

Study on Carbon Emission Reduction Strategy and Effect Evaluation of Manufacturing Enterprises

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ABSTRACT

Against the background of ongoing progress toward China's "dual carbon" goals, manufacturing companies are the largest consumers of energy and producers of carbon emissions, so they are feeling growing pressure to shift toward greener operations. Cutting carbon output matters not just for improving our ecosystems and environment, it also affects how companies control their costs, how well they compete in the market, and how much long-term development capacity they can build up. This paper looks at the real-world starting points, core approaches, ways to measure results, and supporting systems that manufacturing companies use to cut their carbon emissions, and it examines what specific contributions technology upgrades, better energy use, tighter process management, and digital tools make to cutting emissions overall. The work shows that manufacturing companies can only make their low-carbon transition more sustainable and effective, and reach the point where both green development and economic performance improve together, when they fully weave carbon-cutting steps into their daily production and operations and put a solid, science-based evaluation system in place.

KEYWORDS

Manufacturing enterprises; Carbon reduction; Low-carbon transformation; Effectiveness evaluation; Green development

1 Introduction

Manufacturing acts as a key pillar that supports the national economy, and it is also an area where energy use and carbon output are concentrated at relatively high levels. Over many years, manufacturing firms have helped a great deal in growing production sizes and making the overall industrial system work better. But this growth has come along with a number of problems: resource use intensity stays quite high, energy use efficiency varies a lot between different operations, and environmental limits on business activities are getting tighter all the time. As the idea of green development becomes more widely accepted and put into practice, cutting carbon emissions has turned into a major issue that every manufacturing business has to deal with. For individual companies, cutting carbon is not just something they have to do to follow official policy rules. It also directly affects how they manage their costs, how well their products can compete in the market, and how much room they have to grow in the long run. Starting from this context, this paper looks into the carbon-cutting strategies that manufacturing firms use, and how we can check whether these strategies actually work. The goal of this work is to create useful reference points that companies can use when they work to shift toward low-carbon operations and build higher-quality development paths.

2 Practical Foundation and Main Constraints of Carbon Reduction in Manufacturing Enterprises

2.1 The Practical Background for Manufacturing Enterprises to Promote Carbon Reduction

For manufacturing companies, working to cut carbon emissions comes both from pressure created by outside policies and from the internal needs companies have to change and improve their own operations. As ideas like green manufacturing, saving energy, and cleaner production become more widely accepted and applied, the standards that judge how well manufacturing companies compete in the market no longer only look at output volume, production costs and delivery speed. Instead, these standards are slowly growing to cover how well a company uses its resources, how effectively it controls pollution, and how high its carbon emission intensity actually is. For many these companies, cutting carbon is no longer just something they do to meet basic rules and regulations. It is also directly connected to how easily they can get financing, how the public sees their brand, whether they can stay in existing supply chains, and how much room they have to grow over the long term. This is particularly clear for export-focused manufacturing sectors, where green entry requirements keep going up year after year. If companies keep relying on production methods that use lots of energy and produce large amounts of emissions over a long period, their ability to compete in both domestic and international markets will get a lot weaker as time goes on.

Alongside this point, cutting carbon emissions in the manufacturing sector also sits on fairly solid ground built from real-world practice. After decades of growth in industry, a huge number of manufacturing firms now have everything they need to update their equipment, tweak their production processes, and adopt digital changes across the business. What's more, some of the most important manufacturing industries have already built up hands-on experience from upgrading

facilities to save energy and switching to more eco-friendly production methods. What stands out most is that many companies have already laid a solid groundwork in four key areas: tracking energy use, controlling production processes, running operations automatically, and collecting performance data. This existing work gives the support needed to carry out more organized, company-wide carbon cutting work. This means that when manufacturers work on cutting carbon today, they aren't starting from a completely blank slate. Instead, they are building on the management systems and technical tools they already have, and just pushing further to make operations more detailed, more organized, and less carbon-intensive. Keeping this fact in mind helps companies approach their transformation with a much more practical attitude. It also keeps them from writing off carbon reduction as nothing more than an extra financial burden they have to take on.

2.2 Prominent Constraints Faced by Manufacturing Enterprises in Carbon Reduction

Even though the need to cut carbon emissions is now widely accepted across industries, a lot of manufacturing companies still run into all kinds of barriers when they try to put these cuts into practice. One problem that stands out more than most is the inflexible energy structure most firms still use, combined with outdated equipment systems that have been in place for years. A number of these businesses have depended on conventional energy sources for decades, and their core production workflows are tightly tied to machinery that uses extremely large amounts of energy. If they try to change how their energy system is set up, they end up having to handle complicated problems like swapping out old machines, rebuilding production processes, and pausing manufacturing to update facilities. All these extra costs and disruptions make most companies very careful about making big changes in the near term. This caution is even more obvious in sectors like steel production, building materials, chemical manufacturing, and machinery processing. In all these areas, most key production steps need a consistent energy supply and work at very high thermal intensity, so sudden changes are hard to manage. Just cutting back on energy input will not actually deliver real emission cuts, and it can even end up hurting product quality and keeping production from running smoothly. So, cutting carbon in manufacturing does not usually mean lowering how much you produce overall. What it does mean is getting better efficiency from each unit of energy and higher output per unit of input, all while keeping your total production capacity at the same level it was before.

Another common issue that shows up again and again is that businesses have a really weak foundation for their carbon management work. Even though some companies have already done a bit of work on cutting their energy use, they still have not put together a full system for counting their carbon emissions. Because of this, they do not have a clear picture of what makes up their own carbon output, which sources create the most emissions, or how much they could actually cut those emissions down the line. Some companies only focus on straightforward direct metrics, like how much electricity, coal and gas they use. At the same time, they ignore the hidden emissions that get tied up in other parts of their operations: things like buying raw materials, moving goods around, leaving equipment on standby, fixing or reworking defective products, and working with partners across their supply chain. Other businesses might actually set formal carbon reduction targets, but they do not break those responsibilities down across different departments. They also miss consistent process monitoring and clear feedback systems to check if their efforts are working.

This leaves most of their carbon reduction work stuck at just being a slogan that people talk about, rather than something that actually gets done. In the end, the problems that manufacturing companies run into when they try to cut carbon emissions do not just come down to technical issues. They also come from problems with management awareness, organizational ability to get things done, and the evaluation mechanisms they use to track progress. All of this means that businesses have to push forward with their shift to low-carbon operations by thinking about the whole system as a connected whole.

3 Key Strategies and Implementation Paths for Carbon Reduction in Manufacturing Enterprises

3.1 Promoting Source Reduction Through Technological Upgrading and Energy Optimization

For manufacturing companies, the most straightforward and basic way to cut carbon output is to begin at the production source, cutting the energy used and emissions created for each unit of product by updating technology and making energy use work better. When we look at older, traditional manufacturing businesses, how well their equipment runs often sets how much energy they end up using. Older equipment that has not been updated generally has problems like more heat lost, higher energy use when it sits idle, and big swings in how it performs during operation. Even when these machines put out the same total amount of product as newer models, they still end up using more energy and releasing more carbon. Because of this, companies need to put their focus on replacing and upgrading equipment that uses too much energy. This means switching to high-efficiency motors, capturing leftover heat and pressure that would otherwise go to waste, adding smart control systems, and making energy-saving changes to the core production steps.

These changes do a better job of keeping emission cuts going over time without cutting how much a company can produce, when we compare them to just cutting back on production hours. They also fit better with the real-world needs manufacturing companies have to keep their operations running smoothly without unexpected disruptions.

Alongside upgrading technology, making changes to a company's energy structure matters just as much. Different energy types produce very different levels of carbon emissions per unit of energy. If a business keeps depending on just one type of high-carbon energy, the room it has to cut emissions will stay small even if it improves how it manages its production processes. Because of this, companies need to slowly shift their energy mix, raising the share of low-carbon options like electricity, natural gas, clean steam and distributed photovoltaic power. They can do this in line with their own industry features and production process rules, which cuts how much they have to rely on high-emission energy sources. For companies that operate in industrial parks and have the right conditions, they can also test out models like centralized energy supply, stepped energy use, and multi-energy complementarity to make their overall energy use more efficient. We have to keep in mind that changing an energy structure can't happen in a short time. It needs businesses to find a middle ground that works for three things: technological compatibility, what they can afford to spend, and keeping energy supply steady. This is also a real, on-the-ground issue that manufacturing companies have to pay close attention to when they work to cut their carbon emissions.

3.2 Strengthening Process Reduction Through Management Improvement and Process Optimization

Cutting carbon emissions doesn't just happen when companies swap out old equipment or switch to different energy sources. The way a business organizes its production line and handles its internal management can also change how much it actually cuts emissions directly. For a lot of factories, the fact that they use more energy than they need to doesn't only come from outdated gear. A big part of the problem comes from things like badly planned production schedules, slow movement of materials through the facility, bad coordination between different process steps, and extra waste that comes from having to redo flawed work. When businesses make small changes to areas like production scheduling, quality checks, storage and shipping, equipment upkeep, and how different steps work together, they can unlock a fair amount of emission cutting capacity without having to spend a lot of extra money on new things all at once. To give one example, adjusting how quickly production runs can cut the extra energy that gets wasted when machines have to turn on and off over and over. Doing more planned maintenance before things break can cut down on the time equipment runs without doing useful work. Getting fewer defective products done, and so less need to redo work, also cuts down on energy that gets used for no real gain. All these things count as common, practical ways to cut carbon by improving existing production processes.

At the same time, digital tools have started to act as a key support for cutting carbon emissions at manufacturing companies. In earlier years, when companies worked to cut energy use and lower emissions, they mostly depended on workers' personal experience and individual judgment. This approach usually meant companies could only respond to issues after they had already come up, which made it hard to spot odd changes and hidden sources of waste right when they first appeared. As the industrial internet, smart sensors, data gathering, and data analysis tools have become more common across factories, companies can now keep a closer, more constant watch on electricity, steam, gas, compressed air, and the working status of their most important machines.

This continuous tracking lets them set up early alerts for unusual energy use, run analysis on how efficient production processes are, and spot changes in carbon emissions in real time. Using digital methods to manage carbon emissions does not need companies to build extremely complicated systems that are hard to keep. Instead, it uses actual data to turn carbon emission problems – which were once hard to see clearly, measure accurately, or manage in a practical way – into something much clearer and easier to handle. For manufacturing companies that want to cut their carbon footprint, combining standard process management with digital tracking can make their carbon reduction work much more precise and much easier to carry out.

4 Core Contents and Methods for Evaluating the Effectiveness of Carbon Reduction in Manufacturing Enterprises

4.1 Key Indicator System for Evaluating Carbon Reduction Effectiveness

We can't tell if manufacturing firms have actually gotten good results from their carbon reduction efforts just by looking at whether a handful of policies have been rolled out. Instead, we have to judge this through a scientific look at how good and how steady the emission cuts actually are. The first question any effectiveness assessment has to answer is "what should we measure," which means we have to figure out how to build a working set of indicators. Some of the most basic measurements are carbon emissions per unit of output, total energy use per unit of product, electricity use per unit

of product, how intensely fuel is consumed, and how major pollutant emissions change alongside carbon emissions. Each of these indicators shows shifts in production efficiency and energy use pretty directly, and together they make up a key base that we need to do a good emission reduction evaluation. It can happen that a company's total carbon emissions go down, but the energy it uses per product hasn't gotten any better. Or, the visible drop in emissions only happens because the company has cut how much it produces, rather than actually changing its processes. In cases like this, the result doesn't mean anything stable for long-term carbon cutting. So instead of only looking at how total emissions have changed, assessments have to bring in changes in emission intensity and improvements in efficiency to get a full, well-rounded conclusion.

If you look past the most basic measurement tools, we also need to add new indicators that can show how management practices and overall structures are changing within a company. To give a few common examples, these can cover things like how much of a company's energy comes from clean sources, what share of older equipment has been updated to use less energy, how many of a firm's core production processes are tracked with online monitoring, how much defects have been cut across operations, how well waste heat is recovered and reused, and how closely different partners work together to build a greener supply chain. These numbers do not line up perfectly with the direct amount of carbon a company cuts, but they can still show how well prepared a business is for low-carbon change, and how sustainable that change actually is over time. What this means is that when we evaluate how effective carbon cutting efforts are, we should not just look at the final numbers for emissions. We also need to check whether the business has built a solid, long-lasting mechanism for cutting carbon on an ongoing basis. When people only focus on the end results and pay no attention to the process that gets them there, it is common to see a situation where short-term data looks very positive, but emissions bounce back strongly in the longer run. The whole point of building a multi-dimensional system of indicators is to help our evaluations match up better with what companies are actually doing to cut carbon, and where their work on this issue is heading.

4.2 Implementation Methods and Common Biases in Evaluating Carbon Reduction Effectiveness

When looking at how these evaluations are carried out, most assessments of carbon cutting at manufacturing firms compare one baseline time frame with a later period where improvements have been made. The work also needs to include adjustments that account for the specific features of the industry, how large the production operation is, and changes in market conditions.

The methods that get used most often are comparative analysis, intensity calculation, cost-benefit analysis, and overall comprehensive scoring. Comparative analysis works well for spotting how trends change before and after a business makes its low-carbon transformations, and it is also pretty straightforward to use in practice. Intensity calculation makes it easier to remove the impact that shifts in output can have on results, so this method works better for most manufacturing settings. With cost-benefit analysis, businesses can check whether a given carbon reduction plan makes sense to keep using from an economic point of view. Comprehensive scoring lets people put technical, management, economic and environmental impacts all into one single evaluation framework, which makes it a good fit for looking at overall progress across different project stages. Every one of these methods has strengths that work for different situations, so when firms actually do their evaluations, they should not depend on just one approach alone. Instead, they need to mix different methods together to match the specific goal that their evaluation is meant to achieve.

But, it is still pretty easy for certain biases to show up when you run this kind of evaluation. A common example of this is that evaluators usually only count direct emission cuts that come from upgrading energy-saving devices, but they miss the indirect cuts that come from better management, improved production processes and closer work with supply chain partners.

This ends up leaving the evaluation with a much narrower scope than it should have. A second issue that comes up is that when people do the evaluation, they do not give enough consideration to things like changes in production capacity, swings in order volume, and shifts in what raw materials a factory uses. From the outside, it can look like total carbon emissions have gone down, but what actually happened might just be a temporary drop because the factory is running at a lower production load.

On top of that, some companies assume that the amount of money they put into carbon reduction directly equals how good their results will be, and they do not stop to check how well different reduction measures actually fit together and how steadily they work over time. So, when we look at how well manufacturing companies are cutting their carbon emissions, we have to stick to four basic rules: we need to use real data, we have to keep our statistical range consistent, our methods have to fit the specific situation, and we have to keep tracking changes over time. Only if we follow these rules can the results we get actually give useful help for the companies to make their later choices.

5 Safeguard Mechanisms and Optimization Directions for Enhancing the Effectiveness of Carbon Reduction in Manufacturing Enterprises

5.1 Building an Internal Collaborative Promotion Mechanism within Enterprises

If manufacturing firms want to get long-term carbon reduction outcomes, they can't just depend on their technical or environmental protection teams to push this work ahead. What they actually need to do is set up a collaborative system that works across different departments. Carbon emissions touch on many separate parts of a business, from production and equipment to energy use, purchasing, storage, finance, and overall management. When only a handful of job roles are held responsible for this work, carbon reduction will almost always end up being treated as a side task rather than a core priority. Companies need to build a more straightforward responsibility framework specifically for carbon reduction. They should split overall targets down to individual processes, workshop floors, and separate departments, and lay out clear requirements for things like energy consumption, equipment efficiency, defect management, and process improvements.

This way, they can build a connected system that runs all the way from top management down to on-the-ground execution teams. Financial teams also need to get involved in the right way. They can connect energy-saving and carbon-cutting projects to routine work like cost control, calculating investment returns, and putting together budgets. This change makes low-carbon transition something more than just an "extra job" for the company — it becomes a core piece of regular business decision-making.

Building up the skills and knowledge of a company's workforce is another key piece of putting a strong safeguard system in place. At a lot of companies, when carbon reduction efforts fail to deliver the expected results, this is rarely because they have no access to the right technology at all. More often, the problem comes down to not having enough workers with mixed skills: people who know how both production processes work and how to manage low-carbon operations. To fix this gap, companies need to step up their training in these specific areas. This helps managers and technical staff get a better grasp of topics that matter directly, like how to do carbon accounting, plan energy-saving upgrades, implement green production steps, and assess carbon reduction outcomes. For workers who hold frontline production positions, companies also need to put more focus on building good habits — following energy-saving operation rules, checking equipment on schedule, and reporting unusual problems right when they pop up. The reason this matters is that lots of small, seemingly unimportant day-to-day working habits, when added up over time, can change how efficiently a company uses energy by a large margin. This means manufacturing companies can't count only on big, one-off carbon reduction projects to hit their goals. They also need to put more work into tightening up their daily management practices. Carbon reduction work will only be able to move away from being a short-term, occasional push and become a regular, ongoing part of operations when companies combine clear systems, defined responsibilities, and strong worker capabilities all together.

5.2 Promoting External Collaboration and Long-Term Optimized Development

Cutting carbon emissions from manufacturing firms does not stop at activities that take place within the factory walls; how well companies work with outside partners can also change how much carbon they ultimately cut. Even though many businesses have already made their internal production processes more carbon-friendly, problems outside that space hold the overall effort back.

If a company still gets its raw materials from supply chains that rely heavily on high-carbon inputs, if its shipping and logistics operations are still wasteful and poorly run, and if it has no system in place to recycle products or reuse them in a circular economy, the total carbon reduction the company achieves will end up much smaller than it could be. Because of this, businesses need to slowly expand their carbon reduction thinking to cover all the connections up and down their supply chain, adding green rules and requirements into how they choose suppliers, how they organize shipping, what kinds of packaging they use, and how they manage products across their entire life cycle. Big manufacturing companies, for example, are in a perfect position to lead the whole industrial chain. They can use green purchasing rules, share data with their partners, and set up shared improvement systems to push all the partners up and down the chain to cut their own carbon output together. This kind of work does not just make the carbon reduction efforts that happen inside the firm much more effective, it also helps build a greener and more reliable supply chain that works better for everyone over time.

Looking at the bigger picture over time, manufacturing companies still have to manage the relationship properly between short-term cost pressures and building up stronger long-term competitiveness when they work to cut carbon emissions. A big reason why many companies have moved slowly on this work is that they worry transformation will cost too much up front, and that any positive results will take far too long to show up. It is true that if you only look at the immediate costs involved, shifting to low-carbon operations does create some real pressures for a business. But if you

step back and look at what happens over a longer timeline, things like better energy use, less wasted resources, higher green value added to finished products, and stronger ability to enter new markets will all slowly add up to become new competitive edges. For this reason, manufacturing companies need to push forward with carbon reduction as part of their broader push for high-quality development. They should not rush to get quick results, but they should not hold back and wait either; instead, they can build up real gains by making improvements one stage at a time. As things like green finance, carbon markets, green certification, and digital governance keep getting better in the coming years, companies will find it easier to change how they see carbon reduction, moving from seeing it as a "cost constraint" to viewing it as a development driver.

6 Conclusion

Cutting carbon emissions at manufacturing firms is a very complex, long-term project that needs work across many different areas. It does not just need updating old equipment, tweaking production processes, and switching to lower-carbon energy sources — it also needs changes to how the business is managed, consistent tracking of emissions data, and better, more detailed systems for evaluating how well carbon reduction efforts are working. This paper has looked at this topic from four key angles: the practical groundwork that firms need in place, the concrete strategies they can use to roll out changes, how to check whether these changes actually work, and the supporting structures that keep efforts on track. What we can see from this analysis is that if a manufacturing business wants to get consistent, reliable carbon reduction outcomes, it has to bring together technical changes, better process management, and clear performance tracking to build a system that keeps getting better over time. Firms can only really boost how efficiently they use resources and strengthen their green market competitiveness when they push for low-carbon change while still making sure production stays stable and the business keeps performing well. Looking ahead, manufacturing companies need to keep refining their carbon reduction systems, so they can give solid support to broader green development and industry-wide upgrading.

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