A NEW FRAMEWORK FOR CARBON ACCOUNTING AND MITIGATION FOR GREENING THE INDUSTRY

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Abstract

Quantification of industrial emissions to date has been based on several environmental evaluation protocols, which include Life Cycle Assessment (LCA), Environmental Impact Assessment (EIA), Greenhouse Gas Protocol (GHP), and carbon footprint. These protocols, however, have their limitations. LCA, for example, assesses the unit processes in a black-box analysis, while EIA is a tool that has been used to analyze sites, process alternatives, and identify and predict the impact of a project on the environment and human well-being at the planning stage. Until now, a systematic framework for industry to analyze ways to reduce emissions has not been established. In this paper, an integrated carbon accounting and mitigation (INCAM) is proposed and demonstrated, using a case study focused on the plating industry. Initially, the process system will be broken down into several sub-processes, including the Carbon Accounting Center (CAC) for more effective carbon accounting and monitoring. The results show that electricity consumption accounts for the highest amount of carbon emission within the plating process. Substantial emission reduction—of around 20 percent—could be achieved by the implementation of higher efficiency heating tools that require less energy, and also produce better heating performance for the process. Ultimately, by reducing carbon emissions, the industry can ensure cleaner production across the entire plating process.

Introduction

Today, multiple definitions of “green industry” are in use. According to UNIDO (United Nations Industrial Development Organization), green industry can be defined as economies striving for sustainable pathway improvement, by undertaking green public investments and implementing public policy initiatives that encourage environmentally responsible private investments (UNIDO 2014).

Alternatively, green industry is defined as cleaner production with high environmental protection and minimal (or zero) pollution, with the processes of energy production and consumption also being minimal pollution-generators (Lu et al. 2013).

Clearly, enhancing profits is not the main driver for the implementation of green industry; rather, the focus is on the sustainable development of the enterprise in the future. At the same time, though, green industry implementation improves the condition of the environment, promotes economic development stability, creates more jobs for the community, and ensures energy reliability and human wellbeing (Lu et al., 2013). For all these reasons, the assessment of the performance of green industry has gained in importance.

Those countries that are party to the United Nations Framework Convention on Climate Change (UNFCCC) use Greenhouse Gas (GHG) inventories to generate annual progress reports (EPA 2010). According to the GHG and National Greenhouse and Energy reporting programs, the numbers of corporations that include GHG inventories of their operations in annual reports and report to governments are increasing (NGER 2015). Besides helping those corporations comply with regulations, GHG inventories are also used to increase eco-efficiency, product innovation, and legitimacy, as well as to better organize energy and material flows for substantial reduction effects (Schaltegger and Csutora 2012).

Under the terms of the Greenhouse Gas Protocol, the sources of GHG emissions can be considered in three “scopes” (Ranganathan et al. 2004). The first comprises direct emissions from sources owned or controlled by a company (e.g. stationary combustion and mobile combustion). The second relates to indirect emissions associated with the purchase of electricity and steam consumed by the company (e.g. purchased/acquired heating, purchased/acquired cooling). The third and final scope focuses on all other indirect emissions not comprised by Scope 2, including the total supply chain up to the production gates—for example, purchased goods and services, and waste generated in the course of operations (Ranganathan et al. 2004).

The Greenhouse Gas Protocol is the closest thing to a global standard for emissions measurement and disclosure; nevertheless, different methods of carbon accounting are needed in order to assess the varying core tasks of each distinctive industrial sector (Bennet et al. 2003). This is illustrated by the experience of a number of leading companies, including the German automobile manufacturer BMW, which adopted Life Cycle Assessment (LCA) to measure the carbon footprint of its entire product life cycle (Koplin et al. 2007). The consultancy WRc has developed several methodologies—such as the Carbon Accounting Workbook (CAW) and the Carbon Abatement Tool—to identify and estimate the GHG emissions from water industry activities (Galletti and Baffoe-Bonnie 2010). Similarly, industry-specific guidelines from the American Petroleum Institute (API) provide measurement and statistical calculation methods relevant to the oil and gas industry. Table 1 shows the research methods for measuring carbon dioxide emissions in different sectors.

In the absence of a universal framework for carbon accounting and reporting, industries have to determine what to include in their definitions of “emissions,” including the boundaries for carbon accounting. The resulting inconsistencies are predictable. According to Matthews et al. (2008)—who studied the scopes of carbon footprint and emissions in US industries—carbon accounting is not realistic at the corporate and industrial level if it does not considering Scope 3 and the supply chain, given that nearly two-thirds of carbon emissions and footprint from industrial sectors are to be found there. These inconsistencies are exacerbated by the inadequate amount of research on the practical implementation of carbon management accounting—one of the major problems in the development of carbon accounting. (Okereke 2007).

To be sure, there is a wide variety of tool and techniques available today to conduct environmental performance assessment in various types of greening activities. But to date, an integrated framework to quantify the level of green industry performance regarding the five main emission contributors—electricity, fuel consumption, water consumption, solid waste, and wastewater—has not been available.

In this study, a systematic framework for carbon accounting and mitigation (INCAM) is established to enable the comparison of carbon performance indicators (CPI) and carbon accounting center (CAC), both on an industry-to-industry basis and against appropriate benchmarks. It is anticipated that by using this tool, a company can quantify its carbon emissions, monitor its carbon-emission profile, and take effective action to reduce emission on its premises.

SECTORS	METHODS	ADVANTAGES	DISADVANTAGES	DESCRIPTIONS	REFERENCES
WATER MANAGEMENT	Carbon Accounting Workbook (CAW)	-Takes into account all three scopes -Estimates the uncertainty in emission figures	-	-Cradle to grave -Activity data of five different operational areas—drinking water, sewage, sewage sludge, transport, and administrative activities—are comprised by the tool	Gelletti et al., 2010
	Carbon Abatement Tools (CAT)	-Provides an interface for a constrained short list/program to deliver a defined abatement target	-	-Cradle to grave -Helps prioritize carbon reduction programs	Gelletti et al., 2010
AUTOMOBILE	Life Cycle Assessment (LCA)	-Environmental impact assessment or environmental audit system boundaries are broadened to include all burdens and effects in the life cycle of a product	-Generally does not show the distribution of impacts over time -Amortization period is largely arbitrary -Tends not to show short-run impacts	-Generic method -Involves cradle-to-grave analyses of production systems and provides complete evaluations of all upstream and downstream energy inputs and multimedia environmental emissions	Brander, 2015; Azapagic, 1999

	Sustainability Assessment Model (SAM)	-Brings together all the elements of sustainable development into a single tool -Provides a comprehensive monetization of the broader environmental and social issues that occur in the project life cycle	-Not an absolute measure of the complexities of sustainable development	-Originally developed for the oil and gas industry but has since been applied in many different settings in the UK, e.g., offshore hydrocarbon development, landfill gas, tree-planting projects, urban development industry, and the higher education sector -Cradle to grave -Translates a range of conflicting sustainability information into a monetary unit score.	Jasinki et al., 2015; Xing et al., 2009; Fraser, 2012
TOURISM	Bottom-up analysis	Carbon emissions of each tourism element and the methods of each element can be made	The system boundaries are varying; coefficients of the element are relatively subjective	-Used in other sectors, e.g. financial -The calculation is based on the sum of transportation, accommodation, and tourism activity, etc. -The accuracy should	Becken and Patterson, 2006; Perch-Nielsen et al. 2010; Tao and Huang, 2014

				be improved by means of suitable coefficients	
	Top-down analysis	Total emission can be evaluated; result is easy to compare with other industries	The related data of energy consumption and carbon emissions at national scale are required	-Used in other sectors, e.g. financial -The calculation is based on the emissions data from national environment, economics and consumption energy -The accuracy should be improved by means of suitable coefficients	Perch-Nielsen et al., 2010; Tao and Huang 2014
	Life Cycle Assessment	The effects on the environment from entire travel process, or between different sectors in tourism industry, can be studied	The indexes on the environment impacts from visitors are hard to select; outcomes are relative and subjective	-Generic method -Cradle-to-grave -The process of tourism is a relative life-cycle assessment, emissions include three links (travel to, from, and at the destination)	Tao and Huang 2014; Filimonau et al. 2011
	Scenario analysis	Future emissions can be concluded reasonably, which will benefit the	Scenario is affected by historical data, model quality,	-Generic method -Cradle to grave -The prediction model on emission is	Tao and Huang, 2014; Rosselló-

		proposal of measures of energy saving and emission reduction	emergent events, and so on	based on the historical statistical data within a place	Batle et al. 2010; Peter and Dubois, 2010
	Questionnaire survey	Primary materials about energy consumption and carbon emissions are studied; the attitude of stakeholders is incorporated	Conclusions are subjective and one-sided because of questionnaire quality, time and range of survey, etc.	-Generic method -Cradle to grave -Conclusions correspond to the energy conversion factors by means of data acquainted from supplier	Tao and Huang, 2014; Kuo and Chen 2009
STEEL PRODUCTION	Intergovernmental Panel on Climate Change (IPIC) method	Based on different data quality, three-tier methods can be used to estimate GHG emissions	-Time consuming in the collection of the first-hand data -Only shows the total GHG emissions within the studied system boundary	-Cradle to grave -Energy input based analysis -Recommended to be used for plant specific GHG emission estimation because the GHG emitted can vary widely depending on fuel combustion - GHG emissions of fuel and electricity are calculated based on the energy consumption and GHG emission factors	Jing et al. 2014

	Life Cycle Inventory Localization (LCIL) method	-More optional database can be used -Useful in calculating individual sub-processes' GHG emissions and identifying "hotspot" areas to facilitate system and process improvement for GHG mitigation	Many calculations can be included when the LCIL method is applied to estimate GHG emissions	-Cradle to grave -GHG emission is calculated based on the embodied energy of the individual sub-process of steel production provided in the existing life cycle inventory -Process-based analysis	Jing et al. 2014
	Comprehensive Energy Consumption (CEC) method	GHG emissions can be estimated simply based on coal equivalent	-The system boundaries of energy consumption data of each steel manufacturer are different - Could only show the total GHG emissions within the studied system boundary	-Cradle to grave -Energy input based analysis -Sum of all the physical energy consumed by the energy consumption unit within the production process, i.e. the enterprise's main production system, auxiliary production system, and subsidiary production system	Jing et al. 2014

Table 1. Research methods for measuring carbon dioxide emissions in different sectors

Methodology

The key component of carbon accounting is the determination of carbon performance indicators (CPI). In this study, five main emissions contributors in industry—electricity, fuel consumption, water consumption, solid waste, and wastewater—are selected as CPI. The systematic methodology shown in Figure 1 comprises four steps:

1. Defining a Carbon Accounting Center (CAC), whereby the premise is familiarized and the process is divided into smaller scoping units for monitoring.
2. Developing a carbon checklist to identify carbon emission sources for each activity in each CAC, and to perform the plant audit. This is important both to prepare relevant documents for data collection and to define a method to quantify indirect CO_2 emission.
3. Establishing a carbon emission index (CEI) for each CPI and CAC, using the emission factor to calculate carbon emissions from all the predetermined sources. The hotspot for CPI as well as CAC is determined by the highest Carbon Emission Profile (%) of each CEC.
4. Screening for suitable options to implement each carbon emission reduction strategy, based on carbon monitoring and targeting (CMT) and carbon mitigation.

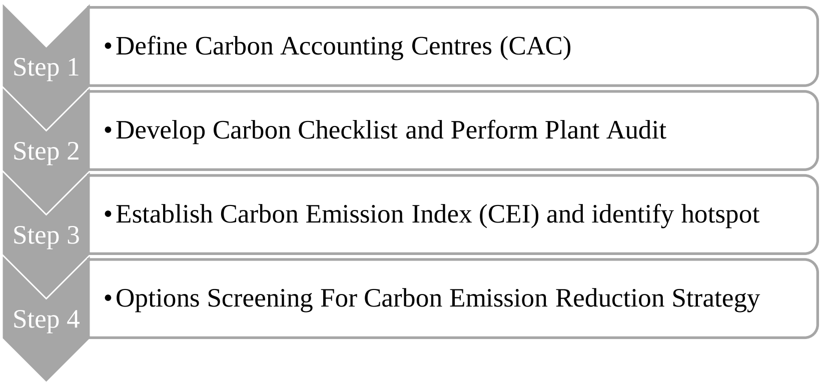

Figure 1. The four steps of INCAM assessment

A case study

Nickel electroplating is the process whereby nickel is deposited on a metal surface. Parts to be plated must free of dirt, corrosion, and defects before plating can begin. To clean and protect the part during the plating process, a water rinsing technique is applied.

Once the piece has been prepared, it is immersed into an electrolytic solution and is used as the cathode. The nickel anode is dissolved into the electrolyte in the form of nickel ions. The ions travel through the solution and deposit on the cathode. The part is then rinsed to remove residue before undergoing a neutralization process. Next, the part goes through a hot-water bathing process and a drying stage. Finally, the part is sent to the packaging department in preparation for distribution to the customer. Figure 2 summarizes the plating process.

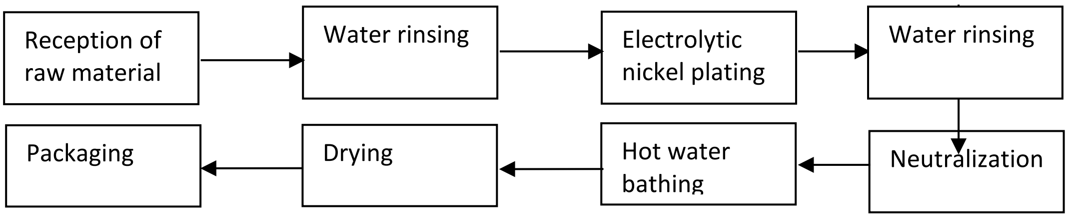

Figure 2. Plating process flow diagram

Results and Discussion

Using the four-step methodology introduced above, a carbon accounting for the electroplating industry can be performed as follows:

Step 1. Define a carbon accounting center (CAC). For this case study, the first step is to become familiar with the processes on the premises. For the overall process analysis, two CAC breakdowns are created:

- CAC 1, representing the process production comprising 4 sub CACs, which are water rinsing, acid, forklift, and heating, and
- CAC 2, representing the warehouse, which comprises 3 sub CACs: forklift, air conditioner, and document.

Step 2. Develop a carbon checklist and perform the plant audit. In this step, sources of emissions in each CAC are identified as shown in Table 1. (In this case, the audit process involved site visits for data collection, based mainly on utility bills, procurement reports, and domestic waste reports.) Meanwhile, data regarding the monthly consumption/generation of 5 CPI is gathered as shown in Table 2, for use in emission analysis in the next step.

Carbon performance indicators (CPI)	**CAC 1 Production**				**CAC 2 Warehouse**		
	Water rinsing	**Acid**	**Forklift**	**Heat**	**Forklift**	**Air conditioner**	**Document**
Electricity				√		√	
Fuel consumption			√		√		
Water consumption	√						
Solid waste							√
Waste water	√						

Table 2. Carbon checklist for electroplating industry

Carbon performance indicators (CPI)	Emission Factor (CO_2e/ unit) [4]	Monthly consumption/generation						
		CAC 1 Process Production				CAC 2 Warehouse		
		Water rinsing	Acid	Forklift	Heating	Forklift	Air condition	Document
Electricity	11700	0	0	0	37,129 kWh	0	30,000 kWh	0
Fuel consumption (Diesel)	1670	0	0	835 L		835 L	0	0
Water consumption	300	3,997 m^3	0	0	0	0	0	0
Solid waste	700	0		0	0	0	0	700 kg
Waste water	1670	200 m^3	0	0	0	0	0	0

Table 3. Monthly consumption/generation for each CAC

Step 3. Establish carbon emission index (CEI) and identify hotspots. Detailed data for the CPI for each subsection in CAC 1 and CAC 2 are shown in Tables 3 and 4. From Table 3, the highest total monthly CO_2e (tCO2e) for the CAC—the heating process in the production area—is identified as the hotspot. The Monthly Carbon Emission Equivalent (tCO_2e) is determined by multiplying monthly consumption/generation of each CAC with the emission factor of each CPI. The Carbon Emission Profile (%) is calculated by divided the total monthly CO_2e (tCO_2e) of each CAC with total monthly CO_2e (tCO_2e) of each CPI and multiply by 100 percent. The Carbon Emission Index for each CAC is determined by dividing the total monthly CO_2e (tCO_2e) for each CAC with the total production amount (t) for a month and multiplying it by 100 percent.

Carbon performance indicators (CPI)	Monthly carbon emission equivalent (t CO_2e)						
	CAC1 Production				CAC2 Warehouse		
	Water rinsing	Acid	Forklift	Heating	Forklift	Air condition	Document
Electricity	0	0	0	4.34×10^8	0	3.51×10^8	0
Fuel consumption (Diesel)	0	0	1.39×10^6	0	1.39×10^6	00	0
Water consumption	1.19×10^6	0	0	0	0	0	0
Solid waste	0	0	0	0	0	0	4.90×10^5
Waste water	3.34×10^5	0	0	0	0	0	0

Total monthly CO_2e (tCO_2e)	1.53 x 10^6	0	1.39 x 10^6	4.34 x 10^8	1.30 x 10^6	3.5 0x 10^8	4.90 x 10^5
Carbon Emission Profile (%)	0.19	0	0.18	54.97	0.18	44.42	0.06
CEI for CAC (tCO_2e)	149.41	0	135.90	4.23 x 10^4	135.90	3.42 x 10^4	47.75

Table 4. Carbon emission profile (%) and CEI for each CEC

Carbon performance indicators (CPI)	**Total monthly CO_2e ($t CO_2e$)**	**Carbon emission profile (%)**	**CEI for CPI ($t CO_2$/ t product)**
Electricity	7.80 x 10^8	99.39	7.60 x 10^4
Fuel consumption (Diesel)	2.79 x 10^6	0.35	272.00
Water consumption	1.19 x 10^6	0.15	117.00
Solid waste	4.90 x 10^5	0.06	48.00
Waste water	3.34 x 10^5	0.04	33.00
Total monthly CO_2e ($t CO_2e$)	7.90 x 10^8		

Table 5. Total monthly CO_2-eq and CEI for CPI

Step 4. Screen for options to support the carbon emission reduction strategy. In this case, it was found that significant emission was contributed by electricity usage due to the heating process and the air-conditioning unit. In order to reduce the energy consumption, therefore, installation of higher-efficiency heating tools that require less energy with better heating performance is recommended (as indicated in Table 6). The other alternative would be the replacement of the existing inverter-type air conditioning unit. As for the forklift—another hotspot—emission reduction can be achieved by switching from diesel forklifts to natural gas-powered lifts. In addition, the usage of fresh water can be reduced by reusing the rinse water, which at the same time reduces wastewater.

CPI	**CAC**	**Emission reduction strategy**	**CPI reduction percentage [4]**
Electricity	Heating process of CAC 1	High efficiency equipment	20%
Fuel consumption (natural gas)	Forklift usage of CAC 1 and CAC 2	Natural gas-powered forklift	99%
Water	Water rinsing activities of	Recycle water for rinsing	25%

consumption	CAC 1	activities	
Solid waste	Warehouse documentation waste of CAC 2	Reduce, reuse, and recycle activities	20%
Waste water	Waste water generated from water rinsing of CAC1	Recycle water for rinsing activities	25%

Table 6. Carbon emission reduction strategy and CPI reduction percentage

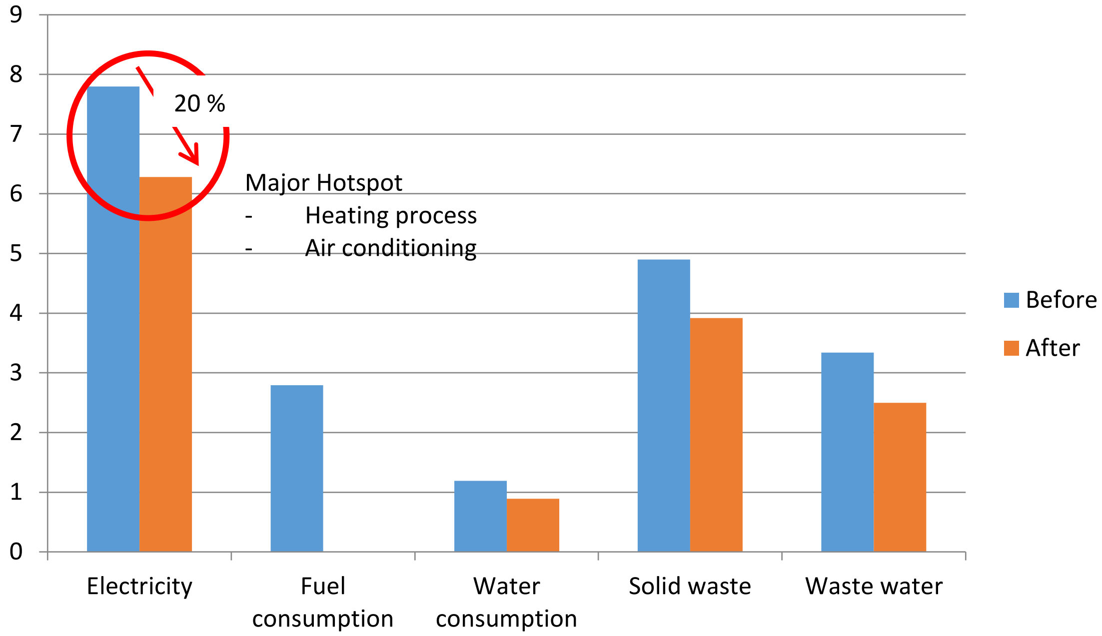

Figure 3. CPI reduction analysis

Detailed data for the CPI for each subsection in CAC 1 and CAC 2 after the implementation of the reduction strategy are shown in Tables 7 and 8. Substantial CO_2 emission reduction is achieved up to 20.3 percent as shown in Figure 3. The greatest reduction percentage after the implementation the reduction strategy comes in the fuel consumption area—due to the switch from diesel to natural gas—as shown in Figures 4 and 5.

Carbon performance indicators (CPI)	Emission Factor (CO_2e/ unit)	Monthly carbon emission equivalent (t CO_2e)						
		CAC1Production				CAC2Warehouse		
		Water rinsing	Acid	Forklift	Heating	Forklift	Air condition	Document
Electricity	11700	0	0	0	3.47 x 10^8	0	2.24 x 10^8	0

Fuel consumption (Natural Gas)	1.92	0	0	1603	0	1603	00	0
Water consumption	300	8.99×10^5	0	0	0	0	0	0
Solid waste	700	0	0	0	0	0	0	3.92×10^5
Waste water	1670	2.50×10^5	0	0	0	0	0	0
Total monthly CO_2e (t CO_2e)		1.14×10^6	0	1603	3.47×10^8	1603	2.80×10^8	3.92×10^5
Carbon Emission Profile (%)		0.198	0	0	55.17	0	44.58	0.06
CEI for CAC (tCO_2e)		112.06	0	0.16	3.38×10^4	0.16	2.73×10^4	38.20

Table 7. Carbon emission profile (%) and CEI for each CEC after reduction strategy implementation

Carbon performance indicators (CPI)	Total monthly CO_2e (tCO_2e)	Carbon Emission Profile (%)	CEI for CPI (t CO_2/ t product)
Electricity	6.28×10^8	99.75	6.12×10^4
Fuel consumption (Natural Gas)	3206	0	0
Water consumption	8.99×10^6	0.14	88
Solid waste	3.920×10^5	0.06	38
Waste water	2.50×10^5	0.04	24
Total monthly CO_2e (tCO_2e)	6.29×10^8		

Table 8. Total monthly CO_2e and CEI for CPI after reduction strategy implementation

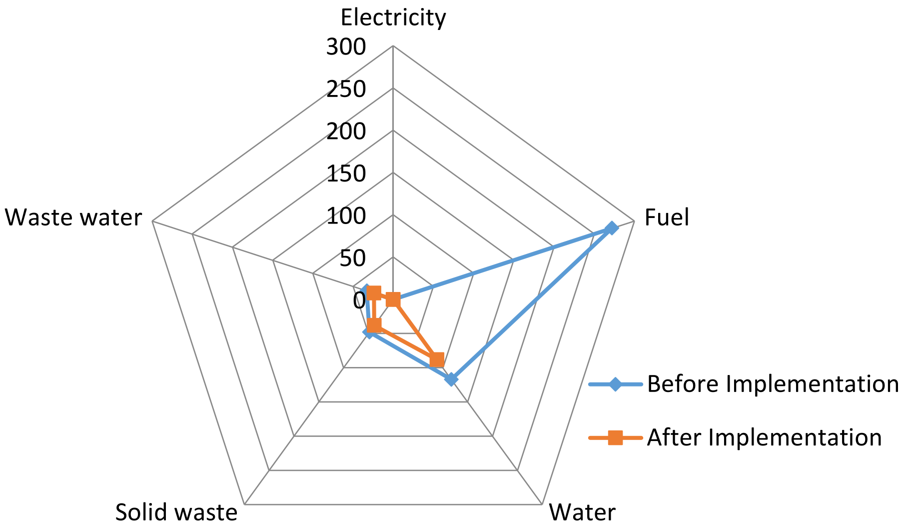

Figure 4. Carbon Emission Index before and after reduction strategy implementation

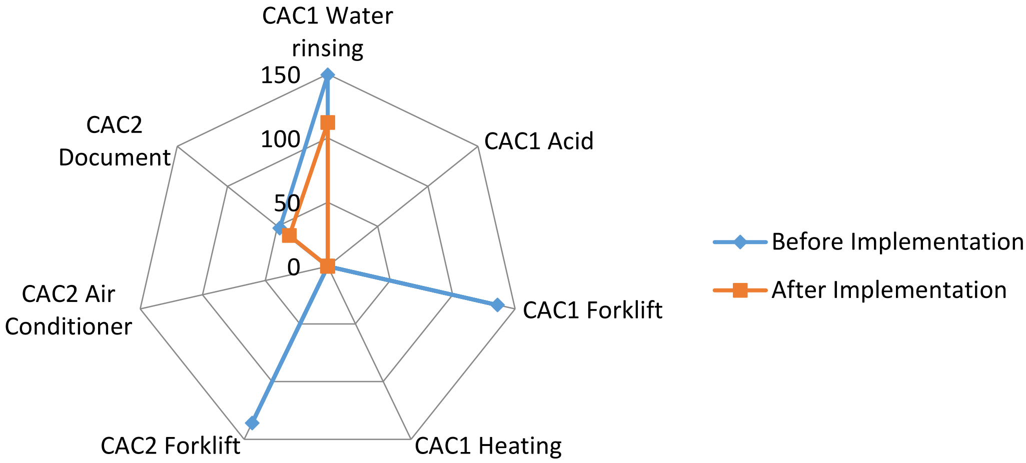

Figure 5. Hotspot comparison in each CPI before and after reduction strategy implementation

Conclusions

In this study, a new carbon accounting and mitigation method known as INCAM has been developed and demonstrated by means of an electroplating company case study. Application of this method revealed that the company—and by extension, the industry—can successfully reduce its electricity and water consumption, with associated savings, and at the same time achieve a 20.3 percent reduction in CO_2 emissions.

Energy efficiency is an example of a realm in which value is already created within the existing commercial environment—for consumers and businesses alike—providing cash flows that can make these investments attractive. At the same time, the industry CEI can be reduced significantly, promoting cleaner production, reducing industry's carbon footprint, and generating goodwill for participating companies.

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