TSMC 2022

Environmental Profit and Loss (EP&L)

東海大學企業永續影響力中心
Corporate Sustainability Impact Center, Tunghai University

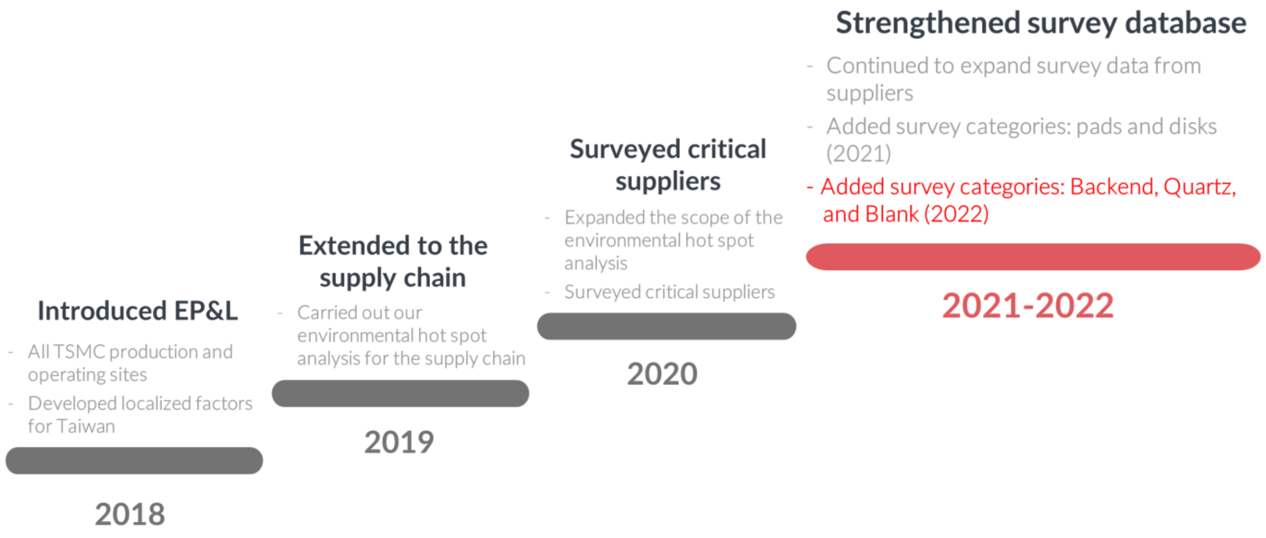
Table of Contents

0. About EP&L

Corporate growth is reliant on natural resources and ecosystem services, but environmental footprints from resource consumption and pollution during the operating process may have varying degrees of negative impact on the world’s natural capital. Such negative impact is referred to as environmental externalities. TSMC first adopted the Environmental Profit and Loss (EP&L) valuation model in 2018. Since then, TSMC has complied with ISO 14008:2019, a methodological framework for the monetary valuation of environmental impacts and related environmental aspects, grounded in principles of welfare economics, and integrated simple financial terms with sustainable corporate management mindsets to measure environmental externalities generated by value chain activities from an outside-in perspective and converted environmental externalities into monetary valuations of social costs.

The EP&L is a management tool grounded in science. As such, the methodology is still in its developing stages. To strengthen the breadth and depth of the methodology and reduce uncertainties in the results, TSMC started to develop localized factors for Taiwan with local environmental characteristics that reflect TSMC’s primary place of business. Since 2019, TSMC has applied EP&L analysis to the upstream supply chain, using hot spot analysis to identify industries with real impacts. TSMC then surveyed critical suppliers to identify significant environmental impact factors and formulated improvement measures accordingly.

TSMC aims to build a comprehensive EP&L database that covers the entire value chain, from the supply chain to production and operating sites around the world. Each year, TSMC will expand the scope of evaluations to help decision-makers allocate and utilize resources more effectively in product design, procurement, manufacturing, research, and development stages, thereby producing more eco-friendly products and a sustainable model for the common good.



2018

Introduced EP&L

- All TSMC production and operating sites
- Developed localized factors for Taiwan

2019

Extended to the supply chain

- Carried out our environmental hot spot analysis for the supply chain

2020

Surveyed critical suppliers

- Expanded the scope of the environmental hot spot analysis
- Surveyed critical suppliers

2021-2022

Strengthened survey database

- Continued to expand survey data from suppliers
- Added survey categories: pads and disks (2021)
- Added survey categories: Backend, Quartz, and Blank (2022)

1. Executive Summary

In 2022, the monetary valuation of environmental externalities from production and operations was around NT$17,893 million; a significant 96.5% or NT$17,262 million of the environmental externalities were the social cost of carbon from greenhouse gas (GHG) emitted from energy and gas consumption for fabrication. In recent years, TSMC has been building and commissioning new fabs, which, coupled with evolving advanced processes, has increased demands for energy, water, and raw materials. In 2022, environmental externalities from production and operations increased by 38.9% from 2018. To mitigate rising environmental externalities from fabrication processes, TSMC continues to promote green innovative practices such as expanding the use of renewable energies, perfecting water reclamation technologies, and optimizing pollution prevention and source reduction solutions. In 2022, environmental externalities per unit product decreased by 12.5% from 2018.

In terms of supply chain, TSMC's 2022 environmental hot spot analysis of 1,050 tier-1 suppliers revealed that environmental externalities from the supply chain generated by TSMC's procurements have a monetary valuation of NT$16,518 million, of which NT$7,137 million is environmental externalities from chemical manufacturing production, accounting for the highest of 43.2% in the overall supply chain contribution. TSMC first conducts a survey on key material supplier based on the hot spot analysis results. In 2022, the survey scope has expanded to Backend, and as of now survey has been conducted on over 95 suppliers. When addressing supply chain environmental issues, TSMC will continue to actively drive responsible supply chain, identify opportunities to optimize fabrication and minimize environmental footprints together with suppliers, drive the enhancement of supply chain sustainability, and make positive impact in society together.

17.9 billion (NT$)
Environmental externalities generated from TSMC production and operations

16.5 billion (NT$)
Environmental externalities generated from supply chain production and services

↓12.5%[*1]
Reduction in environmental externalities per unit product
(Base year: 2018)

43.2%
Environmental externalities from chemical products of the supply chain

>95
Critical raw material suppliers surveyed

Survey scope expanded
From key material supplier to Backend service provider

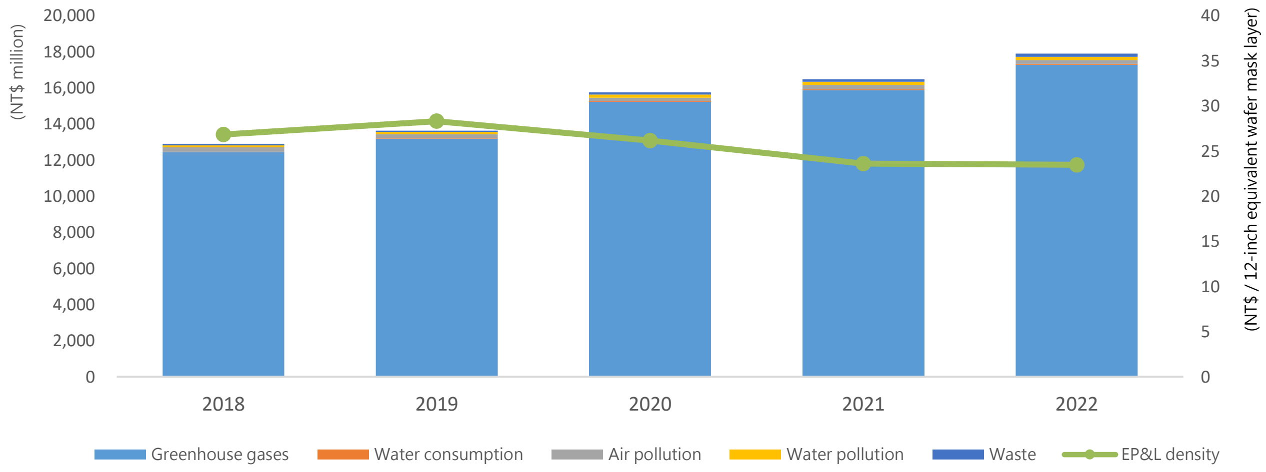
---

[1] *Environmental externalities per unit product were calculated using a 12-inch equivalent wafer mask layer.*

2. Results: Production & Operations

In 2022, analysis results showed that the monetary valuation of environmental externalities from TSMC production and operations was around NT$17,893 million, which is a 10.6% increase from 2021. The increase was primarily caused by a growing demand for energy, water, and raw materials from the increase in fabs and evolving advanced processes. GHG emissions from TSMC facilities were the primary source, accounting for 96.5% of all TSMC's environmental externalities. Other sources such as water resources, air pollution, wastewater pollution, and waste incineration/landfill accounted for only 3.5%. To reduce the environmental impact of TSMC production and operations, TSMC has adopted a variety of green innovative practices such as low-carbon manufacturing, reclaimed water sources, and the circular economy. Compared to the previous year, environmental externalities per unit product have increased by only 1.3%

Environmental externalities for TSMC operations



Unit: NT$ million*[2]

	2018	2019	2020	2021	2022
Greenhouse gases*[3]	12,426	13,160	14,569	15,576	17,262
Water consumption	25	28	36	42	54
Air pollution	253	210	209	241	222
Water pollution	102	123	166	176	170
Waste	93	86	124	147	185

Unit: NT$ / 12-inch equivalent wafer mask layer

EP&L density (Environmental externalities per unit product)	26.8	28.2	25.1	23.2	23.5

---

[2] *The monetary value is the relative value produced by the formula and the scenario analysis rather than the absolute value.*

[3] *To ensure GHG inventory data remains consistent with reduction targets, surveying methods for Scope 1 have been amended in 2020 to adopt the guidelines set forth in the 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories. Results were also updated accordingly. Starting from 2021, all GHG environmental externalities reduced by carbon offset are now included. Historical results were also updated accordingly.*

2.1 Greenhouse Gases

Environmental Externalities from GHG Emissions		Environmental Externalities from GHG Emissions per Unit Product	
(NT$ million)	(Year-on-year)	(NT$ / 12-inch equivalent wafer mask layer)	(Year-on-year)
17,262	**↑ 10.8%**	**22.6**	**↑ 1.5%**

In 2022, the external cost of GHG emission from all TSMC operation sites globally was around NT$17,262 million, which was 96.5% of the overall external cost. CO_2 emissions, primarily from indirect emissions due to purchased electricity, was the most significant factor at 61.7%. In recent years, the external costs of GHG emissions have been trending upwards, increasing by 10.8% from 2021 to 2022. The main causes are evolving advanced processes and the growing number of new fabs becoming operational as the growing consumption of electricity ultimately results in greater GHG emissions. With TSMC actively promoting various low-carbon manufacturing measures, the Company was able to contain the rise of environmental externalities from GHG emissions per unit product to just 1.5% from 2021 to 2022. Please refer to 5.1 for more details on the formula.

To mitigate external costs generated from the large consumption of energy, TSMC continues to promote various energy conservation and carbon reduction measures and was able to achieve net zero emissions in Scope 1 and Scope 2 emissions at overseas locations for the first time in 2022. In the meantime, related efforts generated a total of NT$10.6 billion in positive impact. This includes:

1) Promote Low-Carbon Manufacturing: Adopt best available technologies to reduce GHG emissions and become a benchmark for low-carbon manufacturing in the industry. In 2022, TSMC installed 3,900 local scrubbers for fluorinated greenhouse gases and nitrous oxide, which effectively reduced GHG emissions by five million metric tons, effectively avoiding NT$7.9 billion in social cost of carbon.
2) Use Renewable Energies: In 2022, TSMC increased purchases of renewable energy in Taiwan fabs to 970 GWh, which is a year-on-year increase of around 47%. In overseas locations in the U.S., Canada, Europe, China, Japan, and South Korea, TSMC has achieved zero carbon emissions from energy consumption for five consecutive years. In 2022, TSMC's Taiwan fabs and overseas subsidiaries used a total of 2,190 GWh of renewable energies, which reduces the equivalent of 1.35 million metric tons of GHG emissions and avoids NT$2.1 billion in social cost of carbon, which is a 36% increase from the previous year.
3) Increase Energy Efficiency: Map out new annual energy-saving measures, take action in energy conservation, and increase energy efficiency. In 2022, TSMC carried out 684 energy-saving measures across eight different categories and was able to conserve 700 GWh in energy consumption, TSMC reduced around 360,000 metric tons of GHG emissions and eliminated NT$570 million in social cost of carbon.

2.2 Water Consumption

Water Consumption		Environmental Externalities from Water Consumption per Unit Product	
(NT$ million)	(Year-on-year)	(NT$ / 12-inch equivalent wafer mask layer)	(Year-on-year)
54	**↑ 28.5%**	**0.07**	**↑ 17.7%**

According to EP&L analysis, the external cost of water consumption at all TSMC operation sites globally in 2022 was around NT$54 million, which is 0.3% of the overall external cost to the environment; malnutrition from agricultural water scarcity was the primary factor. The evolution of advanced process technologies and new fabs becoming operational are why external costs of water consumption grew by 28.5% and environmental externalities per unit product grew by 17.7% in 2022. Please refer to 5.2 for more details on the formula.

TSMC continued to promote the four major water conservation measures of "Reduce Facility System Water Consumption, Increase Wastewater Recycling of Facilities, Improve Water Production Rate of the System, and Decrease Water Discharge Loss from the System" in an attempt to uncover opportunities to save water and achieve maximum water conservation. In 2022, TSMC delivered reliable water supplies for fabrication, conserved an additional 3.35 million metric tons of water through water reclamation systems, and supported the government to complete water supply works. As a result, the TSMC Tainan Science Park Reclaimed Water Plant officially started supplying water on September 19, 2022, which has helped reduce demands for tap water. The year 2022 marks the start of water reclamation for TSMC. TSMC is actively working with the government to promote other water reclamation programs and was able to increase the target replacement rate for reclaimed waters by 2030 from 30% to 60%.

2.3 Air Pollution

Environmental Externalities from Air Pollution		Environmental Externalities from Air Pollution per Unit Product	
(NT$ million)	(Year-on-year)	(NT$ / 12-inch equivalent wafer mask layer)	(Year-on-year)
222	**↓ 8%**	**0.3**	**↓ 15.8%**

According to EP&L analysis, the external cost of air pollution emissions at all TSMC operation sites globally in 2022 was around NT$222 million, which is 1.2% of the overall external cost to the environment; the primary source is damage to human health from particulate matters. TSMC continues to improve performances in air pollutant treatment and has been able to effectively reduce the emissions of air pollutants such as acid and alkaline gases, volatile organic gases, $PM_{2.5}$, and ammonia. External costs of air pollution decreased by 8% and environmental externalities per unit product decreased by 15.8% in 2022. Please refer to 5.3 for more details on the formula.

TSMC is actively trying to reduce air pollutants and has adopted the "separation emission sources" method and multi-phase BAT to meet minimum pollutant targets. In 2022, TSMC applied Wet-EP scrubbers to high-temperature sulfuric acid cleaning tools for the first time, effectively reducing acid and alkaline gases and fine particulate matters ($PM_{2.5}$) by 91% and 93%, respectively. TSMC is also actively monitoring and managing emissions from control equipment, expanding the Environmental Lab's responsibilities to include the following three areas: air pollution monitoring, water quality analysis, and environmental protection in surrounding areas. In addition, the Company is conducting verifications to help facilities quickly identify target pollutants and apply BATs, and introducing "Water Quality Management for Scrubbing Towers" to regularly inspect water quality to ensure air pollution control equipment is operating at optimum levels as TSMC continues to strive toward sustainable development.

2.4 Water Pollution

Environmental Externalities from Water Pollution		Environmental Externalities from Water Pollution per Unit Product	
(NT$ million)	(Year-on-year)	(NT$ / 12-inch equivalent wafer mask layer)	(Year-on-year)
170	**↓ 3.2%**	**0.22**	**↓ 11.4%**

According to EP&L analysis, the external cost of water pollution at all TSMC operation sites globally in 2022 was around NT$170 million, which is 1% of the overall external cost on the environment; the primary source is the social cost of greenhouse gases generated from wastewater treatment and damages to human health from heavy metals in effluents. In recent years, TSMC has continued to apply new technologies to prevent and treat water pollution, introducing a membrane bioreactor system, deploying more cobalt sulfate treatment systems, and utilizing RPB (rotating packed bed) technologies at Fab 15B to reduce chemical oxygen demand (COD) levels in wastewater and the water pollution composite indicator reduction rate. In 2022, the external costs of wastewater decreased by 3.2% from the previous year, while environmental externalities per unit product went down by 11.4%. Please refer to 5.4 for more details on the formula.

TSMC is devoted to expanding applications of source distribution management and recycling systems; we are researching how to convert effluent matters into reusable, industrial-grade materials. TSMC has developed 38 distribution systems based on the composition and concentration of wastewater from fabrication for wastewater classification and resource management. The distribution systems can effectively reduce pollutants, increase water recycled rate, and serve as a strong foundation for the circular economy. In 2022, Fab 15B optimized the "Waste Hydrofluoric Acid Regeneration

System" and was, therefore, able to eliminate the outsourcing of HF acid waste liquids in the facility in the third quarter of this year. Fab 15B's efforts are an example of the Company's circular economy practices and were able to further perfect renewable technologies of local circular economy industries. To reduce COD levels in effluents, TSMC introduced the membrane bioreactor system, a technology highly applicable to semiconductor processes, and was able to reduce average COD concentration levels to 151.5 ppm. In addition, due to the increased usage of cobalt sulfate in advanced processes, TSMC also continues to expand the cobalt sulfate treatment system using resin adsorption to meet effluent standards.

2.5 Waste

Environmental Externalities from Waste		Environmental Externalities from Waste per Unit Product	
(NT$ million)	(Year-on-year)	(NT$ / 12-inch equivalent wafer mask layer)	(Year-on-year)
185	**↑ 25.3%**	**0.24**	**↑ 14.8%**

According to EP&L analysis, the external cost of waste at all TSMC operation sites globally in 2022 was around NT$185 million, which is 1% of the overall external cost to the environment; the social cost of carbon from waste incineration is the primary source of impact. In recent years, waste output has risen, especially waste solvents, because of new fabs becoming operational and a greater demand for cleanliness in the new processes. In 2022, the external costs of waste increased by 25.3% from the previous year, while environmental externalities per unit product grew by 14.8%. Please refer to 5.5 for more details on the formula.

TSMC strives to achieve resource sustainability through three major strategies – "Source Reduction, Circular Economy, and Audit & Guidance." In 2022, the Company recycled 96% of waste in Taiwan facilities and has sent <1% of waste to landfills for 13 consecutive years. TSMC enforces source reduction strategies through waste reduction management mechanisms to minimize waste generation. TSMC is also working with vendors to deploy renewable technologies that can successfully produce green energy from organic slurries and reuse activated carbon waste in-house to create a circular system. In addition, TSMC built a Zero Waste Manufacturing Center and continues to evaluate its "Electronics-grade Chemicals Recycling Program," which is expected to purify waste into electronic-grade chemicals for internal use and create a closed-loop circular system. Lastly, TSMC continues to improve its "Intelligent Waste Management Procedure with Full Traceability" to strengthen management, recycle resources, and reduce risks of illegal disposal by vendors.

3. Results: Upstream Procurement

In 2019, the EP&L was further applied to the upstream supply chain. We conducted hot spot analysis through Environmentally Extended Input Output (EEIO)[*4] and started gradually surveying suppliers of key raw materials through life cycle thinking. We hope the valuation can help us drive sustainability across the supply chain and identify opportunities to reduce our environmental footprint and increase social welfare.

3.1 Environmental Hot Spot Analysis of the Supply Chain

Environmental Externalities from the Supply Chain		**Industries Accounting for 90% of Environmental Externalities**		
(NT$ million)	(Year-on-year)	(NT$ million)		(Year-on-year)
16,518	**↑15.5%**	Chemical Products	**7,137**	**–**
		Machinery & Equipment	**4,555**	**↑31%**
		Construction	**1,488**	**↑11%**
		Electronic Components	**1,333**	**↑32%**

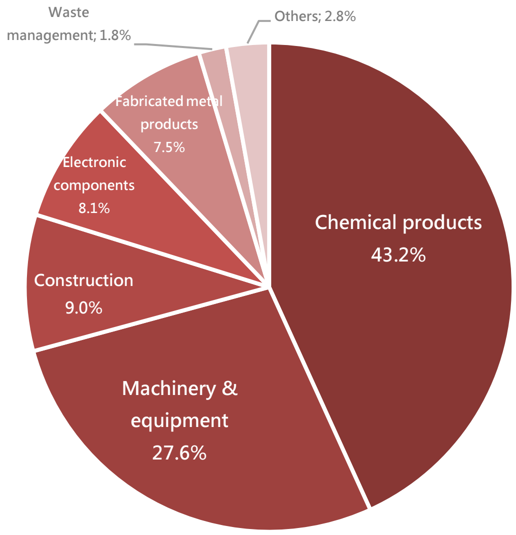
TSMC's 2022 environmental hot spot analysis of 1,050 tier-1 suppliers revealed that environmental externalities from the supply chain generated by TSMC's procurements have a monetary valuation of NT$16,518 million. Environmental externalities generated by the supply chain increased by 15.5% from the previous year. The increase is mainly caused by the growing number of new fabs and increased capacities, which has led to greater demands for construction and hardware equipment. Please refer to 5.6 for more details on the formula.

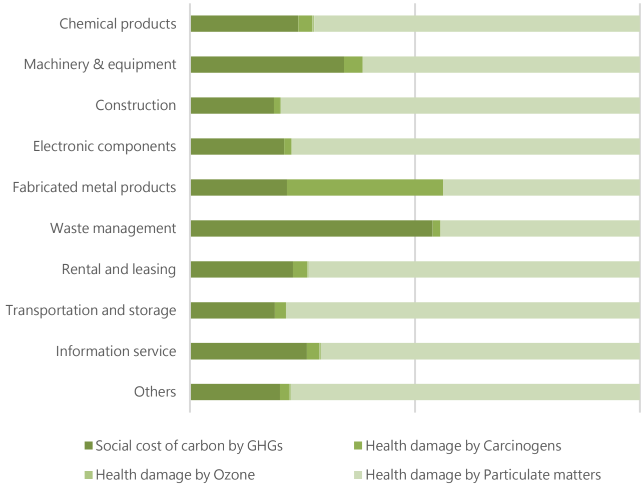
Chemical products, machinery & equipment, construction, and electronic component suppliers have the most significant environmental impacts when providing products or services, with each industry's external cost estimated at around NT$7,137 million (43.2%), NT$4,555 million (27.5%), NT$1,488 million (9%), and NT$ 1,333 million (8.1%), respectively. The primary sources of impact are particulate matter pollution, which has an estimated external cost of NT$11,213 million (67.9%). To reduce impacts from air pollution created by the supply chain, TSMC is helping suppliers reduce the emission of air pollutants from the source through its supplier audit program targeting environmental protection. For example, the Company helped suppliers convert oil boilers to natural gas boilers, effectively reducing $PM_{2.5}$ and GHG emissions. This successful case study was also shared with other suppliers at the "Sustainable Supply Chain Environment, Safety and Health Forum."

---

[4] *EEIO analysis is a common methodology to assess the correlation between economic activities and downstream environmental impact (Kitzes, 2013).*

Applying the environmental hot spot analysis to the supply chain can help TSMC evaluate procurement strategies thoroughly and further identify industries with larger environmental impacts. With analysis results, TSMC is able to prioritize critical suppliers for surveys, identify environmental impact factors, and formulate mitigation measures to reduce environmental externalities and social costs from procurements.


Supply Chain Hot Spots (by Industry)


Supply Chain Hot Spots (by Impact Factor)

3.2 Environmental Externalities of Critical Raw Material Life Cycles

Based on the results of the environmental hot spot analysis on the supply chain, TSMC formulated a survey plan for chemical products and other raw materials with significant environmental impact using the Life Cycle Assessment (LCA)*[5]. The LCA assesses all stages of the product's life cycle from raw material extraction, consumption of energy and resources, pollution emissions, transportation, and distribution to measure environmental externalities from the input and output at every stage and uncover opportunities for improvement.

TSMC categorized key suppliers of higher environmental externalities in its supplier inventory project into eight categories, including Silicon Wafer, Bulk Chemical, Gas, Lithographic, Precursor, Slurry, Specialty Chemical, and Target, with Pad/Disk added in 2021, and Backend, Quartz, and Blank added in 2022. Supplier selection is based on principles such as comparability, level of data completeness, percentage of procurement etc. In addition to the gradually-expanding categories included in the Environmental Profit & Loss (EP&L) assessment, TSMC will further categorize product specification

---

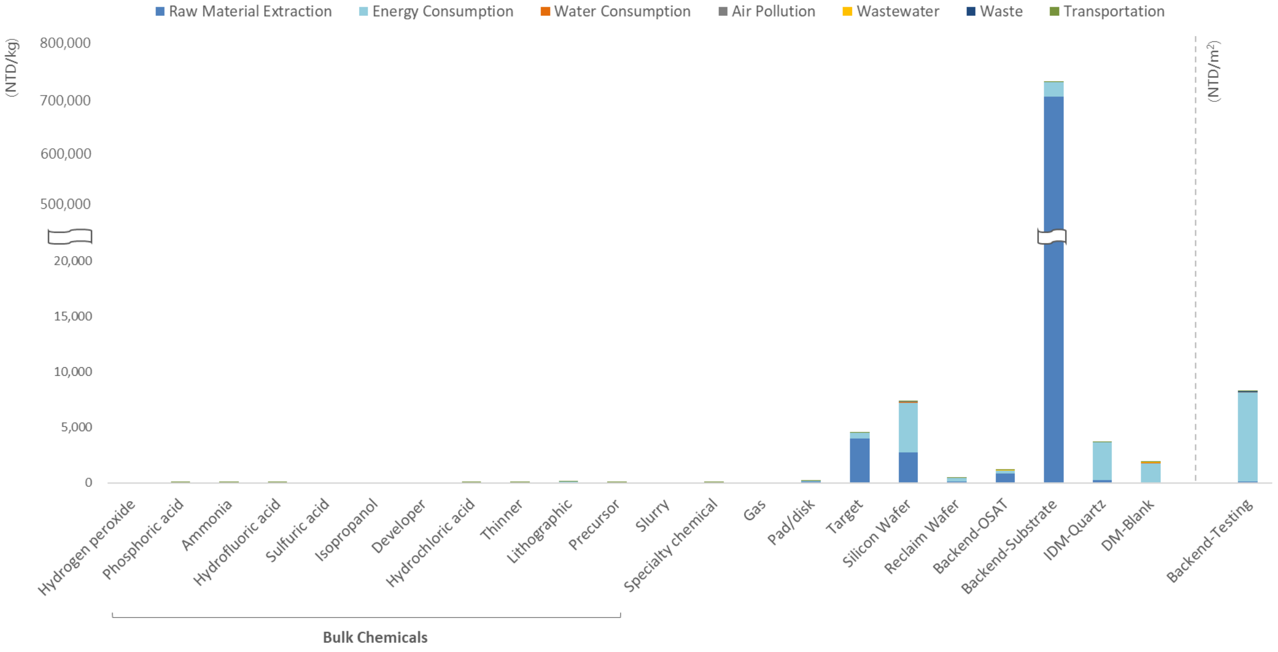
[5] *LCA is an instrument to assess the potential environmental impacts on human health, ecosystem and natural resources of a product or service throughout its life cycle (raw material, manufacturing, distribution, usage, and waste disposal) (ISO 2006).*

and dimension of different raw material to increase the comparability of such assessment. As of 2022, over 95 suppliers have been assessed.

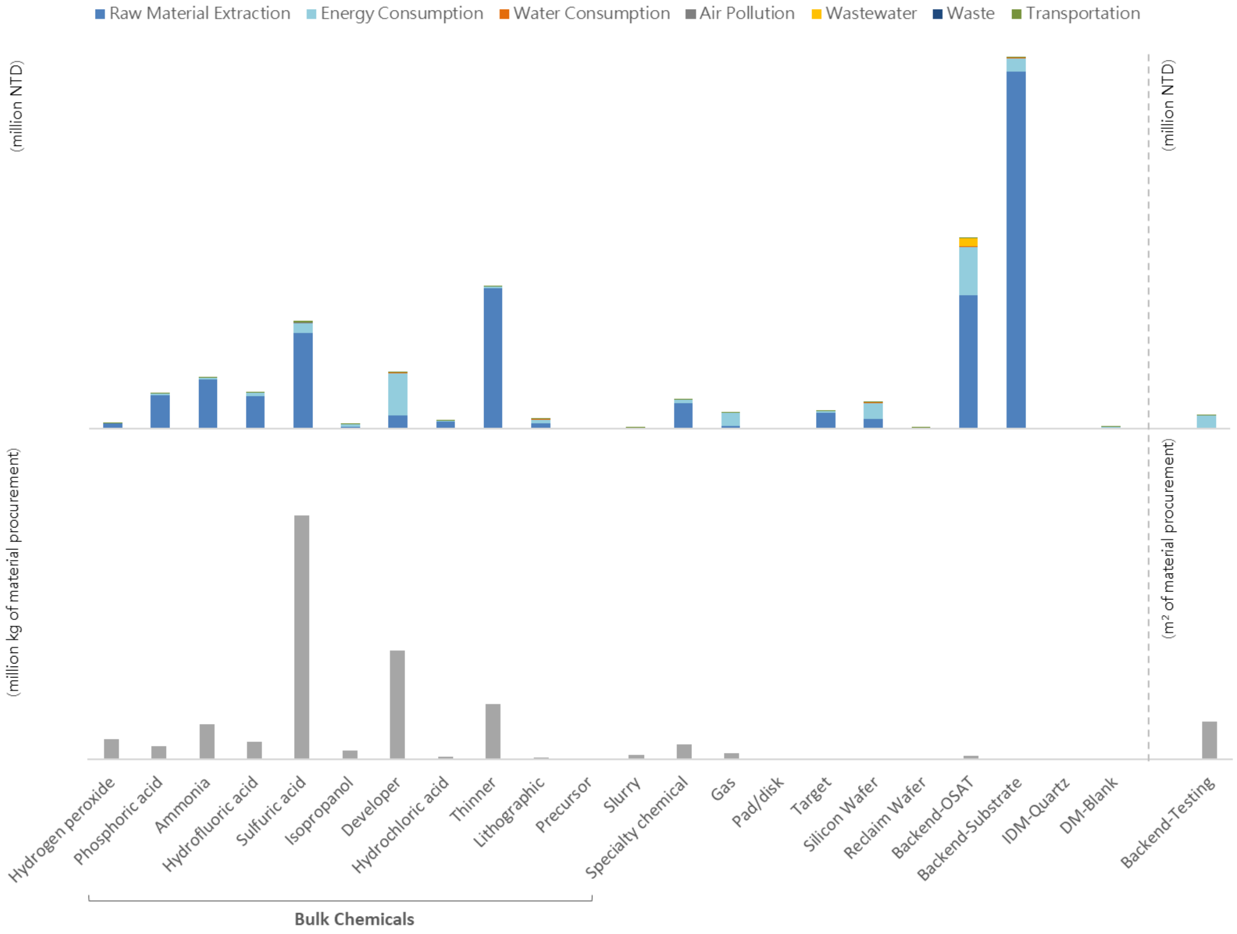
The analysis results of TSMC’s survey scope revealed that in terms of environmental externalities deriving from unit weight (per kilogram), Substrate production in the backend generates the highest social cost at around NT$ 720 thousand/kg. This is mainly because the fabrication process of printed circuit board fabrication process, one that prints electronic component and circuits on a substrate, not only consumes high levels of energy, but also induces larger environmental impact, including multiple chemicals used (such as pickling solutions, alkaline cleaning liquid, degumming solution, copper etchant, and organic solvent) during substrate cutting and wiping, photoresist coating and exposure, etching, gold plating, welding, and testing, and electroplating effluent (containing large amounts of metal ion and organic compounds) and waste (such as waste acid, alkaline, solvents, plastic, sludge, etc.) produced during fabrication. Amount of social cost generated is then followed by wafers (NT$7,342/kg), target (NT$4,550/kg), quartz tubes (NT$3,698/kg), and mask substrates (NT$1,877/kg), where their main impact derives from energy consumed during production and raw material supply chain. When the total environmental externalities of raw material procurement generated during survey is taken into account, then Substrate and OSAT have the most significant environmental externalities. Given that Substrate has a higher environmental hot spot among raw materials, TSMC will provide guidance and assistance to suppliers in technology improve and management of facilities and fabrication process. Such guidance and assistance will start with reduction on chemical usage, strengthen effluent processing, and garbage sorting and recycling to lower production-derived environmental impact. Please refer to 5.7 for more details on the formula.

TSMC will continue to survey and analyze suppliers to compile an EP&L database for the supply chain. TSMC also used differential analysis against peer industries and environmental audits to help suppliers identify potential risks and opportunities for change. We aim to collaborate with suppliers to uncover opportunities to optimize processes and minimize environmental footprints.

Environmental Externalities from 1kg of Raw Materials*[6]



Procurements from Suppliers During the Survey Period & Environmental Externalities

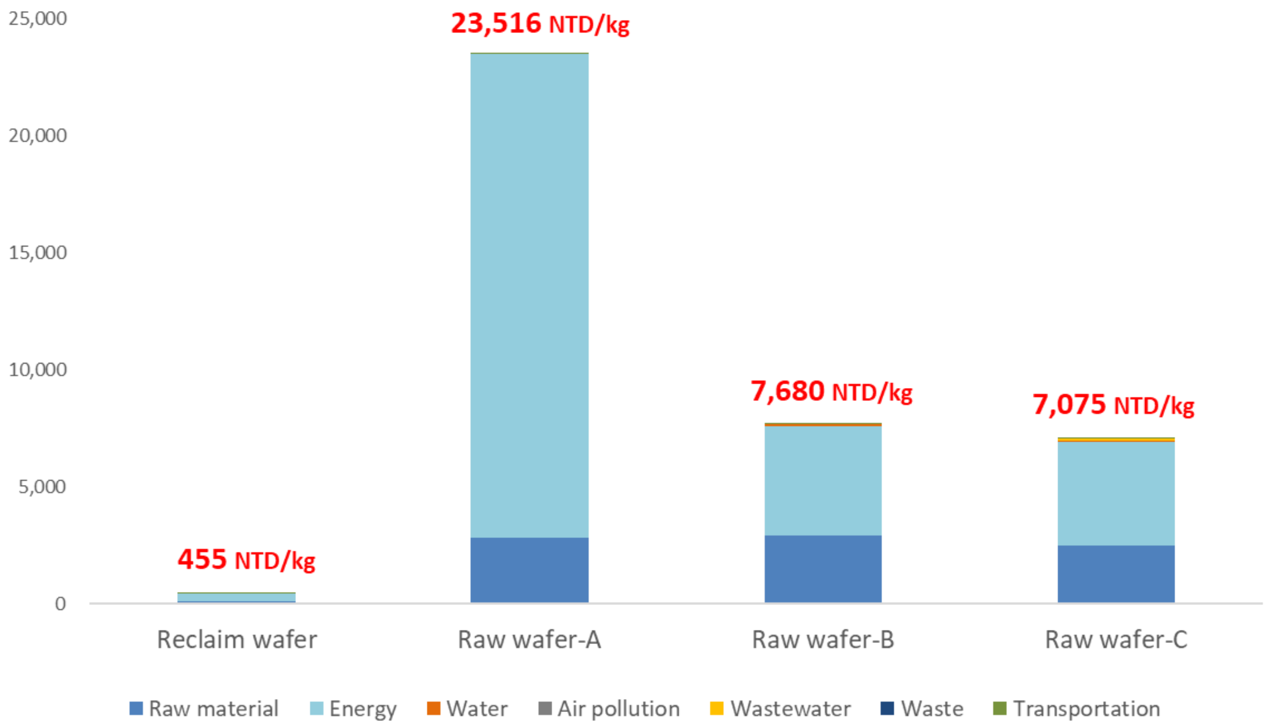


---

[6] *Weighted average calculated based on raw material classification and procurements from suppliers during the survey period.*

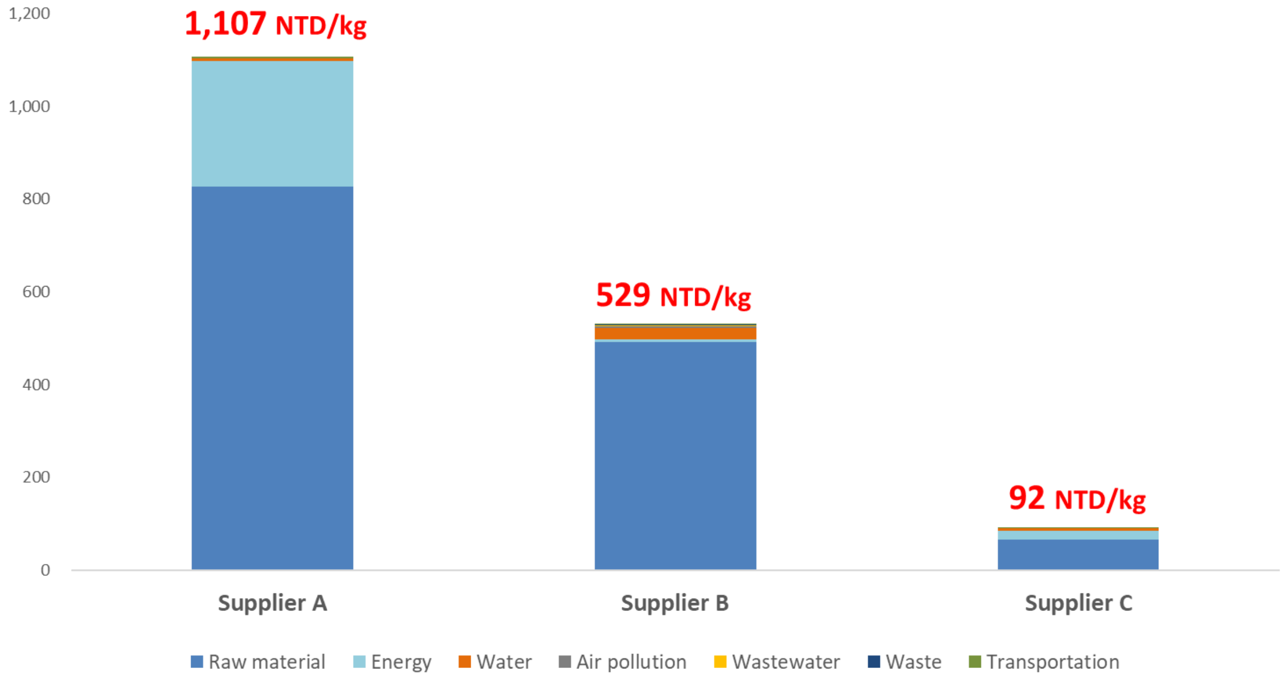
Case Study 1: Silicon Wafer

The environmental externality difference between raw and reclaim wafer mainly lies in the difference in raw materials used, production process and subsequent processing. During accessing raw materials, raw wafer has to use primary minerals, which has high carbon emissions, and during production, raw wafer consumes larger amounts of raw material and energy, which in turn produced more waste and pollutant. As for reclaim wafer, pollution from carbon emission induced by mining can be reduced since it is fabricated with reclaimed materials; its fabrication also reduces use in raw material and energy, and lowers the amount of waste produces, hence it poses lower impact on the environment. In terms of subsequent processing, raw wafer requires more steps to process, including cutting, cleansing, packing, consumes more energy and produces more waste, whereas reclaim wafer only requires a few steps to process, therefore having lower environmental impact. On the whole, reclaim wafer has lower environmental impact than raw wafer. TSMC will continue to develop areas of application for reclaim wafers.



Case Study 2: OSAT

OSAT refers to the assembling of a chip into a package to protect it from impacts of the external environment, as well as to allow the chip to have the functionality to connect with outer environment, therefore, its specification and dimension depends on the different function demands. OSAT process includes cleansing, molding, cutting, welding, testing, and inspection, aiming to protect chips, provide functionality, and ensure their quality. As there are different types and dimension demands of the chip, different process, energy and resource are used during production, resulting in different environmental externalities, such as hazardous gases, effluent, etc. Environmental externalities of products A, B, and C are also different as they are designed with different functions and dimension as per clients' specification demands. For products with higher environmental externalities, guidance and assistance will be provided to suppliers in the future to strengthen their energy and raw material management.

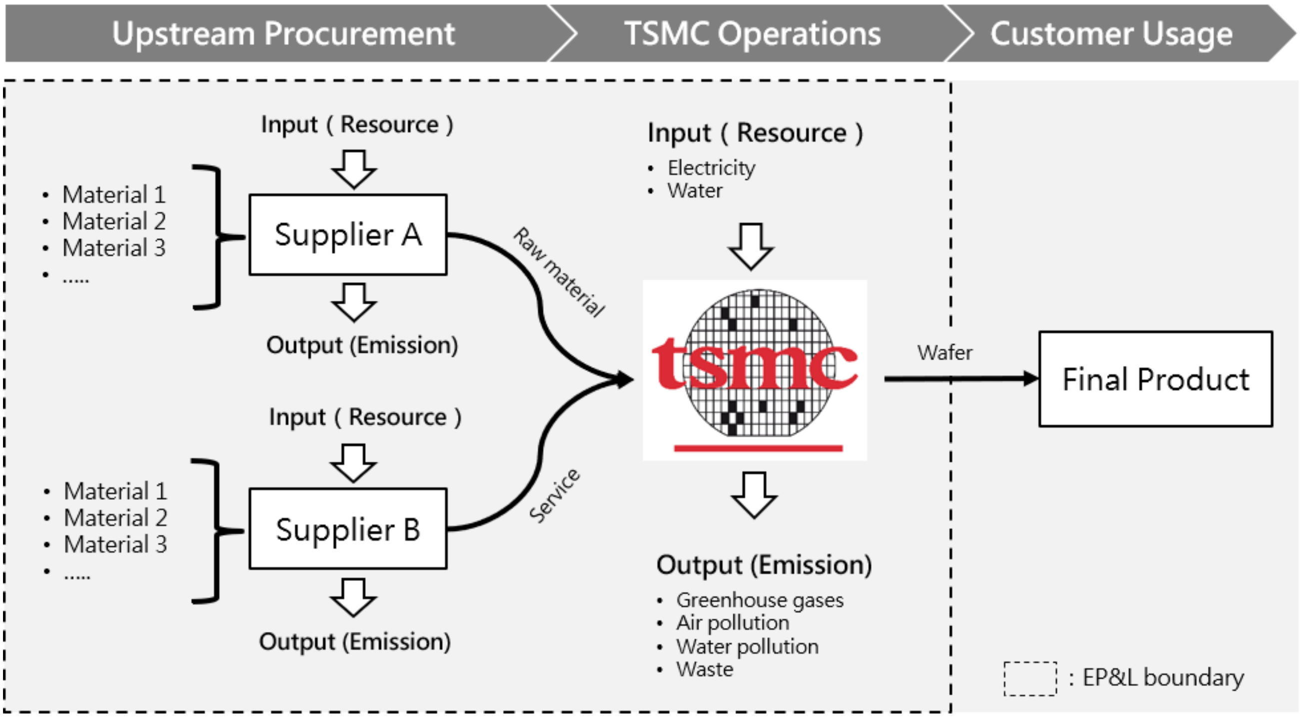


4. EP&L Methodology: Roll-Out Steps

EP&L aims to assess the impact of environmental changes associated with corporate value chains on human wellbeing (PwC UK, 2015). The calculation principle is based on welfare economics that uses willingness to pay (WTP) or willingness to accept (WTA) to measure the value of positive or negative welfare changes resulting from the environmental impact of business (ISO, 2019).

4.1 Define Boundaries & Scope

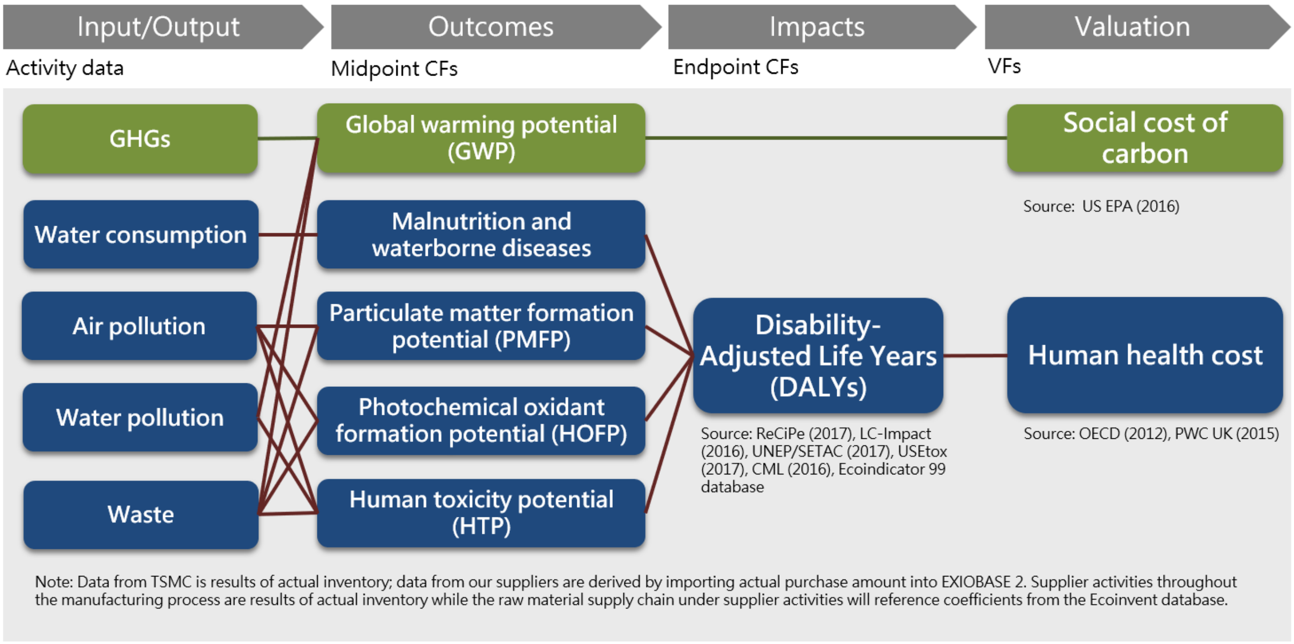
At TSMC, EP&L covers TSMC operations and the upstream procurement stages. TSMC operations include all TSMC fabs in Taiwan, TSMC (China), TSMC (Nanjing), and WaferTech whereas the primary targets for upstream procurement are our suppliers. The scope of the evaluations covers five environmental issues related to green manufacturing in the TSMC materiality matrix: greenhouse gases, air pollution, wastewater pollution, waste, and water consumption. TSMC uses the issues to analyze the externalities on environmental footprint and human welfare, such as the social cost of carbon from greenhouse gas emissions and the damage cost on human health from pollutant emissions into the air and water due to TSMC operations and procurement.



	Upstream Procurement	TSMC Operations
Spatial boundary	Suppliers are directly trading three or more times with TSMC in a year, and where the annual transactions exceed NT$10 million in value; 1,050 suppliers meet the criteria in 2022.	**Taiwan：** Fab 2, Fab 3, Fab 5, Fab 6, Fab 8, Fab 12, Fab 14, Fab 15, Fab 18, Advanced Backend Fab 2, Advanced Backend Fab 3, Advanced Backend Fab 5, Advanced Backend Fab 6 and VisEra **China：** Fab 10 and Fab 16 **USA：** Fab 11
Temporal boundary	2022/01/01 to 2022/12/31	
Scope	Greenhouse gases (GHGs), air pollution, water pollution, waste, and water consumption	
Externalities	Social cost of carbon and human health cost	

4.2 Map Out Impact Pathways

Through the impact pathway approach, TSMC has painted a picture of how operational activities may incur environmental externalities and their complex relationships. Our studies are based on the Life Cycle Assessment (LCA) model and we've worked with academic institutes to develop an EP&L coefficient and methodology in order to conduct environmental impact assessments on all TSMC operation sites globally and the upstream supply chain.



Source: US EPA (2016)

Source: ReCiPe (2017), LC-Impact (2016), UNEP/SETAC (2017), USEtox (2017), CML (2016), Ecoindicator 99 database

Source: OECD (2012), PWC UK (2015)

Note: Data from TSMC is results of actual inventory; data from our suppliers are derived by importing actual purchase amount into EXIOBASE 2. Supplier activities throughout the manufacturing process are results of actual inventory while the raw material supply chain under supplier activities will reference coefficients from the Ecoinvent database.

4.3 Confirm Data Quality

The data used in the calculation process are divided into activity data, characterization factors (CFs), and valuation factors (VFs) according to the impact pathway approach. The activity data is internal raw data (primary data) from TSMC/ suppliers or secondary data derived from databases. The CFs and VFs are the secondary data derived from this study, peer-reviewed literature, and other external data sources.

CFs include midpoint and endpoint CFs. Midpoint CFs refer to changes in environmental conditions caused by resource consumption and pollutant emissions, such as the increase in the concentration of $PM_{2.5}$. Endpoint CFs refer to impacts on human health caused by changes in environmental conditions. This study uses the disability-adjusted life year (DALY)[*7] as a quantitative metric (refer to Sections 5.1 to 5.5 for further information).

VFs include the social cost of carbon and human health cost. The social cost of carbon refers to long-term economic losses caused by global warming and climate changes caused by GHG emissions. Human health cost refers to the value of DALY losses due to resource consumption and pollutant emissions. The value is calculated based on the value of a statistical life (VSL).

Target	Activity data (Input)	Activity data (Output)	CFs	VFs
TSMC	◎	◎	○	○
Supply chain (hot spot analysis)	◎	○		
Critical Raw Material (life cycle assessment)	◎/○	◎/○		

◎ Primary Data (from inventory):

- Data on resource use and pollutant emissions in TSMC operations
- Data of TSMC’s purchase amount (in NT$) in upstream procurements
- Data on material input, energy consumption, pollutant emissions, and transportation for the supplier's manufacturing process

○ Secondary Data (from databases and literature):

- Pollutant emissions data are derived from purchase amount by applying EEIOA, which is referenced from EXIOBASE 2 database
- Data on material input, energy consumption, pollutant emissions, and transportation for all manufacturing stages of the supplier's raw material supply chain is referenced from the Ecoinvent database
- Midpoint and endpoint CFs are derived from this study or from reference sources such as ReCiPe (2017), LC-Impact (2016), UNEP/SETAC (2017), USEtox (2017), CML (2016), IPCC (2006) and Eco-indicator 99
- VFs referred to the US EPA (2016), OECD (2012), and PwC UK (2015)

---

[7] *One DALY can be considered as one lost year of “healthy” life (WHO).*

4.4 Establish Valuation Method

Social cost of carbon

The social cost of carbon is a measure (in 2007 US dollars) of the long-term damage done by a ton of CO_2 emissions in a given year. The social cost of carbon is meant to be a comprehensive estimate of the damage caused by climate change, including changes in net agricultural productivity and human health, property damage from increased flood risks, and changes in energy system costs. The social cost of carbon should increase over time because future emissions are expected to produce large incremental damages, as physical and economic systems become increasingly stressed in response to considerable levels of climatic changes (US EPA, 2016).

Year	Social cost of carbon (in 2007 USD/ton-CO_2) [8]		
	5% discount rate	3% discount rate [9]	2.5% discount rate
2015	11	36	56
2020	12	42	62
2025	14	46	68
2030	16	50	73
2035	18	55	78
2040	21	60	84
2045	23	64	89
2050	26	69	95

Human health cost

According to the OECD (2012), the average VSL for OECD member countries is US$3 million (in 2005 USD). The median age of the study is 47 years, and the life expectancy is 78 years. Therefore, the VSL estimate indicates the WTP to avoid the 31-year risk of loss of life. Prüss-Üstün et al. (2003) indicated that the DALY of different age groups should be given different weights. This study refers to the PwC UK (2015) method that used a 3% discount rate and assumed that an individual was originally expected to live to 78 years but prematurely dies at 47 years (proportion of life loss is 23.4%). Multiplying the proportion of life loss by the expected lifetime yields a loss of DALYs. Finally, dividing VSL by the loss of DALYs gives a human health cost of US$164,366 (in 2005 USD) per DALY value.

---

[8] *The values in the table indicate economic losses caused by global climate changes from CO2 emissions up to 2300. Then discount the value of the damages over the entire time span back to the present value to determine the social cost of carbon. For example, the social cost of carbon for 2018 represents the present value of climate change damage that could occur between 2018 and 2300 that are associated with the release of one ton of CO2 in 2018.*

[9] *One of the most important factors influencing the social cost of carbon is the discount rate. A high discount rate means that people are willing to pay more attention to short-term rather than long-term benefits (Yan, 2014). This study uses a median of 3% discount rate.*

$$Human\ health\ cost = \frac{VSL}{Number\ of\ DALYs\ loss}$$

Parameter	Unit	Value	Source
Age of premature death	Year	47	OECD (2012) PwC UK (2015)
Life expectancy	Year	78	
Proportion of life loss	%	23.4	
Number of DALYs loss	Year	18.3	
VSL	2005 USD	3,000,000	
Human health cost	**2005 USD/DALY**	**164,366**	

Value transfer

Adjustments for spatial, temporal, and other contextual differences should be made to adapt monetary value estimates from other studies (ISO, 2019). TSMC operation sites and suppliers are in nearly 20 countries around the world. We adopt the value transfer method in this study for the monetization of environmental externalities (2018 is the base year).

1) Adjustment for spatial contextual differences: Equity weighting is performed on the gross national income (GNI) per capita and adjusted for purchasing power parity (PPP) by multiplying these monetary values by the power of the income elasticity (OECD, 2012).

$$\mathrm{E}_i = \left(\frac{Y_i}{Y_{ref}}\right)^{\epsilon}$$

Where:

E_i : income adjusted equity weighting factor
Y_i : GNI per capita adjusted for PPP of target region
Y_{ref} : GNI per capita adjusted for PPP of reference region
ϵ : Income elasticity means WTP for a healthy life, ranging from 0 and 1; "1" means that WTP is directly proportional to income; "0" means that WTP has no relationship with income. We use the PwC UK (2015) recommendation value of 0.6 in the study.

2) Adjustment for temporal contextual differences: When a monetary value is determined for a different base year, the value should be adjusted based on inflation and exchange rates.

Value factor	Original	Adjusted
Social cost of carbon[*10]	42 (Unit：2007 USD/ton-CO_2)	1,540 (Unit：2018 NTD/ton-CO_2)
Human health cost	164,366 (Unit：2005 USD/DALY)	Taiwan: 7,073,176
		China: 3,670,405
		USA: 7,790,113
		Japan: 6,272,106
		Korea: 5,900,960
		Germany: 7,099,465
		France: 6,438,535
		Italy: 6,093,175
		Israel: 5,887,703
		Malaysia: 5,022,955
		(list only main operation site and supplier locations) (Unit：2018 NTD/DALY)

---

[10] *CO2 emissions cause a global impact of rising GHG concentrations and will not vary by region.*

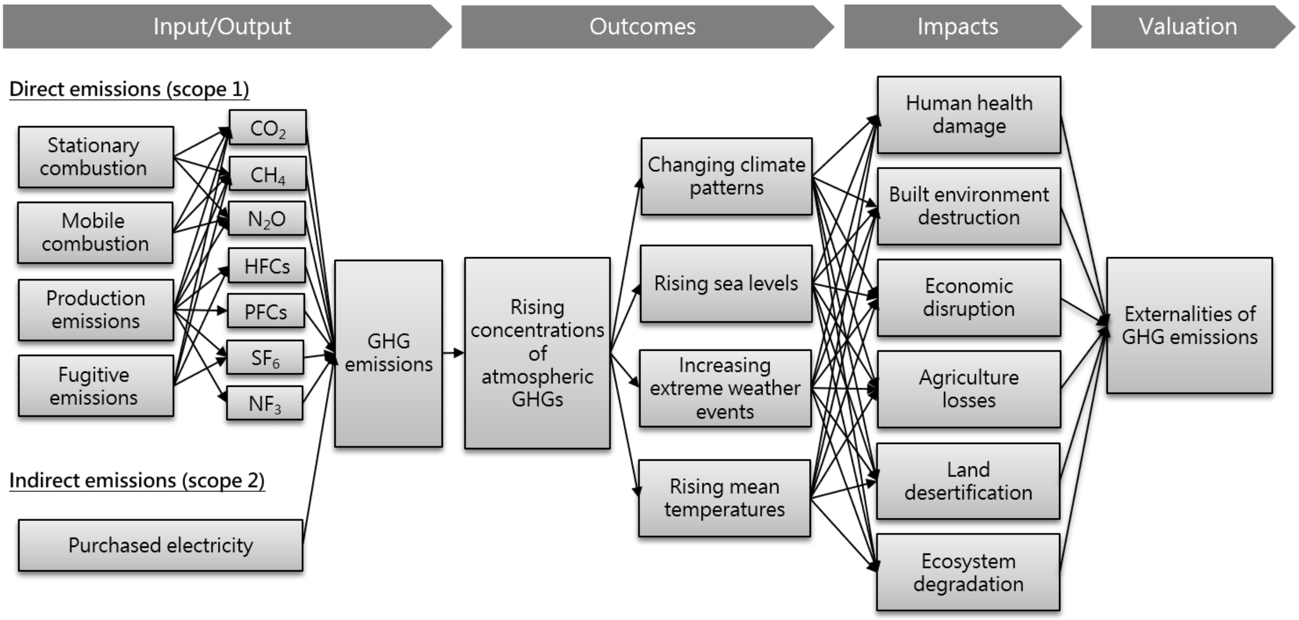
5. EP&L Methodology: Formula

5.1 Greenhouse Gases

Greenhouse gas (GHG) is a gas that absorbs and emits radiant energy, causing heat to be trapped in the Earth's surface and troposphere, thereby resulting in greenhouse effects. The Intergovernmental Panel on Climate Change (IPCC) lists seven principal classes of GHGs, namely, carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), sulphur hexafluoride (SF_6), nitrogen trifluoride (NF_3), various hydrofluorocarbons (HFCs), and perfluorocarbons (PFCs).

In this study, we use the social cost of carbon developed by the US EPA (2015) as the VF for GHG emissions.

Impact pathways



Calculation

$$\text{Externalities of GHG emissions} = \text{GHG emissions} \times \text{Social cost of carbon}$$

- *Externalities of GHG emissions: external environmental costs caused by GHG emissions (2018 NTD/year)*
- *GHG emissions: total GHG emissions from TSMC operation sites (ton-CO_2/year)*
- *Social cost of carbon: long-term economic damage indicators caused by GHG emissions in a given year (2018 NTD/ton-CO_2) (see Section 4.4 for details)*

Assumptions and limitations

1) Numerous uncertainties exist in the model of social cost of carbon, including catastrophic and non-catastrophic effects, climate change adaptation and technological changes, high temperature damage estimation methods, and risk aversion assumptions. Such uncertainties will be continuously improved and updated in future research (US EPA, 2015).

2) We select the social cost of carbon as a better approximation of the impact of GHGs on society than the marginal abatement cost (MAC) or carbon market prices.

   - The MAC shows the cost of reducing the impact of a company at a point in time given prevailing technology.

   - Carbon market prices do not currently reflect the value of a company's impact on society as a result of GHG emissions.

   - The social cost of carbon measures the global impact of climate changes on socioeconomic factors.

3) Other indirect GHG emissions (scope 3) have been excluded in this study, as they involve multiple considerations and limited application cases.

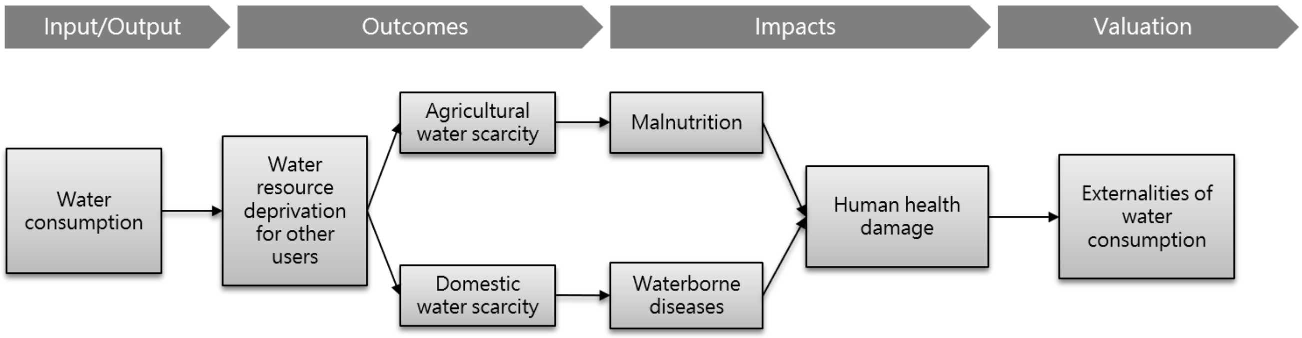
5.2 Water Consumption

Generally, three main types of water use exist for human needs, namely, domestic, agricultural, and industrial (UNEP, 2016). According to Bayart et al. (2010) and Kounina et al. (2013), excessive freshwater consumption will lead to irrigation water scarcity and will subsequently result in health degradation from malnutrition. Malnutrition may result from waterborne diseases that reduce nutrient absorption (WWAP, 2009; Boulay et al., 2011).

Pfister et al. (2009) developed a model for assessing the environmental impact of freshwater consumption. The factors considered are water stress index (WSI), human development index (HDI), and so on. They are used to estimate the effects of malnutrition caused by inadequate local food supplies from shortages in agricultural water use. Motoshita et al. (2011) used a non-linear multiple regression analysis to illustrate the relationship between domestic water scarcity and infectious diseases, such as ascariasis, trichuriasis, hookworm disease, and diarrhea.

This study assumes that the water consumption of TSMC will directly affect the water availability of other users. Thus, we adopt CFs from Pfister et al. (2009), LC-Impact (2016), and Motoshita et al. (2011) for human health loss due to agricultural and domestic water scarcity and estimates the external cost of each operation based on VSL.

Impact pathways



Calculation

$$\text{Externalities of water consumption}$$
$$= \text{Water consumption} \times \text{Health damage factor} \times \text{Human health cost}$$

- *Externalities of water consumption: external environmental costs caused by water consumption (2018 NTD/year)*
- *Water consumption: total water consumption from TSMC operation sites (m^3/year)*
- *Health damage factor: loss of healthy life caused by malnutrition and infectious diseases due to water scarcity (DALY/m^3)*
- *Human health cost: value of every healthy life lost (2018 NTD/DALY) (see Section 4.4 for details)*

Assumptions and limitations

1) This study assumes that the water consumption of TSMC will directly affect the water availability of other users.

2) Agricultural water scarcity
   - This study references Pfister et al. (2009) and LC-Impact (2016) to estimate the CFs of malnutrition as caused by agricultural water scarcity. The primary factors that causes regional differences are the percentage of agricultural water use, water stress index (WSI), and human development index (HDI).
   - The assessment model of Pfister et al. (2009) only considers the impact of the insufficient supply of local food. The model does not consider factors such as trade relations and economic adaptation capacity that farm produce can be imported from other regions or countries.

3) Domestic water scarcity
   - The assessment model of Motoshita et al. (2011) only considers four kinds of infectious diseases and analysis based on country-scale data. The expectation is that regional and local characteristics within each country will be considered in future studies.
   - Given the level of current understanding, evidence is not sufficient to recommend a specific methodology. Evidence refers to causality between water consumption, scarcity, and domestic

water deprivation that causes water-related diseases (UNEP & SETAC, 2016).

4) Out of the scope
    - Ecosystem degradation: methodology is currently being developed.
    - Depletion of groundwater: groundwater is not used at TSMC global operation sites.
    - Indirect impact from water supply sector: this factor is excluded given that processing technology is complicated and data are not readily available.

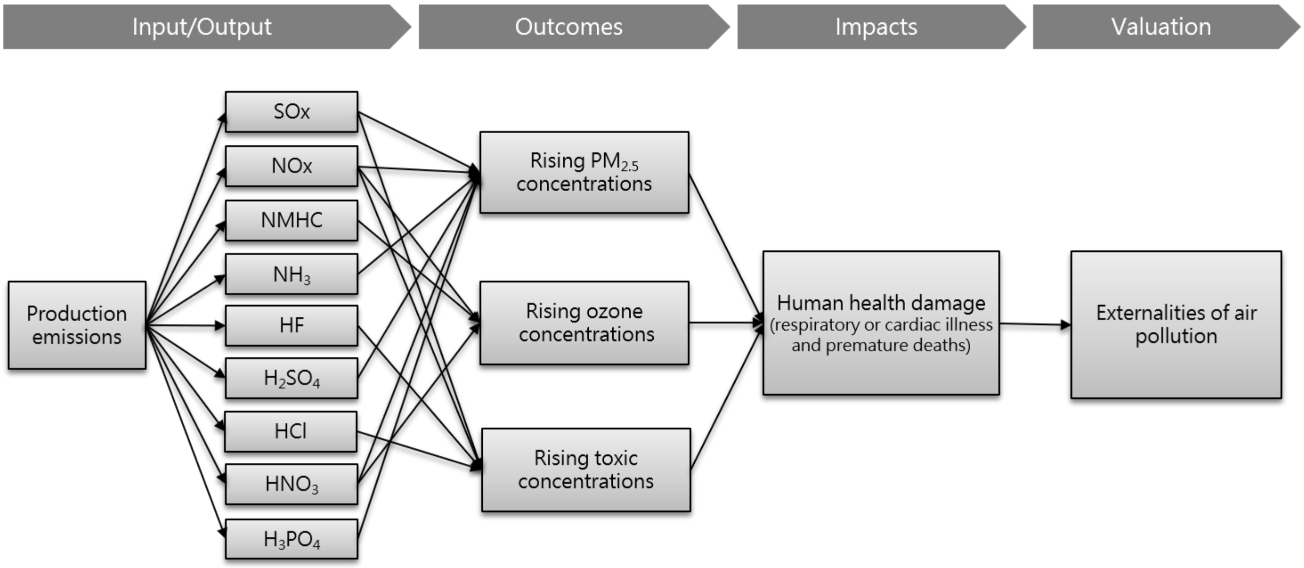
5.3 Air Pollution

Air pollution that produces primary and secondary aerosols in the atmosphere can have a substantial negative impact on human health (WHO, 2006; HEIMTSA, 2011; Burnett et al., 2014; Lelieveld et al., 2015). The majority (94%) of the social cost of air pollution comes from illnesses and mortalities. The rest is from visibility, agricultural losses, and recreational value (Muller & Mendelsohn, 2007).

Air pollutants derived from TSMC are classified into fine particulate matter, ozone, and toxic substances. According to RIVM (2017), fine particulate matter less than 2.5 µm ($PM_{2.5}$) in diameter represents a complex mixture of organic and inorganic substances. Such substances can cause human health problems to the upper respiratory airways and lungs when inhaled and are measured by particulate matter formation potential (PMFP). Ozone is formed as a result of photochemical reactions of NOx and non-methane volatile organic compounds (NMVOCs) that can inflame airways and damage lungs and are measured by human health ozone formation potential (HOFP). Toxic substances have carcinogenic or non-carcinogenic effects on human health and are measured by human toxicity potential (HTP).

This study adopts CFs from CML (2016), ReCiPe (2018), and LC-Impact (2016) for human health loss caused by various air pollutant emissions and estimates the external cost of each operation based on VSL.

Impact pathways



Calculation

$$\text{Externalities of air pollution}$$
$$= \text{Air pollutant emissions} \times \text{Health damage factor} \times \text{Human health cost}$$

- *Externalities of air pollution: external environmental costs caused by air emissions (2018 NTD/year)*
- *Air pollutant emissions: total air pollutant emitted from TSMC operation sites (ton/year)*
- *Health damage factor: loss of healthy life due to $PM_{2.5}$, ozone, and toxic substances inhaled (DALY/ton)*
- *Human health cost: value of every healthy life lost (2018 NTD/DALY) (see Section 4.4 for details)*

Assumptions and limitations

1) $PM_{2.5}$
   - The WHO (2004) concluded that most epidemiological studies on large populations have been unable to identify a threshold concentration below which ambient $PM_{2.5}$ has no effect on mortality and morbidity.
   - Therefore, no thresholds for $PM_{2.5}$ effects are assumed in the effect calculations.

2) Ozone
   - Ozone formation is a nonlinear process that depends on the meteorological conditions and background concentrations of NOx and NMVOCs (Cohan et al., 2005).
   - NMHCs (non-methane hydrocarbons) is a subset of NMVOC consisting of compounds containing only carbon and hydrogen (Petrea, 2007). This study uses CFs of NMVOC.

3) Toxic substances
   - Population density is an important factor that affects the rate of toxic substance uptake. This study assumes and uses the CFs of a high population density region.

4) Out of the scope
    - Ecosystem degradation: methodology is currently being developed.
    - Visibility, agricultural losses, and recreation value: non-primary issues.
    - Indirect impact from power plant: this factor is excluded owing to the difficulty of acquiring activity data.

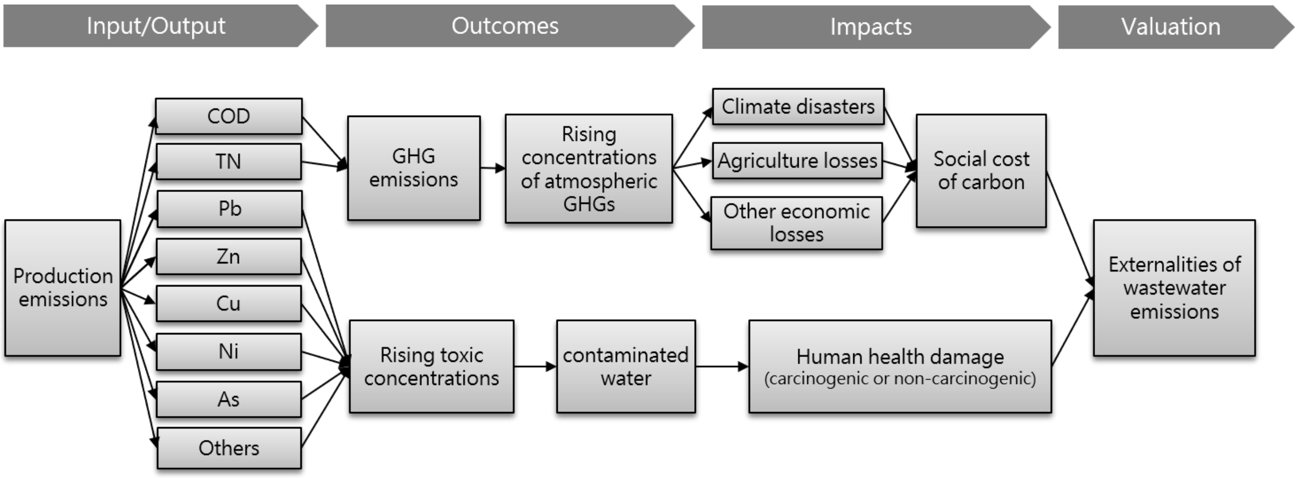
5.4 Water Pollution

Water pollutants can enter humans via a number of pathways, including direct ingestion (e.g., drinking), indirect ingestion (e.g., bioaccumulation), and direct inhalation (e.g., evaporated pollutants). These pollutants are discharged in low concentrations in effluents. Long-term exposure to low levels of chemical pollutants can lead to chronic health problems, such as cancer, increased risks of adverse pregnancy outcomes, and reduced mental and central nervous functions. The most important of these pollutants are heavy metals and chemicals, which are measured by human toxicity potential (HTP) (PwC UK, 2015; CE Delft, 2018). The severity of the potential impact resulting from the discharge of these specific pollutants is diverse. Therefore, the analysis considers specific pollutants to emphasize the impact of water pollution.

The USEtox model, which was developed by UNEP and SETAC, contains more than 3,000 organic and inorganic chemicals that affect human health and ecosystems. This study uses CFs from the USEtox (2017) database for human health loss caused by various types of pollutants and estimates the external cost of each operation based on VSL.

Using chemical oxygen demand (COD) and total nitrogen (TN) as indicators, this study refers to the IPCC (2006) assessment method to calculate the greenhouse gases such as methane (CH_4) and nitrous oxide (N_2O) derived from wastewater discharge at various operation sites to estimate the social cost of carbon.

Impact pathways



Calculation

$$
\begin{aligned}
&\text{Externalities of water pollution} \\
&\qquad = (\text{Water pollutant emissions} \times \text{Health damage factor} \times \text{Human health cost}) \\
&\qquad + (\text{GHG emissions} \times \text{Social cost of carbon})
\end{aligned}
$$

- *Externalities of water pollution: external environmental costs caused by wastewater discharge (2018 NTD/year)*
- *Water pollutant emissions: total water pollutant emitted from TSMC operation sites (ton/year)*
- *Health damage factor: loss of healthy life due to toxic substance intake (DALY/ton)*
- *Human health cost: value of every healthy life lost (2018 NTD/DALY) (see Section 4.4 for details)*
- *GHG emissions: GHG emissions from wastewater treated anaerobically (ton-CO_2/year)*
- *Social cost of carbon: long-term economic damage indicators caused by GHG emissions in a given year (2018 NTD/ton-CO_2) (see Section 4.4 for details)*

Assumptions and limitations

1) Toxic substances
    - Assuming that treated wastewater is discharged into a freshwater basin, the pollutant transport and human intake rates do not vary by region. Any increase in pollution in the water body is likely to cause carcinogenic and non-carcinogenic diseases.

2) GHG emissions
    - Only the GHG emissions of industrial wastewater are considered.
    - CO_2 emissions from wastewater are not considered because of biogenic origin (IPCC, 2006).

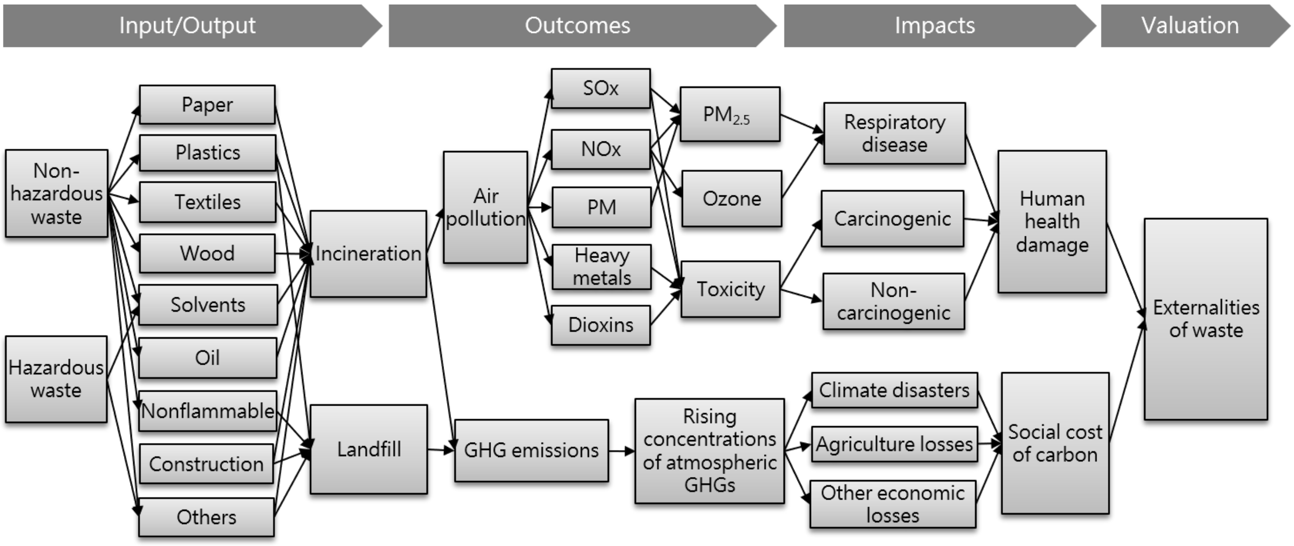
3) Out of the scope
    - Ecosystem degradation: methodology is currently being developed.
    - Agricultural losses and recreation value: non-primary issues.
    - Indirect impact from wastewater treatment plant: this factor is excluded given that treatment technology is complicated and data are not readily available.
    - Indirect impact from power plant: this factor is excluded owing to the difficulty of acquiring activity data.

5.5 Waste

Waste incineration produces a wide variety of air pollutants. PM, NOx, SOx, dioxins, and heavy metals are particularly important, as they can have considerable societal consequences (e.g., causing cancer or loss of intelligence via developmental harm) (EXIOPOL, 2009; PwC UK, 2015). Based on the actual test data of 24 incinerators in Taiwan, this study estimates the emission factors of the incineration of various types of air pollutants. We refer to the LC-Impact (2016) and USEtox (2017) databases for the CFs of human health losses due to various air pollutant emissions. We estimate the external cost of each operation based on VSL.

Greenhouse gases (GHGs) are produced by the decomposition of waste materials at landfill sites and from the burning of wastes in incinerators (PwC UK, 2015). GHGs generated by the waste incineration process include CO_2, CH_4, and N_2O. This study estimates GHG emissions while considering the dry matter weight, fossil carbon content, and incinerator combustion efficiency of various wastes according to the IPCC (2006) method. CH_4 is emitted during the anaerobic decomposition of organic wastes in solid waste disposal sites. GHG emissions from landfill processes are assessed based on the first-order decay (FOD) model to estimate the social cost of carbon from incineration and that derived from landfills.

Impact pathways



Calculation

$$\begin{aligned}\text{Externalities of waste}\\ &= (\text{Waste incineration} \times \text{Emission factor of air pollution} \times \text{Health damage factor}\\ &\quad \times \text{Human health cost}) + (\text{Waste incineration} \times \text{GHGs emission factor}\\ &\quad + \text{Waste landfill} \times \text{GHGs emission factor}) \times \text{Social cost of carbon}\end{aligned}$$

- *Externalities of waste: external environmental costs caused by wastes from incinerators or landfills (2018 NTD/year)*
- *Waste incineration: total waste incineration treatment of TSMC operation sites (ton/year)*
- *Waste landfill: total waste landfill disposal of TSMC operation sites (ton/year)*
- *Emission factor of air pollution: air pollutants generated by incinerator (kg* $_{pollutant}$*/ton)*
- *Health damage factor: loss of healthy life due to air pollution (DALY/ton)*
- *Human health cost: value of every healthy life lost (2018 NTD/DALY) (see Section 4.4 for details)*
- *GHG emission factor: GHG emissions from incinerators or landfills (ton-*CO_2*/ton)*
- *Social cost of carbon: long-term economic damage indicators caused by GHG emissions in a given year (2018 NTD/ton-*CO_2*) (see Section 4.4 for details)*

Assumptions and limitations

1) Air pollution caused by incineration
   - This study assumes and uses the CFs in a high population density region.

2) GHG emissions from incineration
   - This study uses the original statistics of the incinerators to assess the potential of incineration power generation to avoid GHG emissions.

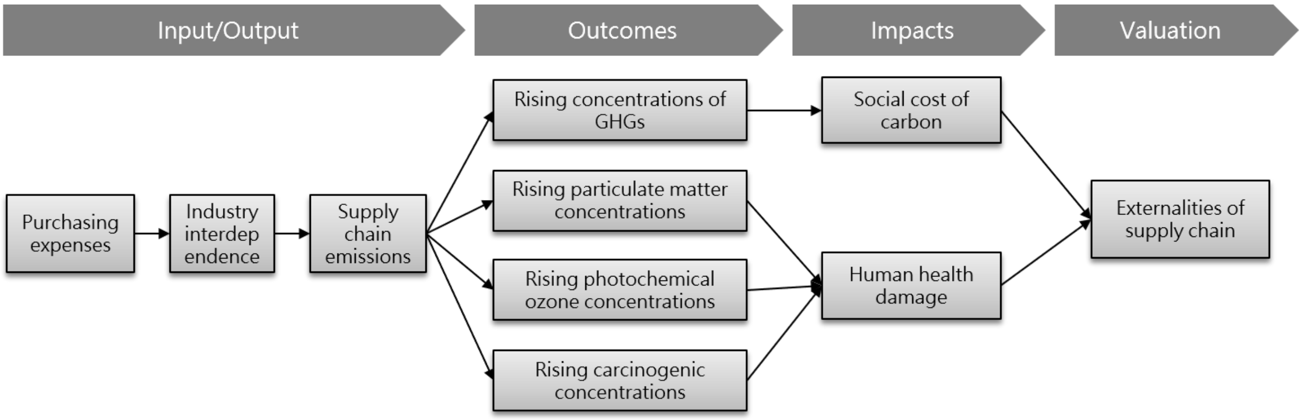
3) GHG emissions from landfill
   - CH_4 emitted during anaerobic decomposition is discharged yearly based on its half-life, which ranges from several years to decades (IPCC, 2006). This study refers to the EPA (2017) recommendation that buried waste takes 50 years to completely decompose.
   - According to the census results of the EPA's 2016 biogas collection and treatment methods for 377 landfills in Taiwan, the proportion of landfill treatment that can be deducted from biogas combustion can be regarded as zero. Therefore, this study does not consider carbon emissions that can be avoided through landfill methane recovery.

4) Out of the scope
   - This study does not consider the externalities of the intermediate treatment of wastes.
   - Ecosystem degradation: methodology is currently being developed.
   - Leachate, noise, land use, and so on: non-primary issues.
   - Recycling externalities: these factors are excluded given that treatment technology is complicated and data are not readily available.

5.6 Environmental Hot Spot Analysis of the Supply Chain

There exists a complex co-dependent relationship between inter-industry economic activities. Applying the input-output analysis, we can understand the economic value directly or indirectly created through procurement. Kitzes (2013) points out that EEIO analysis offers a simple and comprehensive method for evaluating the relationship between consumer activity and its environmental impact. In this study, we apply the EEIO method to our suppliers with annual trading three or more times and transactions exceeding NT$ 10 million to evaluate the indirect environmental footprint and social costs that our procurement has resulted on our supply chain. The scope of our assessment includes the social cost of carbon as a result of greenhouse gas emissions and the damages of air pollutants to human health in terms of respiratory diseases and carcinogenic impacts. The analysis is based on the CFs from EXIOBASE 2 database*[11]; we assess the relationship between procurement from various industries and their environmental impacts, and then we introduce the social cost of carbon and human health cost for a conversion into monetary value.

Impact pathways



---

[11] *EXIOBASE is a global, detailed Multi-regional Supply-Use and Input-Output database jointly developed by the Norwegian University of Science and Technology (NTNU), Netherlands Organization for Applied Scientific Research (TNO), Sustainable Europe Research Institute (SERI), Institute of Environmental Sciences (CML), Institute for Ecological Economics (WU), and 2.-0 LCA consultants. EXIOBASE 2 uses 2007 as the base year and covers economic, environmental, and social data for 5 continents, 43 countries/regions, and 163 industries.*

Calculation

$$\text{Externalities of supply chain} \\ = \text{purchase amount (in NT\$)} \times \text{characterization factors} \times \text{valuation factors}$$

- *Externalities of supply chain: external costs on the environment from TSMC's procurement (2018 NTD/year)*
- *Purchase amount (in NT$): the monetary value of procurement made by TSMC from suppliers (NTD/year)*
- *Characterization factor: environmental externalities from pollutants indirectly caused by TSMC's procurement and subsequent impact on supply and demand in various industries; includes human health costs from air pollution and global warming from greenhouse gas emissions (DALY/NTD and ton-CO_2e/NTD, respectively)*
- *Valuation factor: includes human health costs and social cost of carbon (2018 NTD/DALY and 2018 NTD/ton-CO_2e, respectively); please refer to 4.4.*

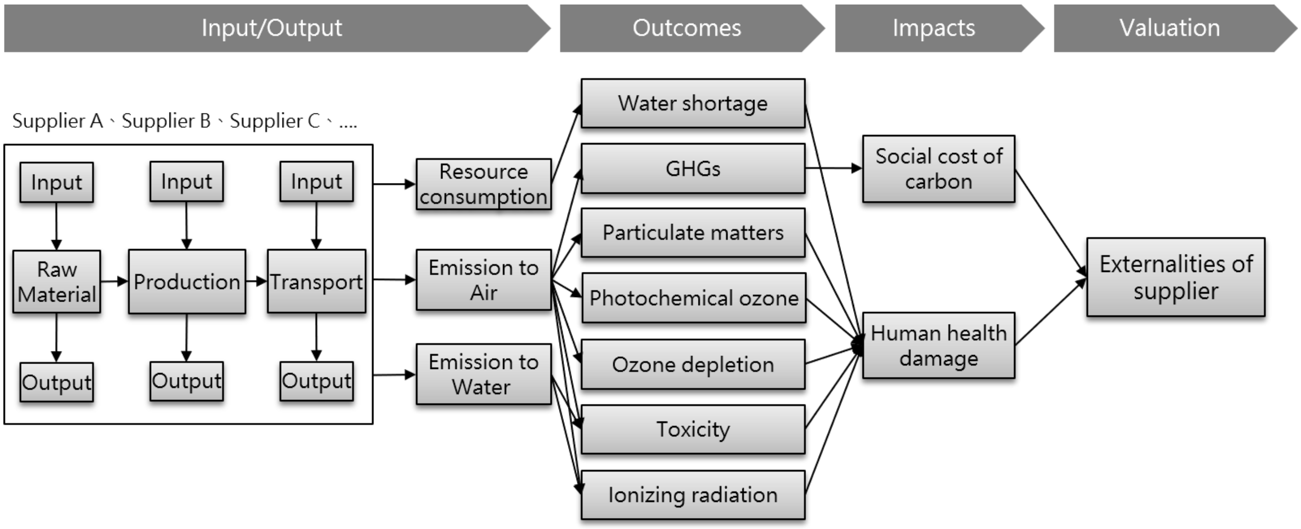
Assumptions and limitations

1) EEIO combines pollutants from various industries with inter-industry supply and demand to estimate the environmental impact indirectly caused by purchasing expenses. The EEIO methodology presents the average impact of multiple industries and therefore the accuracy of the results is highly dependent on how detailed the database has set up its industry categories.
2) Certain suppliers are based in countries without coefficient data in the EXIOBASE 2 database and will be substituted by coefficients of neighboring countries or countries with similar economic structures. But this may result in uncertainties in the calculations. For example, Singapore and Malaysia will be adopting the coefficient for Taiwan.

5.7 Environmental Externalities of Critical Raw Material Life Cycles

For a better understanding of the environmental externalities generated by various raw materials used in fabrication, TSMC has prioritized certain suppliers to survey in consideration of data comparability, integrity, and procurement percentage. TSMC conducted Life Cycle Impact Assessments (LCIA) on the selected suppliers to identify related data on energy and resources consumed (input) and pollutants and waste generated (output) across raw material extraction, production and manufacturing, and distribution and transportation. Version 3.5 of the ecoinvent database*[12] and characterization factors (CFs) from ReCiPe 2016*[13] were adopted as the basis for calculating the product life cycles environmental impact, which was then converted into a monetary valuation after adding the social cost of carbon and cost of damages to human health.

Impact pathways



---

[12] *Ecoinvent is a Swedish NGO. Version 3.5 of the ecoinvent database contains over 16,000 life cycle assessment data points and offers three system models: Cut-off, APOS, and Consequential. TSMC adopted an attribution-based APOS system model.*

[13] *A methodology to assess life cycle impact, ReCiPe aims to convert surveyed data into measurable environmental impact indicators. ReCiPe was first developed by the National Institute for Public Health and the Environment (RIVM), Radboud University, Leiden University, and PRé Sustainability in 2008 and then updated in 2016.*

Calculation

$$\text{Externalities of supplier} = \text{supplier avtivity data} \times \text{characterization factors} \times \text{valuation factors}$$

- *Externalities of supplier: external costs on the environment from TSMC’s raw material supplier (2018 NTD/year)*
- *Supplier activity data: include the input (energy resources) and output (air and water emissions) from raw material extraction and processing, product manufacturing and shipping on the life cycle for supplying products and services, which are represented as physical units of measurements (e.g. kWh, ton, m3, km, etc.)*
- *Characterization factor: environmental externalities caused by energy resources consumption and pollutant emissions in the life cycle of products and services; includes human health damage and global warming (DALY and ton-CO2e, respectively)*
- *Valuation factor: includes human health costs and social cost of carbon (2018 NTD/DALY and 2018 NTD/ton-CO_2e, respectively); please refer to 4.4.*

Assumptions and limitations

1) Activity data of selected suppliers are from actual surveys while activity data of the raw material supply chain are coefficients from databases which may lead to uncertainties in the results based on differences in geographical locations or industrial processes. Coefficients of similar characteristics will be selected when a dedicated coefficient is not available in the database.

2) When the supplier's facility contains a greater diversity of products and the energy resource (input) and pollutant emissions (output) varies by product type and the supplier is unable to identify such information for each product type, TSMC will opt to allocate the activity data based on the total output volume of all products manufactured in the facility.

3) If the supplier subcontracts any part of the manufacturing or distribution process (e.g. products manufactured by Manufacturer A are delivered to Manufacturer B for additional processing or distribution), activity data from both stages shall be included.

6. Bibliography

1. Bayart, J.B., Bulle, C., Deschênes, L., Margni, M., Pfister, S., Vince, F., Koehler, A. (2010). A framework for assessing off-stream freshwater use in LCA. *International Journal of Life Cycle Assessment*, 15(5), 439-453.
2. Boulay, A.M., Bulle, C., Bayart, J.B., Deshenes, L., Manuele, M. (2011). Regional characterization of freshwater use in LCA:modeling direct impacts on human health. Environmental Science & Technology, 45(20), 8948-8957.
3. Burnett, R.T., Pope, C.A., III, Ezzati, M., Olives, C., Lim, S.S., Mehta, S., Shin, H.H., Singh, G., Hubbell, B., Brauer, M., Anderson, H.R., Smith, K.R., Balmes, J.R., Bruce, N.G., Kan, H., Laden, F., Pruess-Ustuen, A., Turner, M.C., Gapstur, S.M., Diver, W.R., Cohen, A. (2014). An Integrated Risk Function for Estimating the Global Burden of Disease Attributable to Ambient Fine Particulate Matter Exposure. Environmental Health Perspectives, 122(4), 397-403.
4. CE Delft. (2018). Environmental Prices Handbook 2017: Methods and numbers for valuation of environmental impacts.
5. Central Bureau of Statistics (CBS). (2011). Environmental Accounts of the Netherlands.
6. CML-Department of Industrial Ecology. (2016). CML-IA Characterisation Factors.
7. Cohan, D.S., Hakami, A., Hu, Y., Russell, A.G. (2005). Nonlinear Response of Ozone to Emissions: Source Apportionment and Sensitivity Analysis. Environmental Science and Technology, 39(17), 6739-48.
8. HEIMTSA. (2011). D 5.3.1/2 Methods and results of the HEIMTSA/INTARESE Common Case Study. The Institute of Occupational Medicine.
9. EPA. (2017). 2017 Taiwan National Greenhouse Gas Inventories Report.
10. EXIOBASE 2 database. (2014). https://www.exiobase.eu/index.php/about-exiobase
11. Exiopol. (2009). Report of the Exiopol project, Dose response function paper, National Environmental Research Institute.
12. IPCC. (2006). 2006 IPCC Guidelines for National Greenhouse Gas Inventories.
13. ISO. (2006). ISO 14040:2006 Environmental management - Life cycle assessment - Principles and framework.
14. ISO. (2019). ISO 14008:2019 Monetary valuation of environmental impacts and related environmental aspects.
15. IVR. (2017). White paper: Operationalizing Impact Valuation.
16. Kitzes, J. (2013). An Introduction to Environmentally-Extended Input-Output Analysis. Resources 2013, 2(4), 489-503.
17. Kounina, A., Margni, M., Bayart, J.B., Boulay, A.M., Berger, M., Bulle, C., Frischknecht, R., Koehler, A., Milà i Canals, L., Motoshita, M., Núñez, M., Peters, G., Pfister, S., Ridoutt, B., Zelm, R., Verones, F., Humbert, S. (2013). Review of methods addressing freshwater use in life cycle inventory and impact assessment. International Journal of Life Cycle Assessment, 18(3), 707-721.

18. LC-Impact. (2016). A spatially differentiated life cycle impact assessment approach, version 0.5.
19. Lelieveld, J., Evans, J.S., Fnais, M., Giannadaki, D., Pozzer, A. (2015). The contribution of outdoor air pollution sources to premature mortality on a global scale. Nature, 525, 361-371.
20. Motoshita, M., Itsubo, N. and Inaba, A. (2011). Development of impact factors on damage to health by infectious diseases caused by domestic water scarcity. The International Journal of Life Cycle Assessment, 16(1), 65-73.
21. Muller, N.Z. and Mendelssohn, R. (2007). Measuring the Damages of Air Pollution in the United States. Journal of Environmental Economics and Management, 54 (1), 1-14.
22. Natural Capital Coalition. (2016). Natural Capital Protocol Principles and Framework.
23. OECD. (2012). Mortality Risk Valuation in Environment, Health and Transport Policies.
24. Petrea, DMV. (2007). Emissions of Non-Methane Volatile Organic Compounds (NMVOC) from Vehicular Traffic in Europe.
25. PwC UK. (2015). Valuing corporate environmental impacts. PwC methodology document.
26. RIVM. (2017). ReCiPe2016: a harmonized life cycle impact assessment method at midpoint and endpoint level, version 1.1.
27. RIVM. (2018). ReCiPe2016 Characterisation and normalisation factors, v1.1.
28. UNEP. (2016). Global Guidance for Life Cycle Impact Assessment Indicators, Volume 1.
29. UNEP and SETAC. (2017). USEtox 2.0 documentation, version 1.
30. US EPA. (2016). Technical Support Document: Technical Update of the Social Cost of Carbon for Regulatory Impact Analysis.
31. USEtox v2.1 database. (2017). https://www.usetox.org/model/download/usetox2.1
32. WHO. (2004). Health aspects of air pollution – answers to follow-up questions from CAFE. Report on a WHO working group meeting. World Health Organization, Bonn, Germany, 15–16 January 2004.
33. WHO. (2006). Health risks of particulate matter from long-range transboundary air pollution. World Health Organization, Copenhagen, Denmark.
34. World Water Assessment Programme (WWAP). (2009). The United Nations World Water Development report 3: Water in a Changing World. The United Nations Educational Scientific and Cultural Organization. Paris, France and London, United Kingdom
35. Yan, Ru-yu. (2014). An Investigation into the Social Discount Rate from a Cost-benefits Analysis of Public Works. Public Finance Review, 43 (1), 149-162.