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A review on methods of energy performance improvement towards sustainable manufacturing from perspectives of energy monitoring, evaluation, optimization and benchmarking

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Abstract

Improving energy performance has been recognized as an effective measure to promote the energy saving and emission reduction and to realize the sustainable development. Methods of improving energy performance towards sustainable manufacturing are numerous and scattered, resulting in insufficiency from the perspective of overall strategies and system integration. After the intensive selection of advanced literatures, about 166 researches papers ~~that are~~ directly related to energy performance improvement are analyzed. A comprehensive review and analysis from multi-perspectives of energy monitoring, evaluation, optimization and benchmarking are performed, which benefits to understand the energy consumption pattern and take effective measures of energy saving. This paper establishes a framework of energy performance integrated method, and four energy management methods and their energy models in energy monitoring, evaluation, optimization and benchmarking phase are analyzed and summarized. Besides, the proposed framework analyzes potential applications and key advantages, and some challenges and potential opportunities for energy performance improvement methods are discussed. This study will provide a significant foundation for energy-efficient production through various methods application.

Keywords: Energy, Energy monitoring, Energy evaluation; Energy optimization, Energy benchmarking, Sustainable manufacturing

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Abbreviations

Internet of Things Management	IoT	Management Software Systems	MSS
Energy Efficiency Indicators	EEI	cutting specific energy consumption	CSEC
metal matrix composites	MMC	Specific Energy Consumption	SEC
variable speed drive	VSD	Response Surface Methodology	RSM
Multi-Objective Optimization Model	MOOM	automated guided vehicles	AGVs
autonomous guided vehicle	AGV	particle swarm optimization	PSO
non-dominated sorting-based genetic algorithm II	NSGA-II	energy-aware scheduling	EAS
Advanced Planning and Scheduling	APS	Major Industrial Plant Database	MIPD

1 Introduction

A substantial amount of energy consumption and emissions have resulted in the serious environmental pollution. According to the 2017 energy efficiency survey report, the world's fossil energy demand was still growing, and global energy consumption has increased by more than 30% in general [1-3]. Investigations show that the industrial sector is responsible for more than 53.81% of the nation's energy consumption [4,5]. CO_2 emissions from industrial energy consumption accounted for more than 80% of China's total emissions since 2005, and the CO_2 emissions caused by industrial energy consumption has become the main source of China's CO_2 emissions [6-9]. Therefore, improving energy performance and reducing CO_2 have become a significant issue in industrial sector [10,11].

Manufacturing industry is a major pillar industry in industrial sector, whose development potential will be weakened due to high resource consumption and the continued application of high-carbon and high-pollution technologies. A sustainable future for manufacturing is built on continuous energy performance improvements. Some countries and governmental agencies have conducted numerous policies on energy performance improvement and CO_2 reduction in manufacturing sectors including some energy performance improvement measures, policies, and standards in **Table 1** and **Table 2**. Related studies indicated that the energy saving potential of the manufacturing industry was expected to reach more than 18%, and the CO_2 emission reduction potential was likely to reach 12% ~23% through taking effective measures of energy performance improvement [12]. However, the management of energy performance and CO_2 emissions has not been taken seriously in the past [13]. The main reason is that manufacturing systems become increasingly flexible and complex, and the energy information is very difficult to accurately monitor and extract. Advanced measuring equipment and monitoring systems still needs further study. Besides, some energy improvement methods including energy monitoring or evaluation are affected by various factors like manufacturing parameters, operator activities and processing environment [14]. Some performance evaluation models usually neglect some necessary information resulting in deviation of the overall optimization strategy. Obviously, national policy or some existing technologies alone are not enough to implement fine energy management in mechanical manufacturing industry. To keep energy efficiently used, there is a trend to address structural or knowledge issues of energy performance improvement in manufacturing industries.

Table 1. Examples of policies supporting implementation of energy management systems. Source: Energy efficiency 2021. [3]

Country / Region	Policy	Description	Year
Belgium	Appliances Energy Efficiency Label Update	The new label indicating the level of energy consumption of electrical and household appliances will be put in place on 1 March 2021. The aim of the change is to keep pace with progress in energy performance and to stimulate the manufacture of ever more energy-efficient appliances.	2021
Austria	Austrian Recovery & Resilience Plan	The plan sets a first target: the Renovation offensive. It plans the implementation of a new Renewable Heat Act. It will promote the replacement of oil and gas heating systems to more eco-friendly alternatives.	2021
Sweden	Budget 2021 - Reduce Carbon Emissions	By means of the green credit guarantees, the government intends to promote major industrial investments that contribute to achieving environmental and climate goals. The cross-sectoral Climate Leap programme will be extended and the Green Industry Leap programme will be developed and broadened to allow more investments to reduce industrial emissions and contribute to the transition to a fossil-free and circular society.	2021
Spain	The Climate Change and Energy Transition Law	Art.3: The long-term objective is the decarbonization of the economy by 2050 with a 100% renewable electricity system. It sets goals by 2030 of reducing greenhouse gas emissions by at least 23% with respect to 1990, achieve 42% renewables in final improving energy efficiency by reducing primary energy consumption by at least 39.5%.	2021
Poland	National Reconstruction Plan	Pillar B of the Polish National Recovery Plan concerns "Green energy and energy efficiency". Its objective is to limit Covid-19 negative impact on the economy and the environment, while improving competitiveness and energy security in Poland.	2021
Germany	Federal funding for energy efficiency in the economy - Funding Competition	Both SMEs and larger industries across numerous sectors are eligible to bid into the competitive tender, which aims to increase the energy efficiency while reducing the CO_2 emissions of industrial/commercial plants and processes.	2019
China	Key Work Plan for Industrial Energy Conservation Supervision in 2020	This plan was formulated in order to implement the "Energy Conservation Law" and "Industrial Energy Conservation Management Measures", give full play to the supervision and protection role of energy conservation supervision and to continuously improve the industrial energy efficiency and green development level.	2020

Table 2. ISO standards related to energy-efficient and environmentally benign manufacturing systems (reconstructed from Yoon et al. [15])

ISO standards	Description
ISO/DIS 14955	Machine tools — Environmental evaluation of machine tools
ISO/DIS 20140	Automation systems and integration — evaluating energy efficiency and other factors of manufacturing systems that influence the environment
ISO/FDIS 22400	Automation systems and integration — key performance indicators (KPIs) for manufacturing operations management

Overall energy efficiency improvement is a systematic project with a full life cycle, and it is also an important role of the future manufacturing industry. ~~In addition to that~~ the longitudinal improvement of energy efficiency should cover the whole life cycle process from product design, production planning, engineering to production implementation and service, the more important is transverse development, that is, energy efficiency improvement includes not only energy saving of a single product, but also system energy saving through project management platform, as well as higher-level enterprise comprehensive energy management based on visualization. Therefore, this review puts forward a framework from three aspects: identification, evaluation and implementation of energy management methods. This framework aims to improve energy performance towards manufacturing from perspectives of energy monitoring, evaluation, optimization and benchmarking. Information related to energy usage within the production processes was extremely difficult to obtain, resulting in certain blindness in energy performance improvement strategies. Many researchers have provided considerable attention to the transparency, accuracy and comprehensiveness of energy performance monitoring solution in manufacturing industry nowadays.

Energy monitoring and evaluation could help the enterprise energy administrators determine the energy consumption and analyze the energy saving potential. Energy optimization and benchmarking are conducive to gain best practices and energy superiority. From the view of practices, this paper summarizes and covers a large number of methods for improving energy efficiency in manufacturing by classification, which can offer effective reference on method selection in real practices. Besides, this work can guide production staff how to manage energy consumption and operate production processes to improve energy efficiency.

Considering that the research on manufacturing system energy consumption is still relatively scattered, this review discusses the research on manufacturing system energy consumption from different levels. Including energy consumption monitoring, energy consumption evaluation, energy consumption optimization and energy consumption benchmarking towards sustainable manufacturing. Each part carefully selects the literature for discussion by using content evaluation analysis. The literature was searched using standard journal databases and search engines such as science direct, Google Scholar and web of science. Based on the search terms conducted in concept analysis, we add the search terms related to sustainable manufacturing with the “topic, title, keywords” used for searching. The search terms include “energy consumption monitoring” OR “promotion of information technology” OR “intelligent energy consumption monitoring” OR “energy consumption evaluation” OR “Energy consumption evaluation model” OR “energy consumption optimization” OR “lightweight” OR “process parameter optimization” OR “process planning” OR “energy saving workshop” OR “workshop logistics” OR “energy benchmarking”.

2. A framework for energy performance improvement

Energy performance analysis is important and has aroused wide concern in various sectors [16]. Manufacturing sector as a high energy-consuming industry, improving the energy performance and realizing the energy-efficient and sustainable manufacturing have become more urgent. This study establishes a framework for energy performance improvement in **Fig.1** and subdivides the methods of energy performance improvement into four aspects: the energy monitoring, evaluation, optimization and benchmarking as follows.

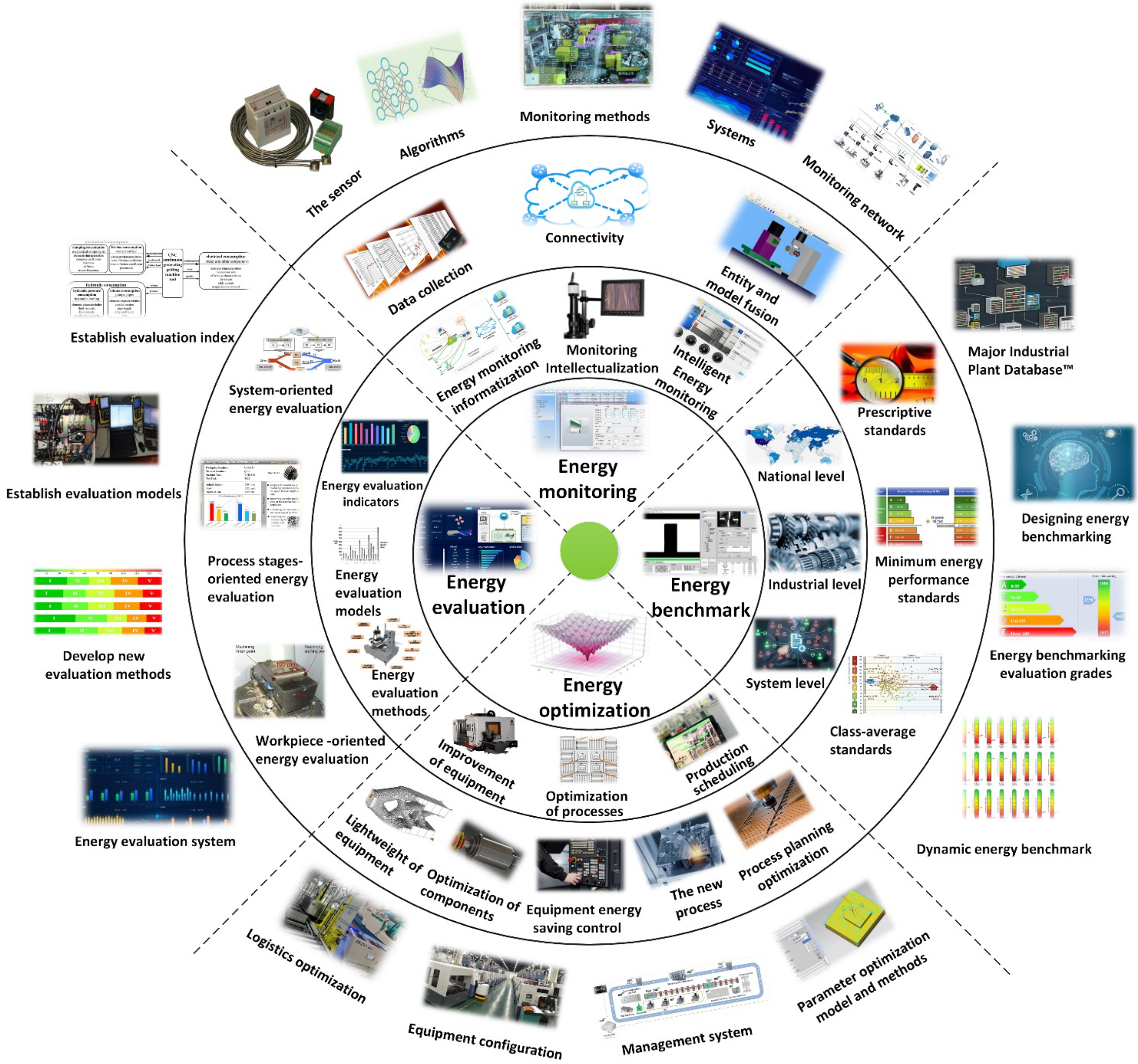

Fig.1 A framework for energy performance improvement

- **Energy monitoring:** The monitoring method and monitoring system should be conducted to gather energy related information such as the energy, production task, process parameters and production scheduling [17]. This data is finally analyzed to reveal real-time energy consumption and energy efficiency information of manufacturing processes. Along with the development of digital technology, energy monitoring method or system become more intelligent. It can not only actively mine and utilize big data resources, but also conduct multidimensional analysis of energy related information such as production tasks, process parameters and production scheduling, automatically monitor real-time energy consumption and energy efficiency information in the manufacturing process, improve energy management efficiency and realize personalized decisions in different scenarios.
- **Energy evaluation:** Energy evaluation includes energy consumption evaluation indicators, energy

consumption model and energy consumption evaluating strategy. It is necessary to establish complete and standard index system of energy efficiency evaluation that can estimate and compare energy performance in different mechanical manufacturing enterprises. Most research relies on a series of experiments and ~~the~~ observed data to establish an energy model, which is proved to be extremely complex and time-consuming. Energy efficiency evaluation indicators and models are divided into three levels: system, process and workpiece oriented. Energy evaluation methods for manufacturing systems, especially for mechanical manufacturing systems, are divided into products, workshops and tasks level. With the rapid development and update of information technology, the software tool was reckoned to be promising tool to estimate machining energy efficiency.

- **Energy optimization:** Reducing the energy consumption of manufacturing system is finally realized through the energy consumption optimization of equipment. Many efforts have been made in energy optimization, such as improvement of equipment, optimization of processes and parameters and production scheduling and management system to achieve energy saving. The improvement of mechanical equipment mainly focuses on the lightweight of key parts, the optimization of component energy consumption and the energy-saving control of equipment. In terms of process parameter optimization, new energy-saving processes, parameter optimization models and process planning have attracted more and more attention. Workshop logistics, equipment configuration and scheduling are all ways to optimize energy consumption of production system.
- **Energy benchmarking:** Energy benchmarking ~~is introduced that~~ has been widely used by each country and enterprise to systematically estimate and manage the energy efficiency of the equipment or product. The existing concept, classification and modeling of energy benchmarking in manufacturing process are analyzed. As there is lack of transparency of energy data sharing between peer sectors and indicators for energy benchmarking on manufacturing or machining and on whole workshop level, this review has positive reference value to design and develop energy benchmarking. Potential opportunities to strengthen energy benchmarking are to implement energy performance certification in manufacturing industry.

3. Energy monitoring towards digital development

Due to the urgency of sustainable development, energy monitoring has become a means to optimize the growing energy demand and consumption [18]. **Fig.2** shows that Steps to analyze the collected energy consumption data. For manufacturing, the energy monitoring method or system can eliminate energy waste, reduce the current using level and make better use of resources. Combined with the vigorous development of digital technology, the development stage of energy monitoring methods or systems in manufacturing can be roughly divided into three stages: energy monitoring informatization, energy monitoring intelligence and smart energy monitoring. Each stage has different contributions to energy conservation.

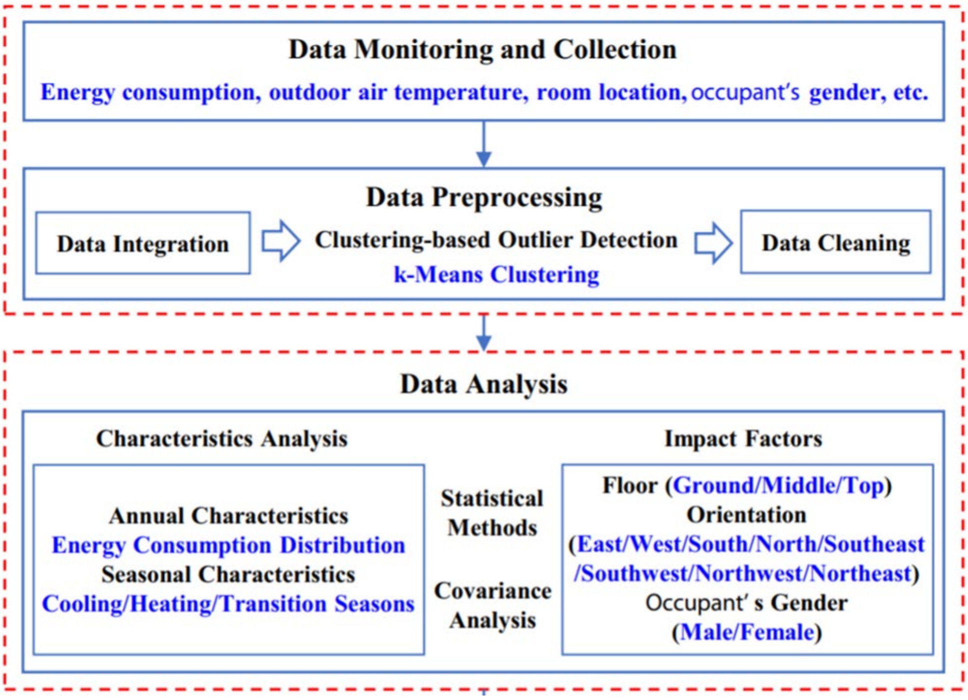

Fig.2 Steps to analyze the collected energy consumption data [18]**.**

3.1 Energy monitoring informatization

This stage is the primary stage of digital development. It mainly focuses on the basic data collection in ~~the~~ energy production monitoring and the application of information and communication technology. There are different forms of energy in a sophisticated manufacturing system, so ~~the~~ accurate energy monitoring related to production operation remains a challenging problem. At present, the energy data in many industries are high-dimensional nonlinear data [18]. The traditional distributed energy operation on-line monitoring methods have poor discrimination ability for this kind of data and are prone to data confusion during collection. Meanwhile, most of the manufacturing enterprise energy monitoring and management systems have relatively single functions, only collect enterprise energy consumption information, and rarely make statistical analysis on enterprise comprehensive resource utilization and production [19]. There are few functions to analyze and evaluate data, and the statistical indicators are relatively single. Further, with the emerging energy demand, the energy monitoring system is required not only to deal with structured data, but also to comprehensively utilize a large number of semi-structured and unstructured data [20,21]. Traditionally, the real-time measurement and acquisition of structured data is obtained through various types of sensors. For example, cutting power during machining is mainly using torque sensors and dynamometers [22]. Besides, a comprehensive review of several essential measuring equipment with its communication mechanisms was presented within the manufacturing industry [23,24].

Overall, there is a lack of intelligent analysis and processing of data at this stage. The information in ~~the~~ energy production, transmission and consumption is relatively closed. The data flow does not form a closed loop, the data is lack of consistency, and it is difficult to centrally access and process a lot of information. The combination of statistics, monitoring, evaluation and supervision of energy consumption with digital technology is not enough to provide a basis for relevant departments to formulate energy conservation and resource utilization policies in a timely and accurate manner.

3.2 Energy monitoring Intellectualization

This stage is the intermediate stage, being promoted at present, of digital development. With the development of information and machining technology, massive researches begin to develop advanced monitoring systems to perform the quantization and acquisition of energy information, which avoids complicated calculation and can continuously return energy feedback to operators. Taking a typical machining system in a manufacturing system as an example, several energy monitoring systems were summarized in **Table 3.**

Table 3 Literature review on energy monitoring system in machining systems

Description	Scholars	Year
An Internet of Things (IoT) based energy efficiency monitoring and management system for machining workshop	Chen et al. [25,26]	2018
IoT-enabled real-time energy efficiency optimization method for energy-intensive manufacturing enterprises	Wang et.al. [27]	2017
Energy Consumption Estimation for Machining Processes Based on Real-time Shop Floor Monitoring via Wireless Sensor Networks	Mourtzis [28]	2016
An energy monitoring framework incorporates standards for energy data exchange, on-line energy data analysis, performance measurement and display of energy usage	Vikhorev et al. [29]	2013
Energy and resource monitoring system incorporates internal sensors, external sensors and simulation	Gontarz et al. [30]	2015
A portable power monitoring system including hardware module and software module for the grinding process	Tian et al. [31]	2017
Real time power consumption monitoring for energy efficiency analysis in micro EDM milling	Tristo [32]	2015
An automated energy monitoring system using MTConnectSM standard and event processing techniques	AVijayaraghavan et al. [33]	2010
Modular modeling of energy consumption for monitoring and controlGlocalized Solutions for Sustainability in Manufacturing	Verl et al. [34]	2011
An on-line approach for energy efficiency monitoring of machine tools	Hu et al. [35]	2012
An Online Monitoring Approach for Energy Efficiency of Machine Tools Based on Characteristics of Additional Load Loss	Ping et al [36]	2013
A methodology for online visualization of the energy flow in a machine tool	Mohammadi et al. [37]	2017
A model-and signal-based power consumption monitoring system to simultaneously monitor and estimate power consumption of machine tool	Eberspächer et al [38]	2014
eSight Energy Monitoring and Targeting/Energy Management System	eSight Energy [39]	2012
Ambient intelligent based monitoring system coupled with management software systems (MSS) to observe energy consumption in manufacturing	Heilala et al [40]	2011
Using SCADA software to process and analyze captured energy data	Hacksteiner et al [41]	2017
Using Engineering Apps to analyze the measured PLC signals	Lenz et al. [42]	2017

At this stage, the integrated application of digital technology should cover all links of energy production, transmission and consumption, so as to realize the comprehensive perception of terminal equipment information, the interconnection of various elements in all links of energy, and the collaborative exchange between people and things. Internet of Things (IoT) technology emerges as a novel tool and has attracted extensive attention. The IoT realizes real-time data capture and analysis by connecting a physical device with the Internet [43]. An IoT based energy efficiency monitoring system was proposed for energy monitoring in a machining workshop from different layers [26]. A software system for real-time monitoring of workshop energy efficiency was developed, and the proposed software system was a multi-layered application consisting of presentation layer, business logic layer, and data layer [27]. Besides, a real-time monitoring system was developed to capture and preprocess the real-time measurement data from sensors embedded in the machine tool [28]. The information acquired was then fused by information fusion mechanism in cloud server to visualize useful results [29], which could be benefit to reuse valuable data from past process planning and also to evaluate energy efficiency of the new workpiece in **Fig.3**.

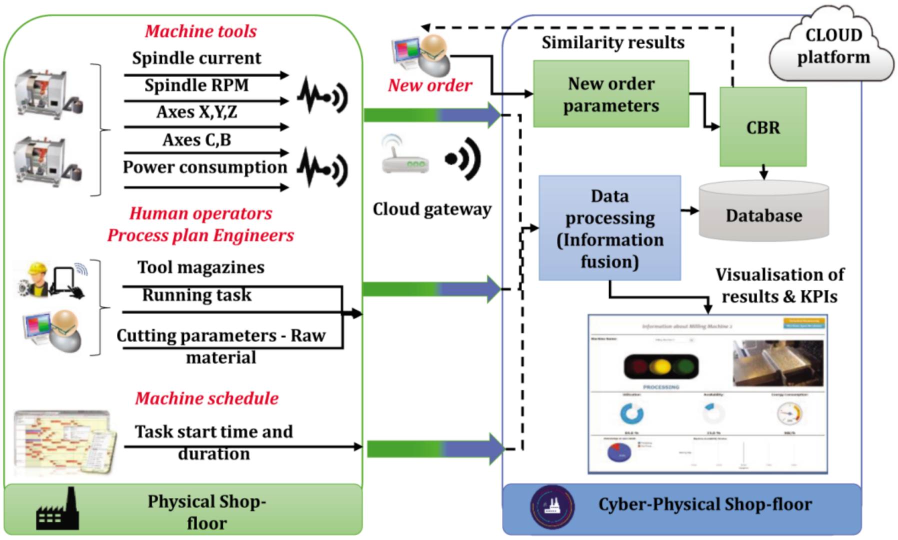

Fig. 3. Overview of the combined methodology consisted of the shop-floor monitoring and the CBR. Source: Mourtzis et al. [28]Copyright 2016, Elsevier Ltd.

Through advanced technology processing, the energy monitoring system can process all kinds of data in real time and realize automatic monitoring. A three-steps methodology was suggested to the application of a comprehensive energy and resource monitoring system [30]. A portable power monitoring system including hardware module and software module was presented for the grinding process power monitoring [31]. Similarly, a data acquisition system based on open-hardware and open-source software was proposed for on-line processing and analysis of energy efficiency of a micro-electrical discharge milling machine [32]. An automated energy monitoring system for energy monitoring for machine tools was developed though employing MTConnectSM standard and event processing techniques [33]. A similar method can be found by Profienergy working group [34]. Besides, there are some studies on a real-time energy monitoring system based on energy consumption models of machine tools [35-37]. A model-and signal-based power consumption monitoring system was presented which combined electric power measurements and control signals with energy consumption simulation models [38]. There was an approach to determine relevant energy efficiency and productivity KPIs of machining processes based on a real-time interpretation of sensor data and machine control data [41]. Moreover, some commercially available energy management systems were also employed by many researchers, e.g., eSight M&T/EMS [39]and EnergyCap [40]. The captured sensor data and machine status control data were fed into a SCADA software to achieve further processing and analysis, and the SPC Mini Data Loggers was utilized to record and analyze the measured data [42]. A real-time monitoring system for manufacturing workflow of intelligent interconnected workers is developed for small and medium-sized manufacturers. The system combines the most advanced machine learning technology with the workplace, realizes the efficient supervision of long-time working conditions and real-time and accurate information analysis, and can effectively reduce the cost related to labor [44].

At this stage, energy enterprises can deeply share and intelligently analyze the closed-loop data through the advanced energy monitoring system, realize the optimal allocation of various resources, give full play to the risk control advantages of forward-looking perception, active early warning and advanced defense, and ensure the flexible, safe, efficient and reliable operation of the energy system.

3.3 Intelligent Energy monitoring

The third is the ~~development stage of~~ intelligent energy monitoring. At that time, the solid model and digital model will be deeply integrated and the real world and virtual world will feed each other in real time [45,46]. The energy monitoring system will have automatic intelligent decision-making ability, support highly unmanned intelligent operation, and completely reshape the mode of energy production, transmission and consumption. With ~~the~~ continuous iterative innovation of relevant technologies and application scenarios, the digitization of energy monitoring will have a significant impact on energy efficiency.

In summary, energy monitoring systems is a necessity because of decreasing the complexity of working with massive ~~of~~ energy data and systems. Most enterprises have employed various advanced monitoring systems to promote the sustainable manufacturing. As contrast, energy monitoring methods are cumbersome to handle even simple machining system, but they are not allowed to be neglected. Several manual and theoretical monitoring approaches are useful for energy measurement and understanding. Noting that energy monitoring system is mainly based on monitoring algorithms. Therefore, while promoting development of energy monitoring system in manufacturing, strengthening energy monitoring algorithms and methods are necessary.

4. Energy evaluation towards sustainable manufacturing

Energy evaluation based on energy performance monitoring data is a tool for analyzing energy performance, which consists of energy evaluation models, indicators, methods and systems. Actually, these are interconnected. For example, the calculation and selection of energy evaluation indicators depend on energy evaluation models and ~~energy evaluation~~ methods respectively and energy evaluation models correspond to various energy evaluation methods. Similarly, energy evaluation systems also require energy evaluation models, energy evaluation indicators and methods. In this part, multi-level energy evaluation is carried out for complex manufacturing process [47]. Energy evaluation indicators, models and methods are comprehensively analyzed from system layer, process layer and workpiece layer. It is worth mentioning that future development trend should pay more attention to establish standard and general energy efficiency evaluation model, energy benchmarking of mechanical products and manufacturing tasks and to develop the complete energy efficiency indicators of machining systems.

4.1 Energy evaluation indicators

In recent years, the research on energy evaluation indicators in manufacturing, especially in machining, has attracted the attention of scholars and enterprises. Establishing energy efficiency indictors and developing evaluation methods have become ~~the~~ effective measures for promoting energy-efficient production.

(1) System-oriented energy evaluation indicators

From the perspective of energy consumption, mechanical manufacturing system is a manufacturing system with machine tools, casting equipment and other mechanical equipment and their corresponding process as the main body of energy consumption. Energy efficiency can be interpreted as the percentage of effective energy and input energy of the system, i.e., energy utilization ratio. In addition, energy benchmarks are used as an evaluation indicator for comprehensive assessment of ~~the~~ energy efficiency in different machining scenarios in certain system [48]. Other related concepts like energy efficiency labels used for standard assessment of energy efficiency of machining systems. **Fig.4** shows an example of power measurement of milling experiment [49]. A new evaluation index system was constructed, which contains three layers and ten indexes [50]. System oriented energy evaluation indicators can be divided into energy efficiency evaluation of main systems and auxiliary systems.

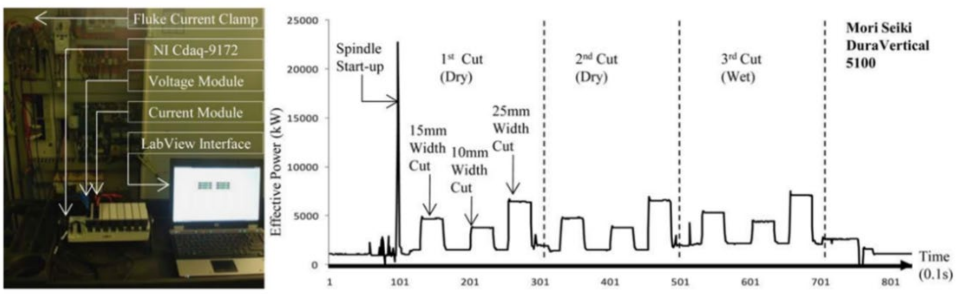

Fig.4 Photography of experimental and an example of power measurement of milling experiment [49].

(2) Process stages-oriented energy evaluation indicators

Process energy efficiency of mechanical manufacturing system refers to the relationship between effective energy or effective output and input energy in a manufacturing process or a period of time. Similarly, the process stages-oriented energy evaluation indicators can be divided into several different indicators according to the processing process, that is, each process stage has a corresponding energy efficiency evaluation indicator. A unique energy label procedure based on a process-independent energy efficiency indicator and the normalized parameter function was developed for evaluating the energy efficiency of milling machines [49]. A structure model for energy efficiency indicators (EEI) system at the industry sector level was established [84]. The index of productive capacity and energy utilization are integrated into the model for interpreting the differences between EEIs.

(3) Workpiece -oriented energy evaluation indicators

The workpiece-oriented energy evaluation indicators are defined as the energy consumed by each part unit in the machining process or the energy required to process the product per unit volume (or mass). For example, in order to reduce ~~the~~ product processing energy consumption, the cutting specific energy consumption (CSEC) is used as the evaluation indicator, and the process parameters are optimized combined with the optimization model of processing time [51]. For achievement of low energy consumption, the Least Energy Demand is presented as a comprehensive reference value to evaluate energy efficiency, which could be obtained by integration of CAD. Even through the interruption between machines controlling data, the calculation can be realized directly on the machine tools during the manufacturing process [52]. A method of changing cutting parameters is introduced. Taking the relationship between material removal rate (MRR) and energy consumption when turning steel with CNC lathe as the energy consumption evaluation indicator, in order to minimize the direct energy consumption in the turning process [53]. Taking the energy consumption per unit material as the index, reducing the energy consumption in the processing of metal matrix composites (MMC) is studied ~~in order~~ to significantly improve the energy efficiency of the manufacturing system [54].

Manufacturing systems, especially ~~for~~ mechanical manufacturing systems, are a complex carrier of product production, which spans different levels such as products, workshops, tasks, manufacturing units and production equipment. Each level has its energy efficiency indicator or indicator system.

4.2 Energy evaluation models

The energy evaluation models are the key to energy evaluation, and their modeling approaches in ~~the~~ machining systems could be generally categorized into three groups including the systems, process stages, and workpiece-oriented energy evaluation models. Energy consumption models for machining systems are summarized in Table 4.

Table 4 Literature review on energy consumption models for machining systems (Specific parameters for models are omitted, see specific literature for details)

Type	Models	Author
Energy efficiency evaluation model based on machine tool components	$E_{total} = E_{spindle} + E_{feed} + E_{tool} + E_{cool} + E_{fix}$	He et al. [55]
	$P_M = P_S + \sum_{i}^{m} P_{x_i} + P_y + \sum_{j}^{n} P_{z_j}$	Jiang et al. [44]
	$\psi = \frac{\sum_{i=1}^{Q_m} \int_0^{t_{Mi}} \frac{-a_{1i} + \sqrt{a_{1i}^2 + 4a_{2i}(P_{in}(t) - P_{ui})}}{2a_{2i}} dt}{\int_0^{t_T} P_{in}(t)dt}$	Liu et al. [48]
Energy consumption model for material removal processes		Draganescu et al. [50]
	$SEC = \frac{P_c}{60\mu MRR}$	
	$SEC = C_0 + \frac{C_1}{MRR}$	Kara and Li et al. [56]
	$SEC = C_0 \cdot V_c^{\alpha} \cdot f^{\beta} \cdot a_p^{\gamma} \cdot D^{\varphi} + \frac{C_1}{V_c \cdot f \cdot a_P}$	
	$SEC = k + k_1 \frac{n}{MRR} + k_2 \frac{1}{MRR}$	Guo et al. [57]
		Li et al. [58]
Energy consumption model of machining system	$FEnergy = FMEnergy + FTEnergy + FAEnergy$	Tang et al. [59]
	$P_{total} = P_{SO} + P_L + P_{CFS} + P_{SR} + P_{XF} + P_{YF} + P_{ZF} + P_{TS} + P_{TC} + P_C$	Lv et al. [60]
	$E_S = \int_{T_0}^{T_q} P_s(t)$	Weinert et al. [61]
	$\eta_c = \frac{E_a}{E_{\varphi}} = \frac{\int_{t1}^{t2} P_a(t)dt}{\int_{t1}^{t2} P_{\varphi}(t)dt} = \frac{P_a(t)}{P_{\varphi}(t)}$	Zhou et al. [62]

(1) System-oriented energy evaluation models

A machine system consists of dynamic system and auxiliary system [55]. The dynamic systems are divided into the main driving system and the feed system, which are applied to maintain the operation of the spindle and machine tool. Theoretically, the energy consumption of the main driving system is a large amount in the whole energy consumption of a machine system and the part of energy consumption is often underutilized resulting in low energy utilization rate. The functions of the auxiliary systems are actually complicated, including cooling, lubricating, removing chips and so on. For example, an analytical investigation on energy evaluation of hobbing machines was studied from the perspective of systems method [63]. Energy consumption of a grinding machine could be divided into the gear system (dynamic system) and auxiliary system based on grinding machine components [64]. Then, an energy consumption model of the multi-source energy flow was established, which offered an important solution for energy performance evaluation of machine tools [65].

(2) Process stages-oriented energy evaluation models

The energy consumption of machining processes for a machine tool mainly can be divided into four kinds including standby, starting, idling and cutting material energy consumption based on different process stages [66]. The standby energy consumption and the idling energy consumption are used to achieve certain functions (such as cutter-changing, clamping workpieces, etc.) and keep the operation of the spindle, respectively. The starting energy consumption is closely related to the spindle speed, which is constant at a specific spindle speed. Actually, the cutting material energy consumption includes ~~the~~ idling energy consumption, ~~the~~ material removal energy consumption and ~~the~~ additional load energy consumption. Similarly, the energy consumption of all features was summed up to evaluate total energy consumption in the early design phase, which actually adopted process stage method to describing one feature of a process [59]. A method based on the energy consumption analysis model was proposed~~, which was used~~ to describe the main functional modules of the machine tool to minimize the energy consumption of the machine tool in the use phase [67]. Although the above methods can acquire the total energy consumption of a machine tool, these methods can not directly predict the material removal energy consumption of a workpiece. To solve the problem, workpiece-oriented energy modeling (material removal energy consumption model) has been widely used [68].

(3) Workpiece -oriented energy evaluation models

For material removal process, Specific Energy Consumption (SEC) that is defined as the energy required to remove material per unit volume or mass in the cutting process [69]. Many scholars have developed different forms of SEC models. Some empirical models for specific energy consumption in machining were built [56], and impact of process parameters on specific energy in machining processes was discussion [70], which provided an effective approach to analyze energy performance and to carry out the energy optimization [57]. The cutting energy consumption models are deemed powerful, but these models cannot accurately describe the energy efficiency of entire machining process. According to the study [71], the energy consumed by the auxiliary equipment is much higher than the material removal process.

4.3 Energy evaluation methods

Energy evaluation is the premise of energy efficiency optimization in machining process. The research on energy efficiency evaluation methods can provide guarantee for energy efficiency optimization in machining process. The energy efficiency evaluation of mechanical manufacturing system can be divided into products, workshops and tasks level.

Energy efficiency evaluation methods for mechanical manufacturing systems are divided into different levels. For example, a comparative experiment using four test methods for evaluating energy efficiency of machine tools was presented by adopting Analytic Hierarchy Process method with consideration of main characteristic criteria [13]. On the product level, a virtual part approach based on energy characteristics and compositions of the constructed virtual part was introduced at the stage before manufacturing the actual parts [47,72]. In addition, the Least Energy Demand method defined as a reference value for calculating the manufacturing energy efficiency was proposed based on the key definition of relative energy efficiency [73]. On the workshop level, a systematic methodology for facility layout modification for increasing energy efficiency was discussed in which a discrete event simulation was applied to kaizen event for assessing energy efficiency of manufacturing systems [74]. On the tasks level, Evaluating and predicting energy consumption in machining process was proposed based on a case-based reasoning approach [75]. With the rapid development and update of information technology, the software tool was reckoned to be promising tool to estimate machining energy efficiency. For instance, a software tool for energy consumption evaluation in machining process was developed based on the interpret and transfer input information knowledge [71]. Consequently, the energy during machining operation can be calculated by the STEP-NC process plan. Meanwhile, a computational tool was presented for automatically assessing energy consumption in machining process based on a product preliminary computer representation, candidate processing operations and its material during the early design phase [76,77].

Energy efficiency evaluation and energy-saving optimization operation of mechanical manufacturing system involve a large amount of information and complex models, processes and methods. Therefore, it needs the support of information platform. Some scholars turned their attention to the research of product life cycle energy consumption assessment and analysis methods based on Internet of Things and cloud technology [78].

5. Energy optimization towards sustainable manufacturing

Understanding energy consumption characteristics and patterns of machining systems through energy consumption monitoring and evaluation fails to meet requirements of sustainable manufacturing. Minimizing or optimizing energy consumption is ultimate goal to achieve sustainability manufacturing. Therefore, this sector includes three aspects: (i) Improvement of equipment, (ii) Optimization of processes and parameters and (iii) Production scheduling and management system to achieve energy saving.

5.1 Improvement of equipment

Manufacturing equipment is the crucial energy-consuming link of production enterprises. The motors, servo drives, hydraulic and pneumatic systems equipped in machine tools are the main energy-consuming components [79]. Researchers have made some efforts to optimize manufacturing equipment like machine tools to achieve energy saving [80,81] from three perspectives of lightweight of equipment, energy consumption optimization of equipment components, and equipment energy saving control.

(1) Lightweight of equipment

The Lightweight of machine tool equipment mainly includes the Lightweight of spindle and other executing parts. Machine tool spindle is one of the most important parts which consumes much energy. Improvement and optimal design of spindle structure can not only achieve more precise machining but also save massive energy [82]. At the machine level, optimization strategies involve turning on and off the spindle when needed ~~the spindle light-weight design~~. At the system level, it is necessary to select criterion of an energy-efficient machine tool [83]. The learning algorithms like BP neural network, improved cellular multi-objective genetic algorithm and genetic algorithm were also implemented for optimizing machine spindle [82-86]. Other actuators in the machine tool also consume some of the energy. It is advisable to reduce weight and energy consumption by simplifying transmission structure. An empirical model of spindle system energy was developed and the purpose of this work was to comprehensively evaluate the energy saving opportunities of introducing direct drive solutions into machine tool spindle systems [83]. At present, most of the equipment with transmission structure can reduce the energy consumption of the whole transmission system through the lightweight bearing. A lightweight design method is proposed to reduce the weight of the flexible rotor of ball bearing with speed and load stiffness characteristics under the constraints of system eigenvalues and bearing fatigue life [87]. Research is also underway on new intelligent lightweight machine sliding structures [88]. In addition to lightweight design in the design stage, the application of new materials is also changing the situation of lightweight [89].

(2) Energy consumption optimization of equipment components

The research on energy consumption optimization of equipment components mainly focuses on motor, hydraulic unit and lubrication unit. Many scholars have committed to prompt the motor performance and transform electrical energy intensive systems. For example, a variable speed drive (VSD) motor in Malaysian rubber industries was adopted, and the experimental results demonstrated that up to about 4000 MWh of energy consumption could be saved in machining [90]. A strategy for machine fixed energy saving was introduced by means of improving the induction motor for a variable speed drive [91]. In machine tools, the optimization of hydraulic systems contributes to a tremendous amount of energy reduction [92]. A novel, energy-efficient hydraulic unit was introduced, which combines a variable displacement pump with a variable speed-controlled drive and hydraulic booster. The coolant pump represented about 26% of the total energy consumption in milling process. Significant energy saving potential was available by adopting energy-efficient cooling systems for machining systems [93,94]. It is found that it is necessary to improve the lubrication system to reduce energy consumption [95]. Some important measures from previous research were reviewed to enhance cutting environment using the minimum quantity lubrication [96], near dry machining [97], electrostatic solid lubrication [98], novel lubricant system [99], cryogenic machining [100] and other assisted machining [101]. Besides, the energy consumption optimization of machine tool equipment components mainly includes motor, cooling part and hydraulic part. At present, the challenge is to coordinate and optimize the energy consumption of each component based on the overall energy consumption of the machine tool system.

(3) Equipment energy saving control

The essence of equipment energy saving control is to complete the processing and production of products under the condition of the shortest running time of machine tools. **Fig. 5** shows the process that the feed system waits for the spindle until it continues to the next move. When synchronizing spindle acceleration/deceleration with the feed system at rapid traverse stage. Results show that this decreases the power consumption from 5.41 kWh to 4.83 kWh. A life-cycle energy consumption of milling machine was analyzed [102], and results demonstrated that several relevant variables (i.e., automation, machining environment, transportation, facility inputs and material inputs) could impact on energy consumption. According to previous literature research and experimental verification, several conclusions were suggested to improve energy efficiency of machine tools [94]. For the developed optimization method and system, it is necessary to study energy consumption characteristics and optimization strategies of machining systems from the software system level. A software framework for machine tools was presented [103], and two methods were developed using the software framework: one was used to identify and automatically reduce peak power between connecting machine tools, and the other was used to monitor and improve the quality of workpieces. **Fig. 6** showed peak values of two connected machines before and after optimization by adoption of proposed systems [104].

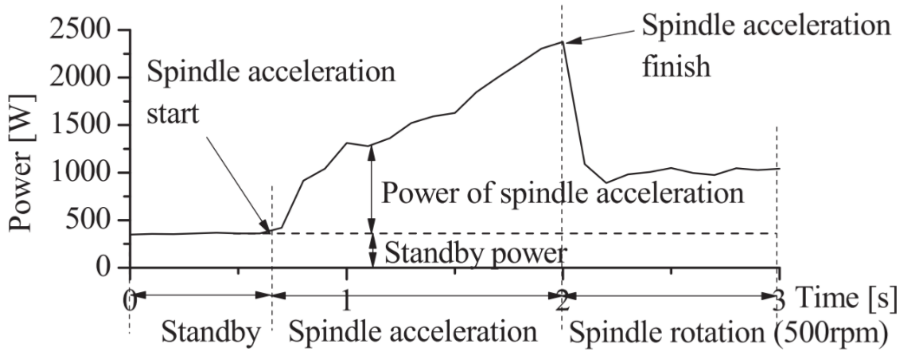

Fig. 5 Power profile of spindle acceleration for CK6153i CNC lathe [84] Copyright 2016, Elsevier Ltd.

Existing studies focus on developing various optimizing methods and systems to cope with the energy saving problem in machining. Experimental methods were conducted by many scholars to identify energy characteristics, and some energy saving strategies were given accordingly [105].

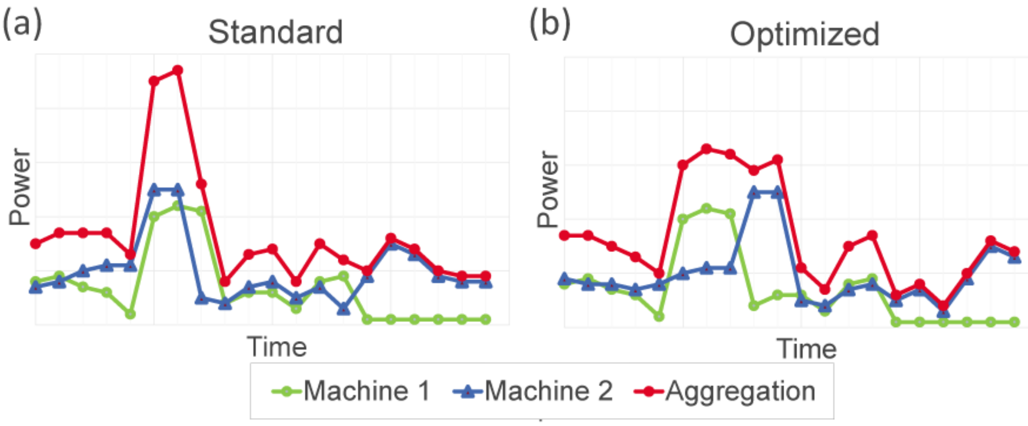

Fig. 6. Conceptional power peak of two machines at the same time (a) Standard; (b) shifted peak of one machine for less grid load [103] Copyright 2017, Elsevier Ltd.

5.2 Optimization of processes and parameters

The research of process and parameter optimization mainly focuses on new energy-saving process, parameter optimization model and method and process planning optimization.

(1) The new process

New energy-saving processes include micro-cutting, high-speed dry cutting, and process simulation, all of which help reduce energy consumption during machining. The use of mechanical micromachining to produce micro-devices is a flexible approach that can reduce energy consumption. Micro-cutting is a machining process mainly including micro-milling, micro-linear cutting, and laser micro-cutting [106]. First, the reasonable cutting tool and microscopic geometry of the cutting edge can not only stabilize the cutting edge, but also have a positive effect on the cutting force, surface roughness and energy consumption during micro-milling [107,108]. By comparing the energy consumption of traditional CNC machine tool and micro-milling equipment, it is found that the energy consumption of traditional CNC machine tool is higher than that of micro-milling equipment [109]. As a new method of laser cutting, laser sawing strategy is still the most cost-effective green manufacturing and rapid processing technology [110].

Process simulation technology is a virtualization technology supported by computer-aided technology and virtual reality technology, which opens a new situation for the research of energy-saving technology. Over the past two decades, both industrial and academic communities have contributed to a large knowledge base on numerous virtual reality topics [111].

(2) Parameter optimization model and method

The energy consumption varies with processing conditions, and energy consumption could be reduced if appropriate process parameters are selected [112-114]. For example, response surface methodology (RSM) was developed through optimizing machining parameters with consideration for energy consumption in turning process [115]. An enhanced energy consumption analytical model was developed based on decomposing machine tools into several energy related components. The proposed model was optimized to obtain optimal cutting parameter set that satisfy the minimum energy consumption criteria in CNC machining centers [116]. A virtual machine tool (VMT) model for evaluating energy consumed in machining was developed considering machine tool design and changing optimization objectives. The model was solved using GA for optimization of machining condition to reduce energy consumption [117]. An approach for optimizing cutting parameters with the aim of improving energy efficiency and reducing machining time was proposed in machining systems [118]. A multi-objective optimization model (MOOM) to improve energy efficiency of CNC machine tools and to minimize the total completion time was proposed, and the multi-objective particle swarm optimization algorithm using crossover method was utilized to solve the proposed model [119]. According to power consumption characteristics of multi-pass CNC face milling, a MOOM based on the adaptive multi-objective particle swarm optimization algorithm method was presented for optimizing the cutting parameters of each pass considering the maximum energy efficiency and minimizing production costs in multi-pass milling [120].

Some literatures focus on the state-of-the-art optimization algorithms combined with experimental studies [121]. These models can be divided into two categories of single-objective optimization models and multi-objective optimization models. For the first research group, studies focused on investigating the effect of machining parameters on energy consumption [122,123].

(3) Process planning optimization

Process planning directly affects the quality of products and energy consumption in manufacturing processes. This paper summarized existing studies from the process method optimization to optimize the process planning with the objection of improving energy efficiency in manufacturing systems.

Selection of production method is a critical measure for reducing energy consumption and carbon emission in manufacturing. Operators need to select proper processing method e.g., determining optimal tool path and selecting optimal machine tools [124-126]. A simulation tool based on an agent-based modeling approach was devised to identify the potential with self-organization process planning in decentralized manufacturing systems [127,128]. This method focused on selecting the optimal machine tool with minimum energy consumption. The sequence of the features of part had a great influence on the actual cutting volume [129] and energy consumption of machine tools [130]. A single objective optimization function based on the non-cutting energy consumption of machine tools was introduced [131]. A novel planning tool using hybrid simulation-based method and an extended GA was designed to increase both machining energy efficiency and performance [132]. A study on identifying and estimating impactful process steps and related design features was presented based on an existing process plan considering cost and environmental influence, then, alternative process plans were determined to minimize ~~the~~ energy consumption [133].

The existing research on process planning optimization aims to arrange the optimal processing sequence to reduce energy consumption. At present, we still face many challenges, such as reducing energy consumption and ensuring product quality.

5.3 Production scheduling and management system

Energy consumption of manufacturing systems is often affected by many factors such as ~~the~~ process planning, production scheduling, system accuracy and equipment environment. Therefore, in order to achieve energy conservation and emission reduction, it is very necessary to optimize ~~the~~ process technology and production scheduling [134]. The research of production scheduling optimization mainly includes logistics optimization, equipment configuration and management system.

(1) Energy-oriented logistics optimization

Many mechanical manufacturing projects are classified as multi-mode resource constrained project scheduling problems, which have attracted extensive attention in recent years [135]. At present, the research is mainly focused on workshop logistics optimization, including logistics routing and logistics scheduling.

In recent years, automated guided vehicles (AGVs) have been applied to manufacturing shop floor logistics, which operate in a guided path network. An autonomous guided vehicle (AGV) is a driverless vehicle that automatically follows a planned path through a variety of guidance and control methods [136]. In manufacturing industry, AGV path optimization is an effective method to reduce energy consumption of workshop logistics. In vehicle routing problem, the location of vehicle depot is the key factor. A hierarchical particle swarm optimization (PSO) was proposed, which including inner and outer layers to obtain the best location to establish a depot and the corresponding optimal vehicle routes using the determined depot location [137]. Synchronous scheduling of multiple AGVs has great potential to reduce logistics energy consumption, but it is difficult to achieve. To solve this problem, a framework was introduced and it is based a disjunctive graph to modeling the joint scheduling problem and a memetic algorithm for machines and AGVs scheduling [138]. Finally, the fertile areas for future study of AGV scheduling and routing was pointed out [139].

Task allocation and resource optimization methods in the field of intelligent manufacturing can solve the practical problems of idle equipment and low resource utilization in a large number of intelligent workshops, which is conducive to improving workshop production efficiency and reducing energy consumption.

(2) Device configuration

There are still many problems in ~~the~~ workshop production, e.g., how to reduce work steps, optimize resource allocation, improve production efficiency and reduce production cost. The optimization of the production scheduling has been regarded as an effective measure in addressing the above problems by reducing unnecessary energy waste of machining systems from the production management level [140].

Many researchers acknowledge that ~~the~~ control of the machine tool status (e.g., on/off, etc.) is the simplest way to save a large proportion of energy consumption during machining operation and has a positive effect on economic benefit [141]. According to the idle time of the machine tool under different operating conditions, the energy saving control profiles were analyzed, and the power consumption of NC machine tool can be reduced [142]. A mathematical model with minimum energy costs for single machine dispatch was established, which takes into account the change of energy price [143]. The scheduling method was able to make decisions to the optimal startup time, the launch time, idle time at machine level, and to enable the decision makers to select the lowest cost production scheduling in production process. A control method combined the state-based energy consumption model with graph-based optimization theory was developed so that the machine controller can make some decision to select the optimal energy-optimal state sequence during non-processing time in order to realizing energy reduction [144]. Reasonable equipment configuration in the production workshop is a new energy-saving strategy, including equipment spatial layout and use scheduling.

(3) Energy management system

Since energy consumption is not an independent performance, there are many associated performance criteria, such as time, makespan, carbon footprint and energy price [145]. Mathematical models, statistical analysis and optimizing algorithms are widely used for solving the multi-objective production scheduling issue.

A multi-objective optimization model for flexible shop floor environment was established [146]. An improved evolutionary algorithm together with the global criterion was used to solve this model. A novel multi-objective mixed integer programming formulation for the shop floor scheduling problem was developed, where energy consumption, peak energy load, cycle time and carbon footprint have been considered [147]. Two complicated multi-objective scheduling problems including a batch-processing scheduling problem and a triple-criteria scheduling problem were investigated and solved on the basis of the non-dominated sorting-based genetic algorithm II (NSGA-II) and an adaptive multi-objective genetic algorithm (AMGA) to reduce both energy consumption and carbon footprint [148]. A generic method for simultaneously minimizing the energy cost and improving the energy efficiency of machining process was proposed in which a state-based energy model by using finite state machines method was built for detailed energy consumption simulation of a single machine [149], which contributed to energy-efficient, cost-effective and demand-responsive machining processes.

Other approaches for optimizing production scheduling also play an important role in improving energy efficiency. For example, an approach that combined the energy-aware scheduling (EAS) model with advanced planning and scheduling (APS) system was proposed to optimize a given schedule and to reduce the workshop power's peak [150].

6. Energy benchmarking towards sustainable manufacturing

Energy benchmarking is practical for understanding energy use patterns, identifying inefficiencies in energy use, estimating potential for energy conservation, and designing policies to improve ~~the~~ energy economy [151]. Generally, the energy benchmarking can be classified into three levels: the national level, industrial level and a certain system level [152]. **Fig. 7** shows the development of energy benchmarks. This sector illustrates the energy benchmarking from perspectives of labels, standards, benchmarking models and methods.

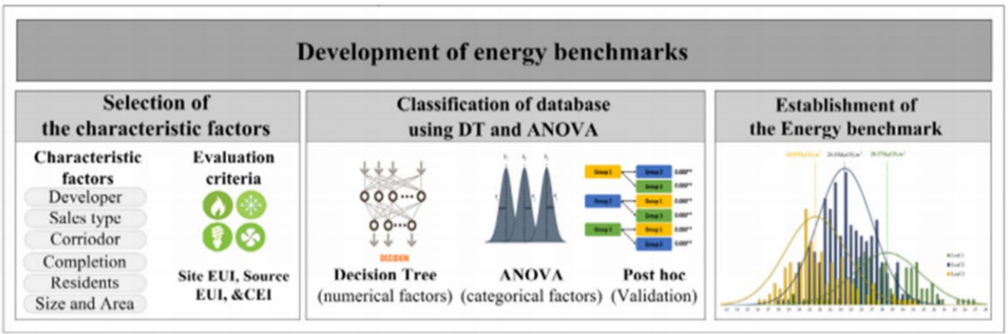

Fig. 7 Development of energy benchmarks [152].

The concept of energy-efficiency labels and standards have been developed and implemented for many products [153]. More and more countries are aware of importance of energy-efficiency labels and standards to a certain product to remove cost-ineffective, energy-wasting products from marketplace and stimulate the development of cost-effective, energy-efficient technology [153,154]. U.S. Agency for International Development developed the energy-efficiency standards and labeling programs for appliances, equipment, and lighting products. In their guidebook, energy-efficiency labels are divided into endorsement labels and comparative labels. Endorsement labels are mainly ’seals of approval’ provided according to the specified standards. Comparing labels allow consumers to use discrete performance categories or continuous sizes to compare the performance of similar products. There are three types of energy-efficiency standards [154,155] including

- prescriptive standards,
- minimum energy performance standards (MEPS),
- class-average standards.

From an industrial point of view, an energy benchmarking analysis generated two significant perspectives. First, it can reveal the performance of a particular industry in managing energy efficiency. Second, it can enable companies to participate in benchmarking and comparing the performance of their factories with industry-wide metrics, which can support strong energy management programs and implement innovative technology and process concepts for industrial plants [156]. An example was that ENERGY STAR of the U.S. Environmental Protection Agency and the U.S. Department of Energy utilized a commercially available database - the Major Industrial Plant Database™ (MIPD) to develop plant energy performance indicators or energy performance benchmarking for manufacturing plants [151]. Various industries have addressed some definitions and methodologies of establishing ~~the~~ energy benchmarking [157]. In conclusion energy benchmarking help enterprises gain better awareness of energy utility, strengthen energy evaluating and optimizing, and improving the competitiveness of today's manufacturing industry.

At the third level, there are many different definitions of energy benchmarking in mechanical manufacturing systems according to ~~the~~ different operating processes, objects and application [66,158]. Considering production time, processing cost and other production requirements, some specific benchmark like the multi-objective energy benchmark [159], dynamic energy benchmark [160] were studied, which can be used to grade the actual energy consumption in comparison with the energy benchmark. To have a better understanding of energy benchmarking and a crucial contribution to development of the energy benchmarking and application, the second rule of energy benchmarking including a benchmarking rating and energy benchmarking evaluation grades were proposed [161]. At the benchmark framework aspects, some studies on product energy consumption benchmark have aroused the attention in the discrete manufacturing industry [162,163]. A holistic energy benchmarking was constructed from three dimensions of a company namely organization, systems and culture. The framework of the proposed energy benchmarking~~, which~~ includes three layers: Heating, Ventilation and

Air Conditioning layer, (Energy) purchase layer and production layer [164]. At the benchmark application aspects, a systematic approach to energy efficiency benchmarking in injection moulding was presented [165] This method has been successfully applied to a real case of engine blocks machining line, and it reflects the significant results in terms of energy use, energy waster, value/efficiencies of benchmarking as well as potential energy optimizing opportunities.

Energy performance management are the focus of enterprises in manufacturing industry. They are eager to integrate energy consumption considerations into their company strategy. Obviously, companies often lack transparency and technology to achieve their strategic energy goals despite they have implemented energy optimizing strategies. Hence, energy benchmarking plays an important role in comparing and improving energy efficiency. Some concepts, classification and some models of energy benchmarking should be enhanced from the nation, industries and machining process perspective. Energy benchmarking especially in manufacturing is a promising tool that will assist decision makers in

- learning about peer field experience with energy benchmarking,
- identifying the effectiveness of energy monitoring, evaluating and optimizing efforts,
- understanding energy data; facilities; and cultural and political, and human resources necessary to achieve their goals [154],
- designing, developing and implementing energy benchmarking in manufacturing system.

However, the research of energy benchmarking towards manufacturing systems is still insufficient as there is a lack of effective methods and criteria on energy efficiency management that allow a comparison between the machining systems of different plants. Therefore, there is the need to develop effective energy benchmark in manufacturing systems.

7. Discussions with regard to energy performance improvement

In the existing works, a lot of efforts have been made to solve the issue of energy efficiency in manufacturing from perspectives of monitoring, evaluation and optimization and benchmarking mentioned above, but there are still several challenges and some potential opportunities.

(1) Energy monitoring

Emerging technologies such as big data, cloud computing, Internet of things and mobile Internet are developing rapidly. Digital technology and energy monitoring technology are deeply integrated and widely used, which has profoundly changed the management mode in the field of energy monitoring in manufacturing. However, it is still a huge challenge to accurately monitor energy performance due to the complexity of manufacturing systems. The difficulties are mainly manifested in: (i) inadequate energy data sharing, which it is hard to realize the aggregation and integration of various energy data; (ii) Insufficient grasp of energy consumption data on the customer side and lagging customer demand perception; (iii) Lack of advanced digital technology monitoring means to grasp the energy consumption of users in real time; (iv) Low utilization rate of energy data resources, in-depth mining of data value to be improved, semi-structured data and unstructured data to be utilized. In the future, it is necessary to further build a big data center platform for energy monitoring, carry out comparative analysis of multi-dimensional energy efficiency data, and build an intelligent monitoring system that can better adapt to the harsh environment (e.g., damp, low temperature) that directly affects energy consumption, so as to comprehensively improve the digital and intelligent level of energy monitoring and management system for manufacturing enterprises.

(2) Energy evaluation

Energy performance evaluation method has its applicable scope and conditions. It is hence important for energy managers reasonably to determine the evaluation criteria according to the different purpose and target of energy performance evaluation for various energy efficiency evaluation models and strategies in manufacturing systems. In fact, the energy consumption evaluation indicators, models and strategies of manufacturing systems are interrelated. The calculation and selection of energy evaluation indicators depend on energy evaluation models and energy evaluation methods respectively and energy evaluation models correspond to various energy evaluation methods. Manufacturing systems can be divided into different levels, so overall energy efficiency is the result of combining the levels of energy efficiency. The current challenges in this area are: (i) Coordinating the relationship between energy efficiency evaluation of all parts of the manufacturing system and overall energy efficiency evaluation, (ii) Establishing accurate energy efficiency evaluation models and corresponding energy efficiency evaluation strategies and indicators. (iii) Because the forms of manufacturing system are diverse, the establishment of energy efficiency evaluation model is particularly complex. Future development should pay more attention to the establishment of standardized and universal energy efficiency evaluation models, the energy benchmarking of mechanical products and manufacturing tasks, and the formulation of complete energy efficiency indicators of processing systems. In addition, it also needs more research efforts, from the perspective of energy, economy, using the method of system analysis, and from the perspective of society and ecology.

(3) Energy optimization

In terms of machine tools, with the rapid development of lightweight design technology and new materials, a new situation has been opened for the energy efficiency optimization of machine tools. In the power part of machine tools, more and more scholars have noticed the importance of the optimization of key equipment such as new motors for the overall energy consumption of machine tools. For the control strategy of machine tool, it is mainly to reduce the waiting time of machine tool. In terms of process, the hot areas of research include new energy-saving processes and planning between processes. In the production workshop, the main ways include efficient management of logistics and rational allocation of equipment. There are still some challenges in this field, (i) the research of new motors and the simplification of machine tool transmission mechanism, (i) the development of new energy-saving technology, (iii) the coordination of machine tool spatial location configuration and logistics management. Energy optimization is expected to have excellent performance to develop new motors and new energy-saving process technology, simplify machine tool transmission mechanism.

(4) Energy benchmark

Benchmarking and comparison of ~~the~~ energy efficiency in manufacturing is one of the critic challenges to implementing of the successful energy management. some input energy efficiency and output energy efficiency are considered as invisible resource for manufactures to share, which leaded to a lack of transparency and detailed information towards energy consumption management in manufacturing. Therefore, there is urgent need to develop and improve energy benchmarking as an analytical and management tool that can contribute to the sharing of energy data and knowledge in manufacturing. In this context, energy performance certification as an important tool to manage energy consumption, identify energy saving potential and directly demonstrate ~~the~~ energy performance level should be established [153]. Energy benchmarking rating system is core of energy performance certification to judge the energy usage level compared to the ideal energy usage of manufacturing processes. To date, energy rating system is used primarily for building industry. For example, U.K. issued the Display Energy Certificate for operational rating, which provided a standard value of building's CO_2 emissions (0-150) in seven grades, from A to G [166]. In the mechanical manufacturing industry, an energy rating system could be designed as Fig.7.The fine energy benchmarking method, new tools or systems of energy benchmarking, and various related energy standards based on energy benchmarking for manufacturing systems or manufacturing product will be the focus of future research, which helps promote sustainable development of manufacturing enterprises.

8 Conclusions and outlook

Methods of energy performance improvement can significantly reduce energy consumption, while reducing CO_2 emissions from machining process. This paper reviews the latest methods of energy performance improvement. However, there are little literatures conducted from the perspective of ~~the~~ thorough technology and knowledge integration. This study ~~is~~ innovated in dividing the methods of energy performance improvement into four aspects and summarized the challenges and development trends of some methods.

Monitoring approaches and energy monitoring systems are provided to achieve real-time energy monitoring and statistical analysis of ~~the~~ energy in machining systems. Energy monitoring includes energy efficiency monitoring methods and energy efficient monitoring systems. Energy monitoring depends on mostly manual energy information measurement together with various monitoring algorithm. Since these methods are cumbersome, as well as the complex development of manufacturing systems, energy efficient monitoring system seems to be more promising that can be easily adapted to flexible and large system by using advanced data processing technology and artificial Intelligence technology etc.

In this endeavor, this work introduces three levels of energy evaluation: energy evaluation indictors, energy evaluation models and energy evaluation methods. The energy efficiency evaluation index and model are divided into three aspects: system oriented, process oriented and workpiece oriented. The major limitation of most of the existing energy models is that they don't consider sufficient energy related information like ~~the~~ cost, maintenance and environment. Based on these models, energy consumption evaluation methods are provided to help energy managers adopt appropriate assessment approaches. In addition, several systematic and standardized energy efficiency assessment index systems are presented to help decision- makers design relevant energy policies more efficiently for manufacturing systems.

Besides, approaches and techniques for energy saving have been presented. First, the energy consumption of the production system can be optimized by improving the equipment, such as~~,~~ lightweight design of machine tool spindle, energy consumption optimization of motor and transmission structure of equipment, and energy-saving optimization of machine tool control strategy. Secondly, developing new energy-saving processes, optimizing process parameters and process planning are effective ways to optimize energy consumption. A large part of the energy loss in workshop logistics and unreasonable production scheduling. Therefore, it is necessary to optimize the workshop logistics path, equipment configuration and management system. How to reduce work steps, optimize production scheduling and optimize resource allocation is a challenge for researchers.

Finally, the concept, classification and models of energy benchmarking are introduced from the nation, industry and machining process perspectives. Energy benchmarking can be used to determine and improve energy efficiency throughout manufacturing process. There is a lack of transparency in regards to energy efficiency sharing as competition for energy and economic improvement between peer companies, and there is a lack of detailed information and data on products, machines and plant to set up an energy benchmark. Through energy rating and energy labeling, manufactures could transform their machining activities into more ecologically productive processes, and customs have some insight into products energy information, which will increase public's awareness of the usage of energy-saving products and encourage users to make full use of the overall efficiency potential of the product. This also benefit the whole country for it strengthens economic and energy development and meet goals to reduce CO_2 emission.

Furthermore, some discussions for methods of energy performance improvement are summarized from aspects of the energy monitoring, evaluation, optimization, and benchmarking to identify some major barriers from knowledge and technology. Significant opportunities towards energy-efficient and sustainable manufacturing are presented together with their potential applications. In summary, the review and analysis on the methods of energy performance improvement are an important reference for enhancing energy management and monitoring and improving energy efficiency of manufacturing industry.

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