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Promoting Green Manufacturing Technology Diffusion Using Innovative Policy Implementation Methods

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Abstract: This paper presents initial findings on current innovative policy approaches to promote green manufacturing technology diffusion in China, which were gathered through a case study of the electric motor upgrading project (EMUP), and it examines the degree of success of local governments' effort to encourage the adoption of high-efficiency motors (HEMs). The barriers to green manufacturing technology diffusion are explored to showcase the challenges faced by local implementers. This research demonstrates the accomplishments of various regions, with an emphasis on Dongguan City which has enjoyed great success in using subsidies and financial tools to promote the use of energy performance contracting as an innovative financing mode. Finally, this paper analyzes the methods and outcomes of the EMUP, thus far to explain the reasons behind the success of this initial phase of implementation. Further research will be needed to monitor the progress of this initiative. This article summarizes the policy system, and describes new models that will help promote energy conservation and environmental protection initiatives within strategic emerging industries.
Keywords: green manufacturing; energy saving and emission reduction; innovative mode

1. Introduction

Since the beginning of China's market reform, the China's economy has witnessed incredibly rapid and intense growth. At the same time, the nation's natural resources and environment have paid a high price to sustain this rapid rate of development. At present, China's energy resources, natural resources, and environment have been expoited to the fullest extent, which leaves no room for further development based on the current growth model. However, to maintain its steady economic growth, China must transit to a path of green development. China's 12th Five-Year Plan has called for a focus on green development and sustainable growth as the guiding models for China's continued prosperity, as dictated by the principles of China's socialism. This work is fundamental in maintaining the foundations of the nation's economy and is vital to upgrading China's industries in order to remain highly competitive in the 21st century.

In order to put China firmly on the path of green development, the China's governments has taken a two-pronged approach aimed at prioritizing environmental protection and using innovative technology to reduce the impact of pollution by improving the efficiency of China's industrial sector and other energy consumers. At present, China's total energy consumption (TEC) is among the highest in the world, and its total energy efficiency (TEE) is low. Hence, the need to improve energy saving is great. In 2014, China's gross domestic product (GDP) energy consumption per unit was 2.14 times the global average, and was 4.56 times the Japan's [1]. If China could reduce its energy consumption by half through improving its energy saving while restricting any further increases in consumption, it would double its competitive advantage in terms of its GDP. At the same time, if China could reduce its energy consumption to the

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same level of Japan's, its competitive advantage would quadruple. Therefore, improving the TEE is a top strategic priority for China.

Energy saving in the industrial sector is of great strategic importance in China's energy dilemma, as the nation's industrial sector accounts for more than 56% of the country's TEC [2]. Upgrading manufacturing equipment like electric motors is vital to reducing the demand for energy in many areas, which in turn will lead to a reduction in the energy supply and carbon emissions from power plants. This type of public project is a major area of work that the China's governments needs to kickstart and support, but market forces will drive the adoption and ultimate success of the above-mentioned technologies. One must also consider the unique circumstances of each region and the distinctive approach that each local governments needs to take. When considering upgrading the industrial equipment of an area, it is necessary to factor in the local manufacturers' competitiveness and local economy's health [3] because the motivation derived from these enterprises will be key to ensuring the success of green manufacturing technology diffusion in the region. There is a high degree of uncertainty and risk in adopting new green manufacturing technology, so it is necessary for local governments to reduce barriers by taking a decisive and commanding approach through mandating changes in the initial phase.

In this paper, the challenges of green manufacturing technology diffusion are examined through a case study of the electric motor upgrading project (EMUP), and the problems associated with this policy implementation method are identified. The unique feature lies in how high-efficiency motors (HEMs) are adopted through the demonstration project, which serves as a platform for promoting the spread of green manufacturing technology among manufacturing enterprises by showcasing the results of adoption. This study attempts to answer several research questions, which can be summarized as follows: What are the primary barriers to the initial phase of implementation of the EMUP? Can better policy results be achieved through policies and measures deployed by local governments? What is the significance to the China's government of these policies and measures for future energy-saving management strategies?

2. Barriers to green manufacturing technology diffusion and the electric motor upgrading project (EMUP)

Demonstration projects designed to promote specific technologies can break technological barriers and accelerate industrial innovation by testing the efficacy of new technologies and reducing the uncertainty that potential adopters may have. This will, in turn, support the development of strategic emerging industries like the green manufacturing sector. According to recent research on such projects by Zhou et al. [4], most green manufacturing technology diffusion research has focused on the promotion of innovational systems through demonstration projects, especially in terms of achieving ecological sustainability and with a heavy focus on the development of new energy technology. However, few people pay attention to innovation in green manufacturing technology at the mainstream level, especially in the marketplaces of developing countries.

The barriers to green manufacturing technology diffusion can be divided into the following three categories: technical barriers, non-technical barriers, and special obstacles. The main technical barriers are related to issues such as safety, reliability, feasibility, applicability, and compatibility of the new green manufacturing technology with existing technologies [5]. Non-technical barriers of green manufacturing technology include information asymmetry, a lack of confidence in performance standards, professional certification, uncertain payback periods, limited financing channels, increases in additional expenses, dissatisfaction with infrastructure, equipment providers, and dissemination channels, inability to control the cost of repairs and maintenance services, vague or overly strict management regulations, and conflicts of interest among stakeholders. In particular, small- and medium-sized enterprises (SMEs) are more willing to invest in expanding production capabilities than in low-priority energy-saving projects. Thus, investment in energy-saving management strategies is low, and SMEs rarely adopt green manufacturing technology [6]. In general, green manufacturing demonstration projects require a multimodal policy approach to be successful [7], as the actualizers must deal with many obstacles and therefore need a combination of policy instruments [8]. However, to be effective with such tools, the implementation of green manufacturing technology requires a clear policy framework and goals. This research is based on the "technology-push" and "demand-pull" policy framework. "Technology-push" policies include government funding of innovative research and development, learning advanced technology, education and training, etc. "Demand-pull" policies can increase revenue and promote innovation through market-based demand and include, for example, the protection of intellectual property rights, tax breaks, and tax reimbursement of customers to buy new technology [9]. A literature review shows that the multimodal policy approach has the effects of technical testing and certification, promoting study and communication, and reducing the risk of economic. This article attempts to explore, through EMUP practices and the typical financial innovation model of the city of Dongguan, how local governments have overcome obstacles to green manufacturing technology diffusion using policy tools and framework.

3. The state of the EMUP at the national level

Electric motors are widely used in the metallurgy, petrochemical, coal, building materials, and paper industries. According to data released by the Ministry of Industry and Information Technology (MIIT) of the People's Republic of

China, China has about 1.7×10^9 kW of electric motor capacity and consumes about 3×10^{12} kW·h of electricity per year. Electric motors are responsible for 64% of the nation's total electricity consumption. Motors of industrial sector consume 2.6×10^{12} kW·h of electricity and account for 75% of the sector's energy consumption [10]. To further improve the efficiency of China's electric motors, the MIIT, in conjunction with the General Administration of Quality Supervision, Inspection and Quarantine of the People's Republic of China, established the EMUP on June 28, 2013through the announcement of the *Motor Efficiency Plan (MEP) of 2013–2015* [10]. This plan proposed the objective of completing upgrades in five years, including: spreading the HEMs to achieve a total of 1.7×10^8 kW, eliminating inefficient motors with a total of 1.6×10^8 kW, implementing energy-saving upgrades to motor systems with a total of 1×10^8 kW, and implementing efficient remanufacturing of motors with a total of 2×10^7 kW. These motor efficiency upgrades were kickstarted by a national initiative and road map, and local governments of provinces and cities issued sets of unique policies, measures, and practices to achieve the MEP , as shown in Table 1.

3.1. Executive-order policy

To realize the EMUP fully, the China's government has mandated the closure of inefficient production facilities through executive orders of the State Council, forcing industrial enterprises to comply with the aims of this initiative. The heavy industry sector includes some of the most energy-intensive industries in China, such as steel, chemicals, cement, and other enterprises whose energy consumption accounts for more than 70% of the nation's annual total [3]. The modernization of the heavy industry sector relies on technological breakthroughs and government pressure to phase out underperforming production facilities. The nation's target-oriented responsibility system serves to strengthen the enforcement of backward production facilities. The MIIT, for example, issued a report cataloging all of the energy-intensive and outdated electro-mechanical units currently in use as the basis of enforcing this policy of phasing out inefficient equipment. Executive-order policy has the ability to eliminate backward production capacity through mandatory measures. However, owing to a large number of entities that must undergo the "downsizing large-to-little" process (converting big businesses into SMEs), the governments' approach to upgrading SMEs must use more market-oriented means of incentivizing, supervising, and guiding these enterprises to achieve the goal of energy conservation.

3.2. Capacity-building policy

Capacity-building policy helps enterprises understand and adopt advanced green manufacturing technology to enhance their potential energy-saving capacity and energy management capabilities. This type of policy is characterized by guidance from governments, investment by enterprises, and market-oriented operation. The focus of such policy is mainly on improving energy-saving technology and management. However, it lacks appropriate policy tools to deal with the technical and financial risk faced by enterprises.

3.3. Economic incentive approach

The economic incentive policy approach mainly consists of energy subsidies, investments, and financing tools, such as funding, replacing subsidies with awards, interest subsidies, and settlement according to the real amount. The capacity development policy has three features: government guidance, entrepreneurial investment, and market-oriented operation. This policy approach is focused on energy-saving technology for the purpose of improving enterprise-level management. However, with this approach, proper policy tools to cope with technology risks and economic risks to the enterprise are lacking.

As a more traditional approach to green manufacturing technology-promotion policy, administrative-command policies make use of heavy government involvement in big business. However, when faced with an enormous quantity of SMEs, the executory costs of energy-saving target-oriented responsibility system are high, and the government needs to use economic incentives to mobilize resources in the energy market. Relying on energy-saving subsidy policies is not sustainable, and the government must depend on capacity building. In the end, companies rely on technology to promote sustainable development in manufacturing.

In the carrying out of a comprehensive, systematic demon-

Table 1. Types of policies for the EMUP.

Policy type	Measures	Characteristics	Advantages	Disadvantages
Executive order	Eliminate backward production capacity, energy-saving target-oriented responsibility system	Mandatory, top-down	Enthusiasm of the governments, effective for large enterprises	High execution costs, invalid for SMEs
Capacity building	Information guide, technology promotion	Demonstration, bottom-up	Technology push, improve competitiveness	Technical risk, financial risk
Economic incentive	Subsidies, investment financing	Capital guide, market operation	Solve financing problems, expand the market	Limited financial capital, unsustainable subsidy

stration project, motor efficiency is a key selling point of energy conservation and emissions reduction, playing a vital role in motivating manufacturers and other stakeholders. Executive orders, economic incentives, and the ability to implement constructive policy altogether will force inefficient production facilities to shut down while elevating the role of the marketplace in diffusing energy-conserving and emission-reducing technological innovation. Local governments need to implement a solid multi-tool policy platform that integrates the use of legal, administrative, economic, technical, industrial, fiscal, tax, financial policy, and governmental support to guide enterprises interested in energy savings. A full range of measures is required to stimulate the endogenous power of energy conservation and emissions reduction fully.

4. Dongguan's innovative implementation of the EMUP

The city of Dongguan is known as a manufacturing hub in Guangdong Province in China and also consumes the most electricity in the province. The Dongguan municipal government (DMG) has pushed the "ten thousand injection molding machines upgrading project" as part of its efforts to promote green manufacturing demonstration projects. The city has implemented a combination of local energy conservation policies, including using capacity-building as the primary means of policy and financial innovation to ensure high-level motor efficiency.

4.1. Current status of Dongguan manufacturers and electric motors

In 2013, Dongguan used more than 6×10^{10} kW·h of electricity. Of this sum, more than 4.5×10^{10} kW·h were consumed by the industrial sector, which has long been the largest consumer of electricity. Since the 11th Five-Year Plan was implemented, Dongguan's industrial electricity consumption has an average annual growth of 3.77%, with an added value of 9.56 % in the same diameter. This growth is 5.79% faster than the growth in industrial electricity consumption. However, Dongguan's level of power consumption per 10 000 yuan GDP still ranks highly in Guangdong Province, with more than 1 200 kW·h consumed per 10 000 yuan in 2013 (Fig. 1) [11].

In January 2014, Dongguan's Energy Industry Association carried out a motor efficiency study by sampling data from the city's 653 key power companies, showing that these plants have a total capacity of about 5.12×10^{6} kW. The total power consumption of local enterprises was recorded at 1.99×10^{10} kW·h in 2012 and accounted for about 45% of the city's industrial electricity consumption (4.4293×10^{10} kW·h). The papermaking and paper products industry had the highest electricity consumption rates for electric motors, accounting for 44.73% of the city's industrial electricity consumption (Fig. 2).

4.2. Implementation challenges for Dongguan

Dongguan's industrial enterprises face three problems: lack of awareness of the need for and benefits of motor efficiency and energy savings, lack of technical personnel to install and maintain efficient motors, and lack of capital to invest in green motors. Motor users in Dongguan are primarily SMEs that have had no previous contact with motor energy conservation projects and lack awareness of motor energy-saving methods. Because the motor is mainly used for each firm's main production line or is the primary source of all power, the user may worry about how the motor energy conservation transformation will affect normal production, quality assurance issues, safety, etc. Therefore, the user may not be willing to invest resources in motor energy-saving strategies. In addition, most of these enterprises lack professional and technical human resources, so they cannot implement energy-saving renovations on their own. The financial strain of implementing motor efficiency projects is another major challenge, especially in recent years because of

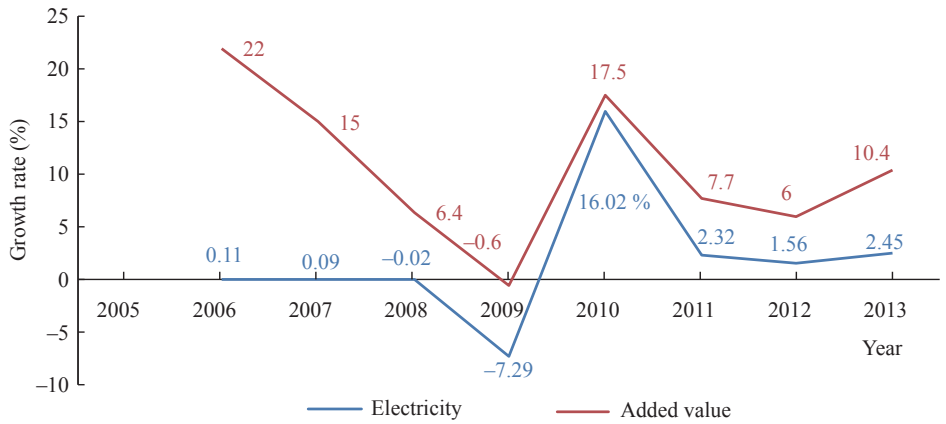

Fig. 1. Industrial power consumption and added value growth rates in Dongguan (2005–2013).

the economic downturn and weak market demand for increasing energy savings through retrofitting production facilities due to low enthusiasm. Finally, motor efficiency is not supported at the policy level. Despite the governments' supervision of retrofitting motors, there is a lack of clear basis for policy reform; thus, the retrofitting of small injection molding machine motors fully relies on enterprise alone.

4.3. Dongguan government's innovative approach to EMUP

Since 2013, the city of Dongguan has been using a multi-tool policy approach while aiming to resolve difficulties faced by the MEP (Table 2) [13]. In June 2013, Dongguan surveyed the city's stock of injection molding machines. At the end of July 2013, Dongguan issued the *Dongguan ten thousand injection molding machines upgrading project pilot scheme*. In October 2013, the city selected an energy conservation service company and refined its energy-saving reform tasks. In December 2013, subsidies and detailed rules for implementation were issued. In July 2014, the city began its online subsidy declaration system. The *Plan about promoting the integration of energy-saving service industry and finance industry to accelerate the typical demonstration project*

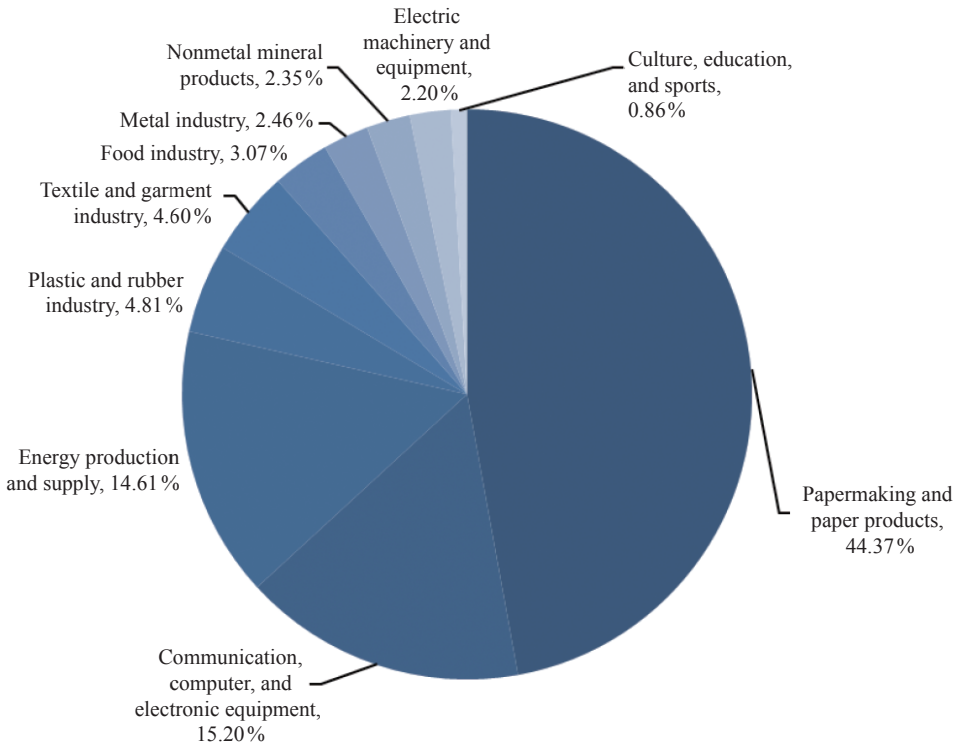

Fig. 2. Distribution of electric motor power consumption by industry in the city of Dongguan.

Table 2. Major multi-tool policies and promotional measures of the EMUP in Dongguan [12].

Time	Key events
Jan. –Mar. 2013	Dongguan set up pilot tests (two machines) for technology proofs
May. 2013	Xuhe Company became the exemplar firm and upgraded 10 machines
Jun. 2013	Dongguan organized a pre-survey, and the estimate was 20 000 machines.
Jul. 2013	Dongguan launched its official local policies, including subsidies (up to 200 yuan·(kW·h)$^{-1}$, according for 10% to 15% of the upgrading cost)
Aug. 2013	Dongguan accredited five energy conservation service companies
Aug. –Dec. 2013	County-level authorities launched additional subsidies (50–100 yuan·(kW·h)$^{-1}$)
Jul. –Dec. 2013	Local authorities organized information sessions (e.g., seminars, online surveys, official letters, official inspections, etc.)
Jan. 2014	Dongguan conducted the mid-term assessment (covering 638 firms) and affirmed that most firms acknowledged the receipt of information
May. 2014	Local authorities reported on progress to MIIT
Jul. 2014	The online subsidy declaration system started
Nov. 2014	The *Plan about promoting the integration of energy-saving service industry and finance industry to accelerate the typical demonstration project construction of energy saving and emissions reduction* was released

construction of energy saving and emissions reduction was released in November 2014.

The main measure of the proposal is to build a third-party guarantee into loan packages for new energy-saving reforms, which is shown as follows.

4.3.1. The introduction of financial credit through guaranteed financing for investing in HEMs through government support (Fig. 3)

Energy-consumption units will receive an energy-saving guarantee from the energy conservation service company for bank loans taken out to pay for motor energy-saving upgrades. The energy-saving guarantee ensures bank loans for energy-consumption units and produces a stable cash flow, at the same time it can ensure that the energy conservation service company receives a contract for energy management. Government subsidies are granted to the energy-saving users, and the bank also expands its customer base group and increases its deposits. In the end, the government uses subsidies and financial means to balance the interests of all parties and promote energy-saving projects and motor efficiency.

4.3.2. The promotion of a financial leasing model to reduce financial risks (Fig. 4)

According to the situations of partnerships and completion, governments provide installments to deposit in the pilot financial institutions. Pilot financial institutions provide an amplify credit with no less than 10 times the size of the risk compensation fund pool to support energy-efficiency management projects. When the implementation of motor energy-saving projects incurs losses

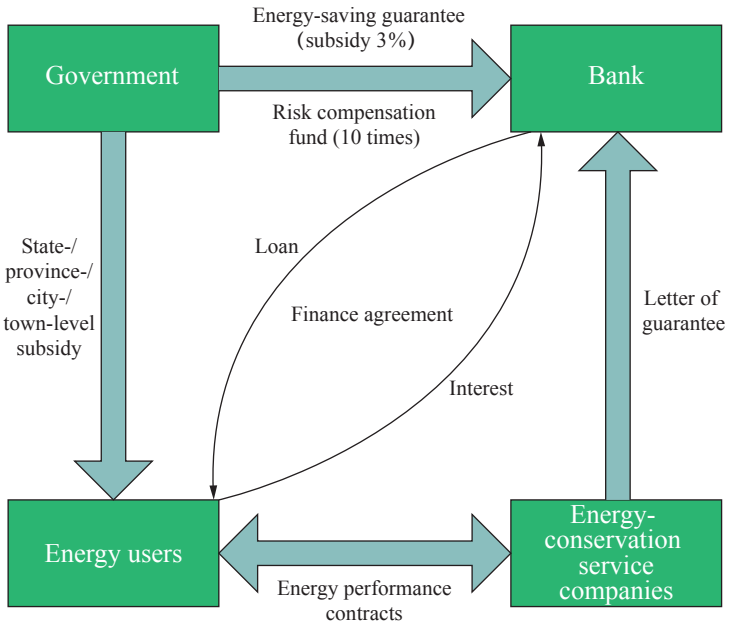

Fig. 3. Framework for financial credit through guaranteed financing model in Dongguan.

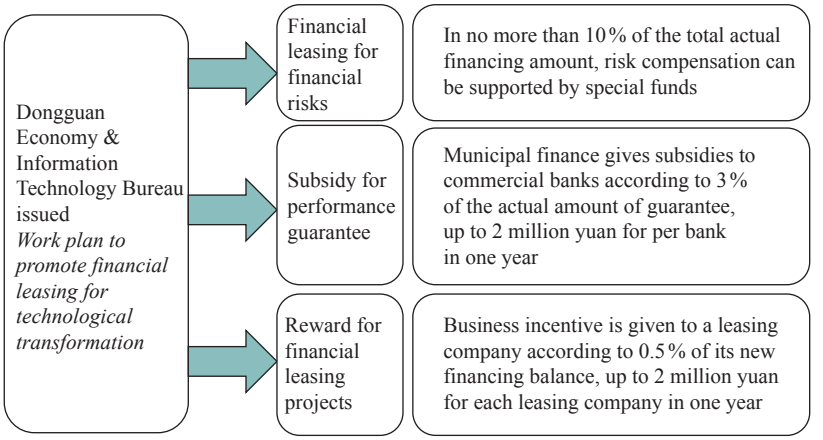

Fig. 4. Work plan and specific measures for promoting a financial leasing model in Dongguan.

because of open payment guarantees risks, the local government finances no more than 10% of the total amount of each financial institution through an issued letter of guarantee within the quota. A risk loss of more than 10% of the total limit shall be borne by the respective financial institutions.

4.3.3. The establishment of a third-party verification system to ensure proper implementation and operation of HEMs

Through public selection, the government entrusts a third party to carry out verification and resolve problems of the authenticity of the energy-saving effect. Approved by the letter of tender method, the professional third-party energy-saving audit institutions (hereinafter referred to as third parties), which are selected publicly, are entrusted with evaluating energy-saving effects of a project and issuing a professional inspection report, which can be used as the main basis for assessing energy-saving effect and applying for subsidies. According to the third-party inspection report, if the project achieves the intended energy-saving effect and meets the conditions of the contract, financial institutions will pay the energy-saving technical service units to provide an irrevocable letter of guarantee. The Dongguan government is responsible for organizing the third-party inspection, monitoring, and auditing work.

4.4. Preliminary summary of the EMUP in Dongguan

The city of Dongguan has initiated the first phase of the EMUP using a combination of policy tools, including executive orders, capacity-building, and a range of economic incentives, as well as innovative financial programs to solve the problems of upgrading electric motors.

4.4.1. Implementation by executive order

The town-level governments in Dongguan signed the motor efficiency target responsibility pledge with electric enterprises, in which motor efficiency target completion was an important component of the assessment of enterprise energy-saving goals. Dongguan strictly enforces the mandatory motor efficiency standards, reinforces the inspection and elimination of backward electric motors, and strictly prohibited enterprises to adopt the backward electric motor elminated by the formal decree of the state. An online declaration system provides support in real-time for upgrading old motors to comply with these regulations and reduces the execution costs of motor energy conservation policy.

4.4.2. Activities of capacity-building

A live demonstration event can help enterprises in Dongguan better understand motor energy-saving technology. By hosting training classes of motor efficiency inspection, the local governments and personnel from local manufacturers could improve proficiency with energy-saving, training, and basic knowledge of motor technology, motor energy conservation policy, and third-party verification procedures. Stakeholders would learn about technical authentication and eliminate information gaps about the upgrade. A demonstration would help to push forward a constructive policy and highlight the leading role of enterprise in promoting green manufacturing technology diffusion in SMEs through the fostering of informed choices and encouragement of active participation.

4.4.3. Use of economic incentives

Dongguan City awarded special funds for the energy-saving reconstruction of motor efficiency and injection molding machine servo, with the first prize benefiting 44 projects, including 23 motor system renovation projects and 20 injection molding machine servo energy-saving reconstruction demonstration projects, as well as an efficient motor replacement project. These projects received 20.6 million yuan in incentive funds. The Dongguan government, through the financial credit guarantee policy, expanded the risk compensation fund to 10 times. The government used a small amount of financial information to lever a large amount of financial capital, so as to reduce financing difficulties and resolve the problems of credit guarantee for motor energy-saving renovations.

4.4.4. Methods of innovative financing programs

The city of Dongguan has implemented a “three integration” (integrating energy conservation, industry, and finance) innovation model of upgrading enterprise energy-saving capabilities. This new model promotes the integration of the energy conservation service and financial industries in diffusing green manufacturing technology, and strengthens the supervision of the energy savings management system: first, help the energy conservation service company duly resolve the concerns of sharing benefit of energy-saving with the energy-consumption units; and second, help energy-consumption units eliminate misgivings for the technical ability of the energy conservation service company and for the results of project modification. Through this model of financial innovation, the concerns over technological and capital risks involved in energy-saving reforms of electric enterprises in Dongguan can be resolved. Further, the energy-saving marketization model provides an example for other cities to explore.

5. Conclusions

This paper summarizes the current status of China’s EMUP and the policy tools being used to achieve the goal of conservation, including executive orders, capacity-building activities, and economic incentive policies. Based on Dongguan’s “ten thousand injection molding machines upgrading” demonstration project, the findings successfully answered the primary research question of this study. The results reveal that demonstration projects can be used to promote the diffusion of green manufacturing

technology, and a combination of policy instruments and an innovative policy model can be used to overcome specific barriers during the diffusion. The case study of Dongguan explores a new model in China's sustainable development and innovation in the implementation of policy governing green manufacturing technology adoption on a regional scale.

The multi-tool policy approach differs from traditional policy models in many respects. First, green manufacturing demonstration projects may face various problems that are market-driven and be affected by the realities of the market economy. This is particularly true when facing large-scale technology diffusion problems regarding costs and benefits because of a large number of SMEs. Second, the government resolves these problems by prioritizing policies using "demand" in the marketplace to drive interest in economic payback for upgrading. In addition, the actors implementing policy in their supportive roles and enablers of market forces must be considered. Energy conservation service company, for example, can more effectively meet the needs of manufacturing enterprises in need of energy-saving services than enterprises themselves. Third, demonstration projects tend to be complex and cannot be relied upon as the sole policy tool to solve the problem.

These innovative policies in China also have some special characteristics. First, China is transitioning from the administration model to the market regulation and control model. Using the market as guidance, the top-level-designed policy framework and policy tool are receiving more and more attention. In this case, the Dongguan government realized that the traditional command-based approach to policy cannot mobilize enough market resources and therefore explored the use of stakeholders (such as energy conservation service companies) with shared interests. Second, to moderate China's high-speed growth with sustainable development, policymakers need to exercise patience in promoting the development of technology, so as to reduce market uncertainty and enhance the confidence of the potential users. New policy models, however, still require the coercive power of the China's government to ensure acceleration after the initial phase of implementation. Third, the existing advanced technology and economic conditions are very important in promoting the successful adoption of green manufacturing technology by SMEs. Many demonstration projects show that the successful diffusion of green manufacturing technology relies on the low-cost local technology and stable positive cash flow of enterprises. Considering abovementioned conditions, China should avoid slowing down in terms of technological innovation and economic development.

There are some limitations of this study. At present, it is only an exploration and pilot study, and summarizes the framework of a combination of policy instruments. The next step would require more case studies on policy framework. In addition, the policies and measures requires time to evaluate their full effects, and future policies governing electrical energy saving should continue to be studied. While this research focuses on government promotion of demonstration projects, a meaningful next step could approach the issue from the research scope of research institutions, industry associations, and competitors through a thorough comparative study.

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