120415. https://doi.org/10.1016/j.energy.2021.120415.
[259] Zhang R, et al. Incorporating production task scheduling in energy management of an industrial microgrid: a regret-based stochastic programming approach. IEEE Trans Power Syst 2021;36(3):2663–73. https://doi.org/10.1109/TPWRS.2020.3037831.
[260] Zhao X, Yuan H, Zhang Z, Bai H. Optimization and management of on-site power plants under time-of-use power price: a case study in steel mill bt - energy technology 2020: recycling, carbon dioxide management, and other technologies. 2020. p. 39–47.
[261] Pérez-Lechuga G, Aguilar-Velázquez SL, Cisneros-López MA, Martínez FV. A model for the location and scheduling of the operation of second-generation ethanol biorefineries. J. Math. Ind. 2019;9(1):3. https://doi.org/10.1186/s13362-019-0060-0.
[262] Azimi Z, Hooshmand R-A, Soleymani S. Energy management considering simultaneous presence of demand responses and electric vehicles in smart industrial grids. Sustain. Energy Technol. Assessments 2021;45:101127. https://doi.org/10.1016/j.seta.2021.101127.
[263] Shen F, Wang X, Huang L, Ye Z, Qian F. Modeling and optimization of a large-scale ethylene plant energy system with energy structure analysis and management. Ind Eng Chem Res Jan. 2019;58(4):1686–700. https://doi.org/10.1021/acs.iecr.8b05247.
[264] Elsholkami M, Elkamel A, Vargas F. Optimized integration of renewable energy technologies into Alberta's oil sands industry. Comput Chem Eng 2016;90:1–22. https://doi.org/10.1016/j.compchemeng.2016.03.028.
[265] Nosratabadi SM, Hooshmand R-A, Gholipour E. Stochastic profit-based scheduling of industrial virtual power plant using the best demand response strategy. Appl Energy 2016;164:590–606. https://doi.org/10.1016/j.apenergy.2015.12.024.
[266] Wang Y, Chen C, Tao Y, Wen Z, Chen B, Zhang H. A many-objective optimization of industrial environmental management using NSGA-III: a case of China's iron and steel industry. Appl Energy 2019;242:46–56. https://doi.org/10.1016/j.apenergy.2019.03.048.
[267] Zeng Z, et al. Integrating process optimization with energy-efficiency scheduling to save energy for paper mills. Appl Energy 2018;225:542–58. https://doi.org/10.1016/j.apenergy.2018.05.051.
[268] Roesch M, Linder C, Zimmermann R, Rudolf A, Hohmann A, Reinhart G. Smart grid for industry using multi-agent reinforcement learning. Appl Sci 2020;10:19. https://doi.org/10.3390/app10196900.
[269] Talebjedi B, Khosravi A, Laukkanen T, Holmberg H, Vakkilainen E, Syri S. Energy modeling of a refiner in thermo-mechanical pulping process using ANFIS method. Energies 2020;13:19. https://doi.org/10.3390/en13195113.
[270] Rajalakshmi M, Jeyadevi S, Karthik C. An application of hybrid firefly and pso with support vector regression for modeling A clarifier process in sugar industry. In: 2018 national power engineering conference. NPEC); 2018. p. 1–10. https://doi.org/10.1109/NPEC.2018.8476695.
[271] Ji X, Ye H, Zhou J, Yin Y, Shen X. An improved teaching-learning-based optimization algorithm and its application to a combinatorial optimization problem in foundry industry. Appl Soft Comput 2017;57:504–16. https://doi.org/10.1016/j.asoc.2017.04.029.
[272] Owolabi TO, Suleiman MA, Adeyemo HB, Akande KO, Alhiyafi J, Olatunji SO. Estimation of minimum ignition energy of explosive chemicals using gravitational search algorithm based support vector regression. J Loss Prev Process Ind 2019;57:156–63. https://doi.org/10.1016/j.jlp.2018.11.018.
[273] Ullah I, Hussain I, Singh M. Exploiting grasshopper and Cuckoo search bio-inspired optimization algorithms for industrial energy management system: smart industries. Electronics 2020;9(1). https://doi.org/10.3390/electronics9010105.
[274] Al-Falahi MDA, Nimma KS, Jayasinghe SDG, Enshaei H, Guerrero JM. Power management optimization of hybrid power systems in electric ferries. Energy Convers Manag 2018;172:50–66. https://doi.org/10.1016/j.enconman.2018.07.012.
[275] Garcia-Santiago CA, Del Ser J, Upton C, Quilligan F, Gil-Lopez S, Salcedo-Sanz S. A random-key encoded harmony search approach for energy-efficient production scheduling with shared resources. Eng Optim 2015;47(11):1481–96. https://doi.org/10.1080/0305215X.2014.971778.
[276] Qadeer K, Qyyum MA, Lee M. Krill-herd-based investigation for energy saving opportunities in offshore liquefied natural gas processes. Ind Eng Chem Res Oct. 2018;57(42):14162–72. https://doi.org/10.1021/acs.iecr.8b02616.
[277] Xu L, et al. Mid-term prediction of electrical energy consumption for crude oil pipelines using a hybrid algorithm of support vector machine and genetic algorithm. Energy 2021;222:119955. https://doi.org/10.1016/j.energy.2021.119955.
[278] Xu Z, Han G, Liu L, Martínez-García M, Wang Z. Multi-energy scheduling of an industrial integrated energy system by reinforcement learning based differential evolution. IEEE Trans. Green Commun. Netw. 2021:1. https://doi.org/10.1109/TGCN.2021.3061789.
[279] Oskouei MZ, Mohammadi-Ivatloo B, Abapour M, Shafiee M, Anvari-Moghaddam A. Privacy-preserving mechanism for collaborative operation of high-renewable power systems and industrial energy hubs. Appl Energy 2021;283:116338. https://doi.org/10.1016/j.apenergy.2020.116338.
[280] Ishaq H, Dincer I. Investigation of an integrated system with industrial thermal management options for carbon emission reduction and hydrogen and ammonia production. Int J Hydrogen Energy 2019;44(26):12971–82. https://doi.org/10.1016/j.ijhydene.2019.03.067.
[281] Naeimi A, Bidi M, Ahmadi MH, Kumar R, Sadeghzadeh M, Alhuyi Nazari M. Design and exergy analysis of waste heat recovery system and gas engine for power generation in Tehran cement factory. Therm. Sci. Eng. Prog. 2019;9:299–307. https://doi.org/10.1016/j.tsep.2018.12.007.

[282] Afshar P, Brown M, Austin P, Wang H, Breikin T, Maciejowski J. Sequential modelling of thermal energy: new potential for energy optimisation in papermaking. Appl Energy 2012;89(1):97–105. https://doi.org/10.1016/j.apenergy.2011.01.022.
[283] Lu R, Li Y-C, Li Y, Jiang J, Ding Y. Multi-agent deep reinforcement learning based demand response for discrete manufacturing systems energy management. Appl Energy 2020;276:115473. https://doi.org/10.1016/j.apenergy.2020.115473.
[284] Ates SA. Energy efficiency and CO2 mitigation potential of the Turkish iron and steel industry using the LEAP (long-range energy alternatives planning) system. Energy 2015;90:417–28. https://doi.org/10.1016/j.energy.2015.07.059.
[285] Ates SA, Durakbasa NM. Evaluation of corporate energy management practices of energy intensive industries in Turkey. Energy 2012;45(1):81–91. https://doi.org/10.1016/j.energy.2012.03.032.
[286] Parida A, Choudhury S, Chatterjee S, Chatterjee D. A cost effective trade-off based renewable power augmented energy efficient load model for manufacturing industries for demand side management. Cogent Eng. Dec. 2016;3(1):1239299. https://doi.org/10.1080/23311916.2016.1239299.
[287] Gong Z-X, Stanovský J, Mujumdar AS. Energy audit of a fiberboard drying production line using Simprosys software. Dry Technol Feb. 2011;29(4):408–18. https://doi.org/10.1080/07373937.2010.498069.
[288] Lawrence A, Karlsson M, Nehler T, Thollander P. Effects of monetary investment, payback time and firm characteristics on electricity saving in energy-intensive industry. Appl Energy 2019;240:499–512. https://doi.org/10.1016/j.apenergy.2019.02.060.
[289] Abbas S, Chiang Hsieh LH, Techato K, Taweekun J. Sustainable production using a resource–energy–water nexus for the Pakistani textile industry. J Clean Prod 2020;271:122633. https://doi.org/10.1016/j.jclepro.2020.122633.
[290] de Souza Amorim FM, da Silva Arantes M, de Souza Ferreira MP, Motta Toledo CF. MILP formulation and hybrid evolutionary algorithms for the glass container industry problem with multiple furnaces. Comput Ind Eng 2021;158:107398. https://doi.org/10.1016/j.cie.2021. 107398.
[291] Pan R, Wang Q, Li Z, Cao J, Zhang Y. Steelmaking-continuous casting scheduling problem with multi-position refining furnaces under time-of-use tariffs. Ann Oper Res 2021. https://doi.org/10.1007/s10479-021-04217-7.
[292] Kumar V, Naresh R, Sharma V. GAMS environment based solution methodologies for ramp rate constrained profit based unit commitment problem. Iran. J. Sci. Technol. - Trans. Electr. Eng. 2021. https://doi.org/10.1007/s40998-021-00447-4.
[293] Zondervan E, Grossmann IE, de Haan AB, G. B. B. T.-C. A. C. E. Ferraris. Energy optimization in the process industries: unit Commitment at systems level. In: Pierucci S, editor. 20 European Symposium on computer aided process engineering. vol. 28. Elsevier; 2010. p. 931–6.
[294] Diekerhof M, et al. In: Hadjidimitriou NS, Frangioni A, Koch T, Lodi A, editors. Production and demand management BT - mathematical optimization for efficient and robust energy networks. Cham: Springer International Publishing; 2021. p. 3–25.
[295] Jabari F, Mohammadi-ivatloo B, Bannae Sharifian MB, Nojavan S. Design and robust optimization of a novel industrial continuous heat treatment furnace. Energy 2018;142:896–910. https://doi.org/10.1016/j.energy.2017.10.096.
[296] Clerget C-H, Petit N. Dynamic optimization of processes with time varying hydraulic delays. J Process Control 2019;83:20–9. https://doi.org/10.1016/j.jprocont.2019.04.013.
[297] Ianda TF, Sales EA, Nascimento AN, Padula AD. Optimizing the cooperated 'multi-countries' biodiesel production and consumption in sub-saharan africa. Energies 2020;13:18. https://doi.org/10.3390/en13184717.
[298] Dempster MAH, Hicks Pedrón N, Medova EA, Scott JE, Sembos A. Planning logistics operations in the oil industry. J Oper Res Soc Nov. 2000;51(11):1271–88. https://doi.org/10.1057/palgrave.jors.2601043.
[299] Gkanas EI, et al. Study on the operation and energy demand of dual-stage Metal Hydride Hydrogen Compressors under effective thermal management. Int J Hydrogen Energy 2021. https://doi.org/10.1016/j.ijhydene.2021.02.062.
[300] Ishaq H, Dincer I. A new energy efficient single-stage flash drying system integrated with heat recovery applications in industry. Dry Technol Apr. 2020;38(5–6):735–46. https://doi.org/10.1080/07373937.2019.1702557.
[301] Wu B, Li J, Liu H, Zhang Z, Zhou Y, Zhao N. Energy information integration based on EMS in paper mill. Appl Energy 2012;93:488–95. https://doi.org/10.1016/j.apenergy.2011.12.021.
[302] Karlsson M. The MIND method: a decision support for optimization of industrial energy systems – principles and case studies. Appl Energy 2011;88(3):577–89. https://doi.org/10.1016/j.apenergy.2010.08.021.
[303] Porzio GF, et al. Reducing the energy consumption and CO2 emissions of energy intensive industries through decision support systems – an example of application to the steel industry. Appl Energy 2013;112:818–33. https://doi.org/10.1016/j.apenergy.2013.05.005.
[304] Catrini P, Panno D, Cardona F, Piacentino A. Characterization of cooling loads in the wine industry and novel seasonal indicator for reliable assessment of energy saving through retrofit of chillers. Appl Energy 2020;266:114856. https://doi.org/10.1016/j.apenergy.2020.114856.
[305] Jia S, et al. Energy modeling and visualization analysis method of drilling processes in the manufacturing industry. Energy 2021;228:120567. https://doi.org/10.1016/j.energy.2021.120567.
[306] Jouhara H, et al. Investigation on a full-scale heat pipe heat exchanger in the ceramics industry for waste heat recovery. Energy 2021;223:120037. https://doi.org/10.1016/j.energy.2021.120037.
[307] Lee S-K, Teng M-C, Fan K-S, Yang K-H, Horng RS. Application of an energy management system in combination with FMCS to high energy consuming IT industries of Taiwan. Energy Convers Manag 2011;52(8):3060–70. https://doi.org/10.1016/j.enconman.2010.12.031.
[308] Nunes J, Neves D, Gaspar PD, Silva PD, Andrade LP. Predictive tool of energy performance of cold storage in agrifood industries: the Portuguese case study. Energy Convers Manag 2014;88:758–67. https://doi.org/10.1016/j.enconman.2014.09.018.
[309] Likkasit C, Maroufmashat A, Elkamel A, Ku H, Fowler M. Solar-aided hydrogen production methods for the integration of renewable energies into oil & gas industries. Energy Convers Manag 2018;168:395–406. https://doi.org/10.1016/j.enconman.2018.04.057.
[310] Önüt S, Tuzkaya UR, Saadet N. Multiple criteria evaluation of current energy resources for Turkish manufacturing industry. Energy Convers Manag 2008;49(6):1480–92. https://doi.org/10.1016/j.enconman.2007.12.026.
[311] Dal Magro F, Meneghetti A, Nardin G, Savino S. Enhancing energy recovery in the steel industry: matching continuous charge with off-gas variability smoothing. Energy Convers Manag 2015;104:78–89. https://doi.org/10.1016/j.enconman.2015.05.012.
[312] Baumgärtner N, Delorme R, Hennen M, Bardow A. Design of low-carbon utility systems: exploiting time-dependent grid emissions for climate-friendly demand-side management. Appl Energy 2019;247:755–65. https://doi.org/10.1016/j.apenergy.2019.04.029.
[313] Elsevier's abstract and citation database. https://www.scopus.com/; 2021.