TSMC 2020

Environmental Profit and Loss (EP&L)

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Corporate Sustainability Impact Center, Tunhai University

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1. Executive summary

"Better, Together" is our commitment to corporate sustainability and the key to TSMC's continuous growth and influence. Since 2018, TSMC has been collaborating with the Corporate Sustainability Impact Center at Tunghai University to introduce an Environmental Profit and Loss (EP&L) valuation model that integrates simple financial terms with corporate sustainable management thinking. The valuation model can convert all environmental externalities produced from global production and operations into monetary valuations of the social costs from an outside-in perspective. During our decision-making process, the valuation can help us consider opportunities to reduce our environmental footprint and increase social welfare. In 2019, the EP&L was further applied to the upstream supply chain. We conducted hot spot analysis through Environmentally Extended Input Output (EEIO)[*1] and started evaluating each and every key supplier. With life cycle thinking, we also started surveying and evaluating suppliers of key raw materials in hopes that TSMC can drive sustainability across the supply chain and generate synergy throughout the value chain.

In 2020, the monetary valuation of environmental externalities from production and operations was around NT$15,745 million; a significant 96.6% or NT$15,209 million of the environmental externalities were the social cost of carbon from GHG emitted from energy and gas consumption for fabrication. In recent years, TSMC has been increasingly expanding new fabs, which, when coupled with migration of advanced process technologies, increases the demand for energy, water, and raw materials. To mitigate the rising trends of environmental externalities, TSMC continues to expand use of renewable energies, perfect water reclamation technologies, and optimize pollution prevention and source reduction solutions. Our efforts helped reduce EP&L density by 7.5%[*2] from the previous year.

Furthermore, as TSMC procurement demands are driving the supply chain's output value, environmental issues relating to the supply chain becomes more pressing as well. TSMC will first detail the environment hot spot analysis on the supply chain; in 2020, the monetary valuation of environmental externalities from TSMC procurements was around NT$11,503 million[*3]. Manufacturing of chemical products indirectly contributed to the largest environmental externality across the supply chain, accounting for 51% or NT$5,829 million of the environmental externalities. Based on aforementioned results, TSMC will prioritize conducting life cycle environmental impact assessment on raw materials for processes. As of 2020, a cumulative total of 40 suppliers have been surveyed. Research shows that sulfuric acid, developers, and ammonia solution have the most significant impact in terms of environmental externalities while silicon wafers and targets generate the largest environmental externality per unit of raw material input. In the face of environmental issues across the supply chain, TSMC continues to strive for a responsible supply chain to reduce the resulting impact on our environment and society.

TSMC hope that our enduring efforts can advance corporate sustainability management. With the four major principles of Insights, Collaborate, Transformation, and Impact, we strive to tackle climate risks and opportunities early on and generate a significant net positive impact on society.

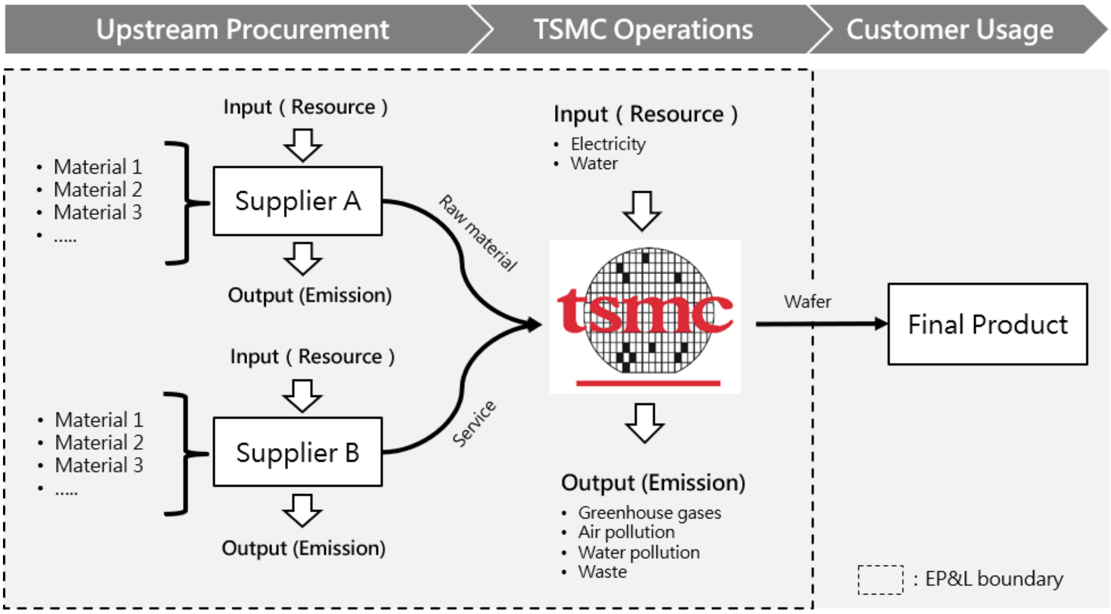
*Note[*1]: EEIO analysis is a common methodology to assess the correlation between economic activities and downstream environmental impact (Kitzes, 2013).*

*Note[*2]: EP&L density refers to the monetary valuation of environmental externalities generated by a 12-inch equivalent wafer mask layer*

*Note[*3]: In 2020, the supplier selection standard was amended and therefore the valuation scope was extended to facility and equipment suppliers. Please refer to 5.1 for more details.*

2. Scope and boundary

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; 1,041 suppliers meet the criteria in 2020.	**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, and VisEra **China：**Fab 10 and Fab 16 **USA：**Fab 11
Temporal boundary	2020/01/01 to 2020/12/31	
Scope	Greenhouse gases (GHGs), air pollution, water pollution, waste, and water consumption	
Externalities	Social cost of carbon and human health cost	

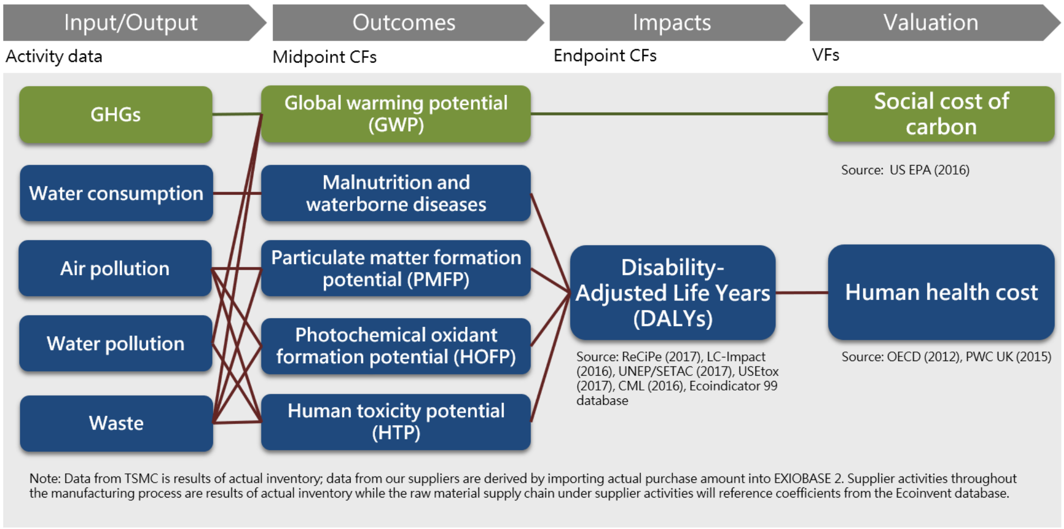
3. Methodology

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). 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)[*4] 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.

*Note[*4]: 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).*

3.1 Data sources

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.



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.

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)[*5] as a quantitative metric (refer to Sections 4.1 to 4.5 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).

*Note[*5]: One DALY can be considered as one lost year of "healthy" life (WHO).*

Target	Activity data (Input)	Activity data (Output)	CFs	VFs
TSMC	◎	◎	○	○
Supply chain (hot spot analysis)	◎	○		
Supplier (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)

3.2 Monetary valuation

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)		
	5% discount rate	3% discount rate	2.5% discount rate
2016	11	38	57
2017	11	39	59
2018	12	40	60
2019	12	41	61
2020	12	42	62

*Note*6: The values in the table indicate economic losses caused by global climate changes from CO_2 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 CO_2 in 2018.*

*Note*7: 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).*

*Note*8: This study uses a median of 3% discount rate.*

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.

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

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.

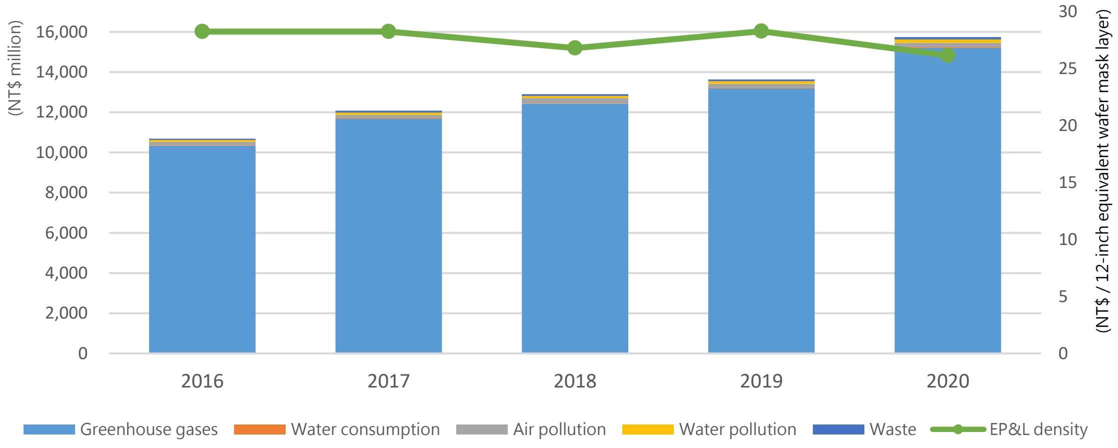
Value factor	Original	Adjusted
Social cost of carbon[*9]	42 (Unit：2007 USD/ton-CO_2)	1,540 (Unit：2018 NTD/ton-CO_2)
Human health cost	164,366 (Unit：2005 USD/DALY)	Taiwan: 7,073,176 China: 3,670,405 USA: 7,790,113 Japan: 6,272,106 Korea: 5,900,960 Germany: 7,099,465 Grance: 6,438,535 Italy: 6,093,175 Israel: 5,887,703 Malaysia: 5,022,955 (list only main operation site and supplier locations) (Unit：2018 NTD/DALY)

*Note[*9]: CO_2 emissions cause a global impact of rising GHG concentrations and will not vary by region.*

4. EP&L valuation: TSMC operations

In 2020, the environmental externalities in TSMC operations was estimated to have a monetary value of around NT$ 15,745 million. Greenhouse gas (GHG) is the main source of impact accounting for 96.6%, while other types of air pollution, water pollution, waste, and water consumption comprise 3.4%. In recent years, the environmental externalities of TSMC operations have been trending upwards because of new facilities and migration of advanced process technologies, resulting in the growing demand on electricity, water, and raw materials. In the production stages, TSMC will strive for low-carbon manufacturing, expand the use of renewable energies, and improve energy efficiency. We will also work on regenerated water and the circular economy to mitigate the social cost and impact brought on by consuming significant quantities of energy and resources. Our efforts helped reduce EP&L density by 7.5% from the previous year.

Environmental externalities for TSMC operations



Unit: NT$ million

	2016	2017	2018	2019	2020
Greenhouse gases	10,330	11,662	12,430	13,183	15,209
Water consumption	24	24	25	28	36
Air pollution	179	190	253	210	209
Water pollution	92	107	102	123	166
Waste	63	96	93	86	124

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

EP&L density	28	28	27	28	26

*Note[*10]: The monetary value is the relative value produced by the formula and the scenario analysis rather than the absolute value.*

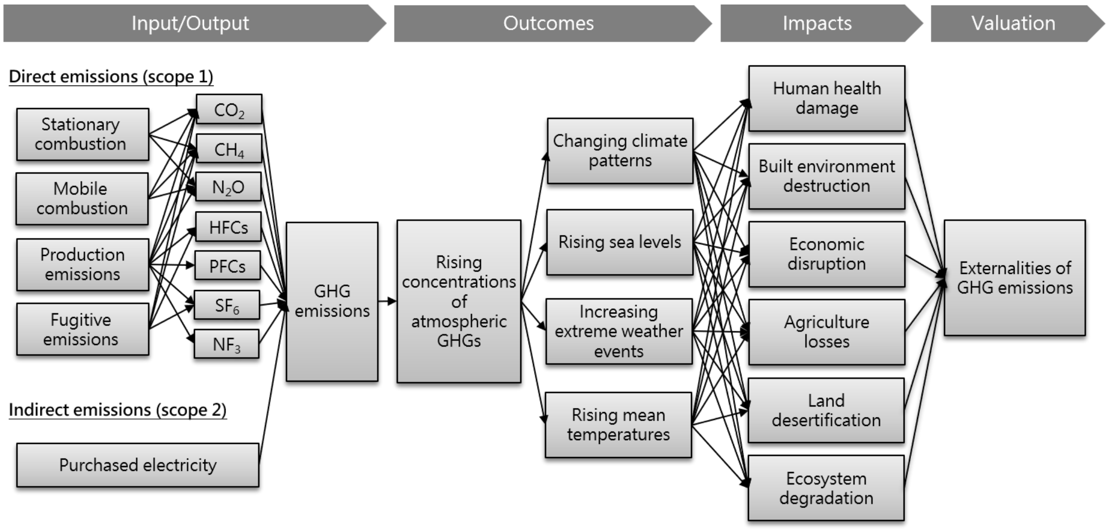
*Note[*11]: EP&L calculations have been revised due to updated GHG emissions from 2016 to 2019.*

4.1 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

$$Externalities\ of\ GHG\ emissions = GHG\ emissions \times Social\ cost\ of\ carbon$$

- *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 3.2 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.

Results

According to EP&L analysis, the external costs of greenhouse gas emissions of all TSMC operation sites globally in 2020 was around NT$ 15,209 million which was 96.6% of the overall external cost. CO_2 emissions, at 77.4%, from indirect emissions due to purchased electricity, was the most significant factor. In recent years, the external costs of greenhouse gas emissions have been trending upwards because of the progression of advanced technologies and various new fabs becoming operational; the growing consumption of electricity ultimately results in greater greenhouse gas emissions.

In 2020, TSMC joined RE100, a global renewable energy initiative, and committed to 25% renewable energy in all TSMC fabs (production facilities) and 100% renewable energy in all non-fab facilities by 2030; and 100% renewable energy in all global operation offices by 2050. TSMC is setting forth relevant measures to mitigate the social costs and impacts of massive energy consumption. Measures include:

1) Promote Low-Carbon Manufacturing: Adopting the best available technology (BAT) to reduce GHG emissions and become an industry benchmark in low-carbon manufacturing. In 2020, TSMC eliminated, replaced, or installed 1,684 local scrubbers for fluorinated greenhouse gases and nitrous oxide which helped reduce GHG emissions by 420,000

metric tons and eliminate NT$6.5 billion in social cost of carbon.

2) Renewable Energies: Purchased renewable energies and installed solar-energy power systems to increase the use of renewable energies. As of 2020, 100% of the energy in US and China facilities is from renewable energy, reducing GHG emissions by around 690,000 metric tons and eliminating NT$1.1 billion in social cost of carbon.

3) Increase Energy Efficiency: Map out new, yearly energy-saving measures, take action in energy conservation, and increase energy efficiency. In 2020, TSMC carried out 460 energy-saving measures across 8 different categories and was able to conserve 500 GWh in energy consumption, reduce around 250,000 metric tons of GHG emissions, and eliminate NT$3.8 billion in social cost of carbon.

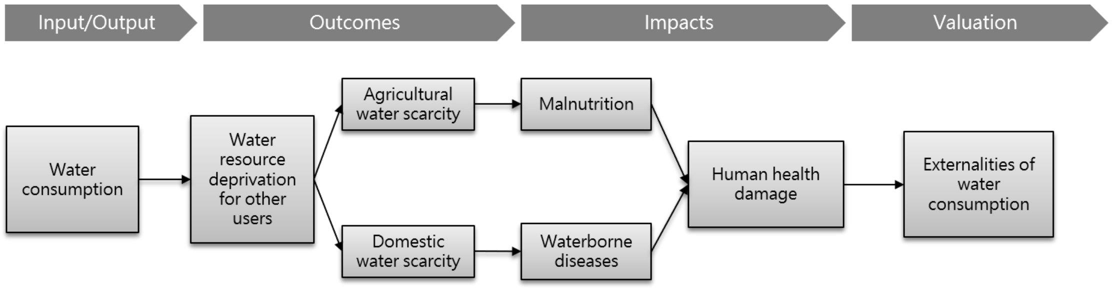
4.2 Water consumption

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

$$\begin{aligned} &\mathit{Externalities\ of\ water\ consumption} \\ &\qquad = \mathit{Water\ consumption} \times \mathit{Health\ damage\ factor} \\ &\qquad \times \mathit{Human\ health\ cost} \end{aligned}$$

- *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 3.2 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.

Results

According to EP&L analysis, the external cost of water consumption at all TSMC operation sites globally in 2020 was around NT$ 36 million, which is 0.2% of the overall external cost on the environment; malnutrition from agricultural water scarcity is the primary effect. The migration of advanced process technologies and new fabs becoming operational are why external costs of water consumption grew in 2020.

TSMC will adopt a dual-track approach by seeking alternative water sources and conserving water consumption. We will integrate internal and external resources to facilitate water risk management, seek diverse water sources, recycle and reuse water, and adopt various water-saving measures. In 2020, TSMC successfully introduced a backwashing system and effectively conserved an additional 297,000 metric tons of water, putting the annual water conservation amount at 1,927,000 metro tons. We believe that when the TSMC Water Reclamation Plant in Southern Taiwan Science Park is operational, it will provide 10,000 metric tons of recycled water daily, reducing our use of tap water, pushing us towards water recycling, and offering diverse water sources.

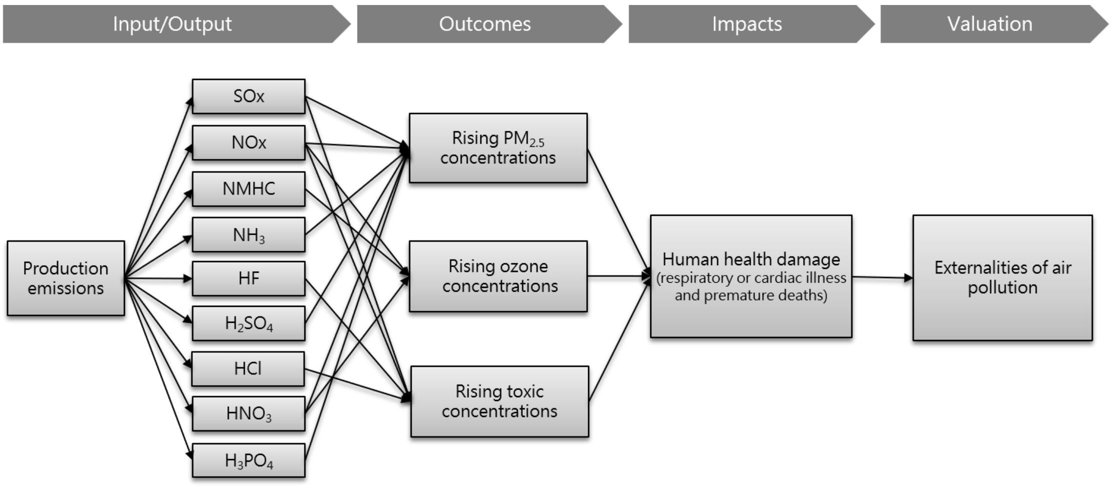
4.3 Air pollution

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

$$\begin{aligned} &\mathit{Externalities\ of\ air\ pollution} \\ &\qquad = \mathit{Air\ pollutant\ emissions} \times \mathit{Health\ damage\ factor} \\ &\qquad \times \mathit{Human\ health\ cost} \end{aligned}$$

- *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 3.2 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.

Results

According to EP&L analysis, the external cost of air pollutant emissions at all TSMC operation sites globally in 2020 was around NT$ 209 million, which is 1.3% of the overall external cost on the environment; the primary reason is damages to human health from particulate matters. In recent years, TSMC has effectively implemented source reduction and prevention equipment at later stages of the life cycle to strengthen the measures. In 2020, TSMC was able to contain air pollution externalities from production and operations despite the construction of new fabs and migration of process technologies.

TSMC has spared no efforts in air pollution control. In 2020, facilities started implementing the following three technologies: High-Efficiency Acid and Alkaline Scrubber, Improvement Program for Inefficient Thermal Oxidizer of Zeolite Rotor Concentrators, and AI Parameter Optimization for Single Zeolite Rotor Concentrators. The new technologies were able to increase the reduction rate of volatile organic gases (VOCs) to over 98%. During the same time, TSMC has been using effective source distribution and highly efficient local scrubbers to treat air pollutants through multi-phase BAT processing to reduce air pollutant emissions per unit product and reduce the social costs and impact generated from pollutants spreading in the atmosphere.

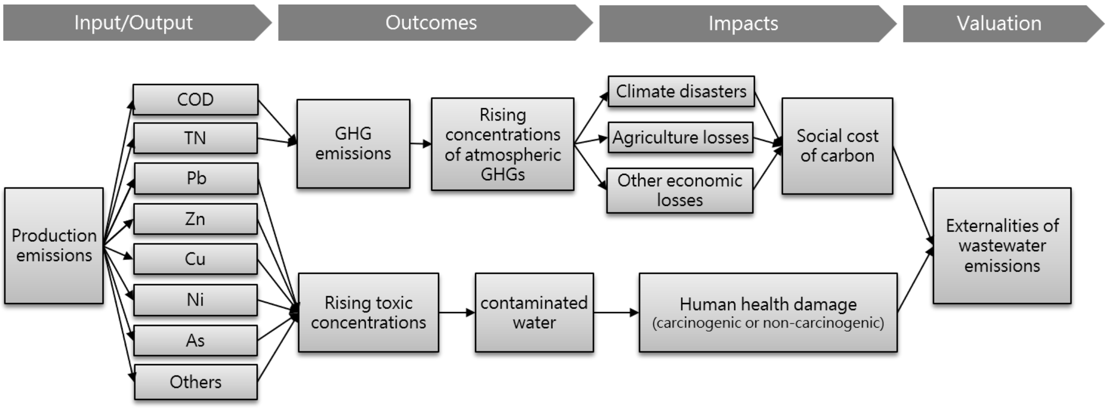
4.4 Water pollution

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

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

- *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 3.2 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 3.2 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.

Results

According to EP&L analysis, the external cost of water pollution from all TSMC operation sites globally in 2020 was around NT$ 166 million, which is 1.1% of the overall external cost on the environment; the social cost of carbon and human health cost from heavy metals arising from the wastewater management process are the primary sources. In 2020, the external costs of wastewater have risen because of new fabs becoming operational, a greater demand on cleanliness for the new processes, and optimization for operational systems.

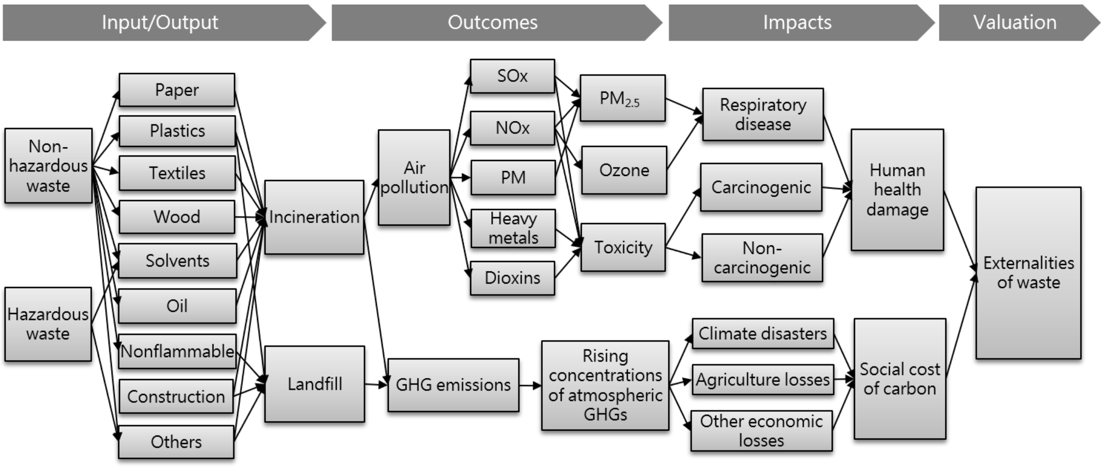
TSMC is devoted to expanding applications of source distribution management and recycling systems; we are researching how to convert effluent matters into reusable, industrial-grade materials. As of 2020, TSMC has successfully uncovered 10 recycled materials that can be recycled and reused. To reduce effluent COD, TSMC has successfully developed a biological thin film treatment system for semiconductor processes that can improve COD reduction capabilities. At the same time, we continue to seek more efficient dosages for treatment processes to apply improvement measures and achieve the dual targets of pollutant reduction and recycling.

4.5 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

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

- *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 3.2 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 3.2 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.

Results

According to EP&L analysis, the external cost of waste from all TSMC operation sites globally in 2020 was around NT$ 124 million, which is 0.8% of the overall external cost on the environment; the social cost of carbon from waste incineration is the primary source of impact. In recent years, many new fabs have become operational and migration of technologies pose a higher demand for cleanliness. Both have contributed to a larger amount of waste, particularly solvent waste and sludge waste, and increased waste externalities in 2020.

TSMC will continue to follow the managing principle of "minimizing waste and maximizing resources" to ensure the commitment to source reduction is realized. We continue to research various regeneration technologies for various resources to transform ourselves from producers of waste to circular economy practitioners and to reduce the environmental impact from production as much as possible. In 2020, TSMC expanded circular economy practices and approved building plans for the first Zero Waste Manufacturing Center of the industry. Once the center becomes operational in 2023, TSMC will be able to reduce 140,000 metric tons of waste that are being commissioned to outside agencies for treatments. We hope to expand the zero waste manufacturing practice to Hsinchu and Tainan facilities and strive towards our goal of sustainable resources.

5. EP&L valuation: upstream procurement

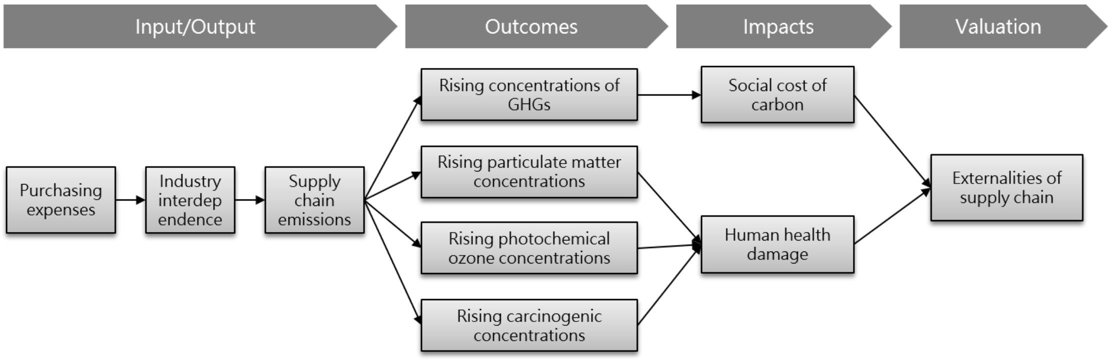
In 2019, the EP&L was further applied to the upstream supply chain. We conducted hot spot analysis through EEIO and started gradually surveying suppliers of key raw materials through life cycle thinking. We hope the valuation can help us drive sustainability across the supply chain and identify opportunities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

5.1 Supply chain hot spot analysis

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[*12]; 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.

*Note[*12]: 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.*

Impact pathways



Calculation

$$\begin{aligned}&\mathit{Externalities\ of\ supply\ chain}\\&= \mathit{purchase\ amount\ (in\ NT\$)\ X\ characterization\ factors\ X\ valuation\ factors}\end{aligned}$$

- *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 3.2.*

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.

Differences from last valuation

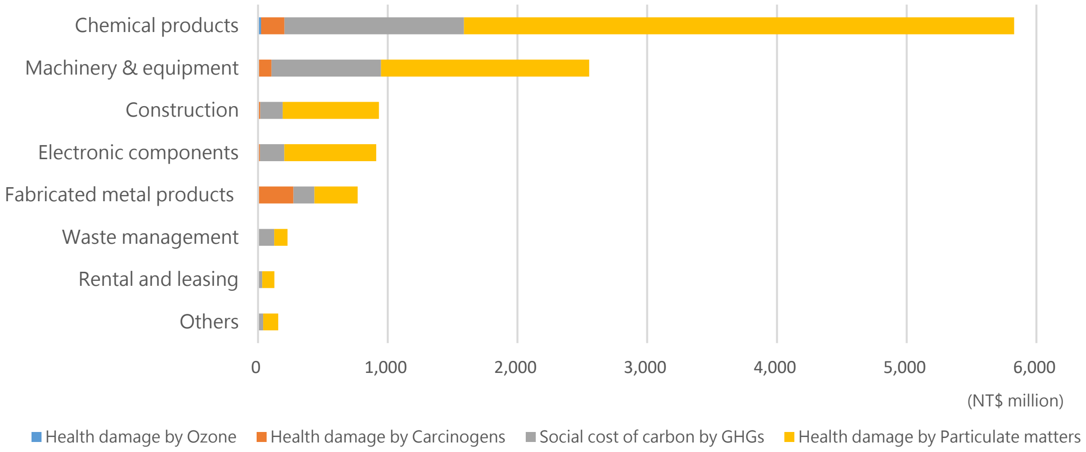
1) The selection criteria were amended in 2020 to include building, facility, and equipment suppliers for a more comprehensive analysis. In 2019, the EP&L valuation covered 441 suppliers and calculated NT$ 6,679 million in environmental externalities; in 2020, the EP&L valuation covered more suppliers and 2019 environmental externalities were retroactively adjusted to NT$ 9,454 million.
2) When suppliers were based in countries without dedicated coefficients, the 2019 valuation adopted continental coefficients but the 2020 valuation now adopts coefficients from neighboring countries or countries with similar economic structures as the continental coefficient takes the weighted average of all the countries in the continent and contributes to a higher level of uncertainty.

Results

In 2020, environmental externalities as a result from TSMC procurement are estimated to have a monetary value of around NT$ 11,503 million. Chemical products, machinery & equipment, construction and electronic components industries have the most significant environmental impacts when offering their products or services, with each industry’s external cost estimated at around NT$ 5,829 million (50.7%), NT$ 2,553 million (22.2%), NT$ 933 million (8.1%), respectively, and NT$ 911 million (7.9%). The primary sources of impact are the impact of particulate matter pollution on human health and the social cost of carbon from greenhouse gas emissions which are estimated to have external costs of NT$ 7,943 million (69.1%) and NT$ 2,933 million (25.5%), respectively.

TSMC is fully aware that procurement will not only drive the semiconductor industry development and its production value to grow but also bring about environmental impacts on the supply chain. TSMC will conduct a comprehensive evaluation from our purchasing strategies to seek opportunities to reduce impacts on society and the environment.

Environmental externalities from TSMC's supply chain in 2020

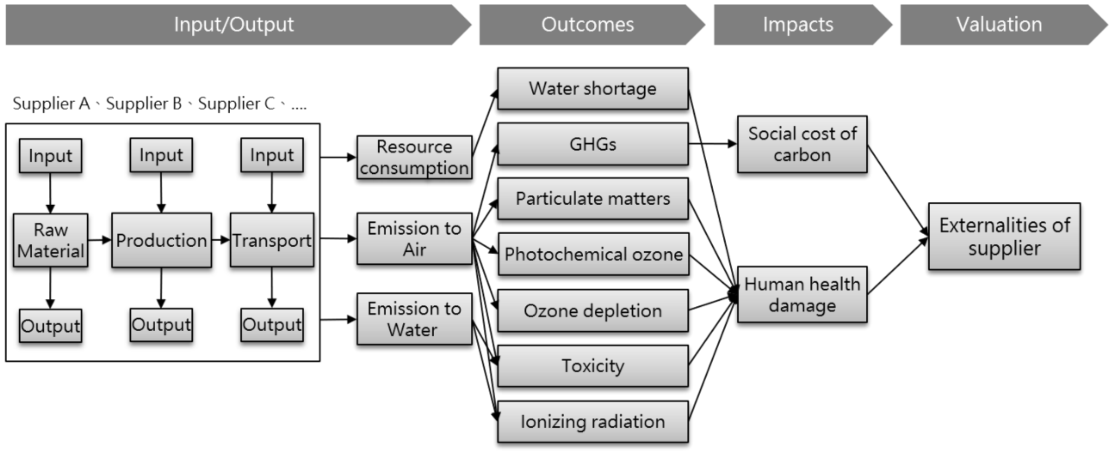


5.2 Supplier life cycle assessment

In addition to assessing the environmental externalities through procurement amounts, TSMC is also surveying the supplier's raw materials, energy consumption, pollutant emissions, and shipping with life cycle thinking to evaluate the environmental externalities from various inputs and outputs.

During this stage, we classify raw materials used in the manufacturing process and conducted EP&L analysis on a selected number of suppliers, including silicon wafer, bulk chemical, gas, lithographic, precursor, slurry, specialty chemical and target materials. As of 2020, TSMC has evaluated over 40 suppliers.

Impact pathways



Calculation

$$\begin{aligned} &Externalities\ of\ supplier \\ &= supplier\ avtivity\ data\ X\ characterization\ factors\ X\ valuation\ factors \end{aligned}$$

- *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 3.2.*

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.

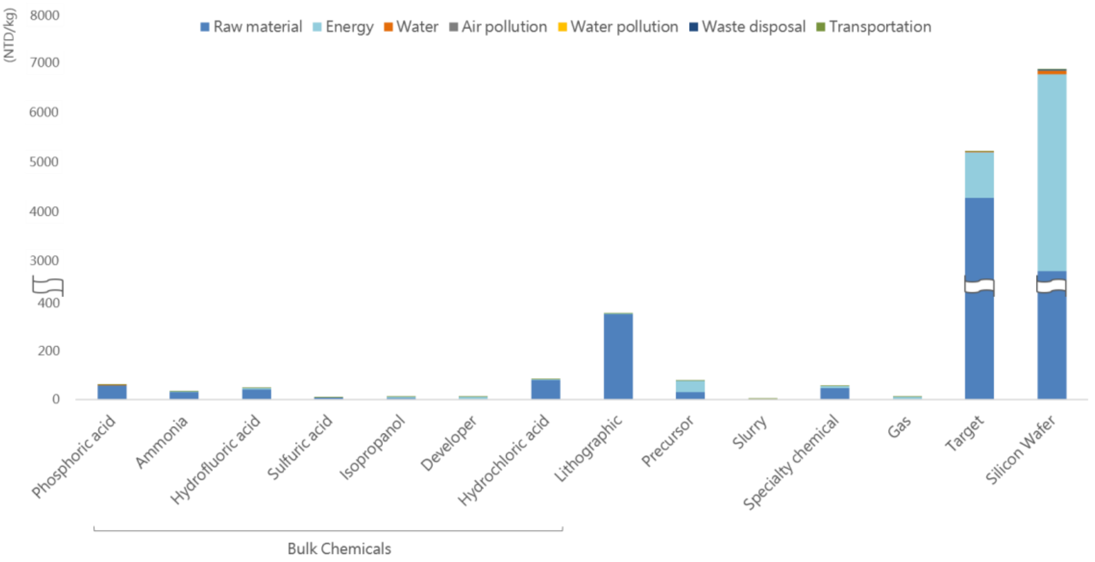
2) When the supplier's facility contains a greater diversity of products and the energy resource (input) and pollutant emissions (output) varies by product type and the supplier is unable to identify such information for each product type, TSMC will opt to allocate the activity data based on the total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

Results

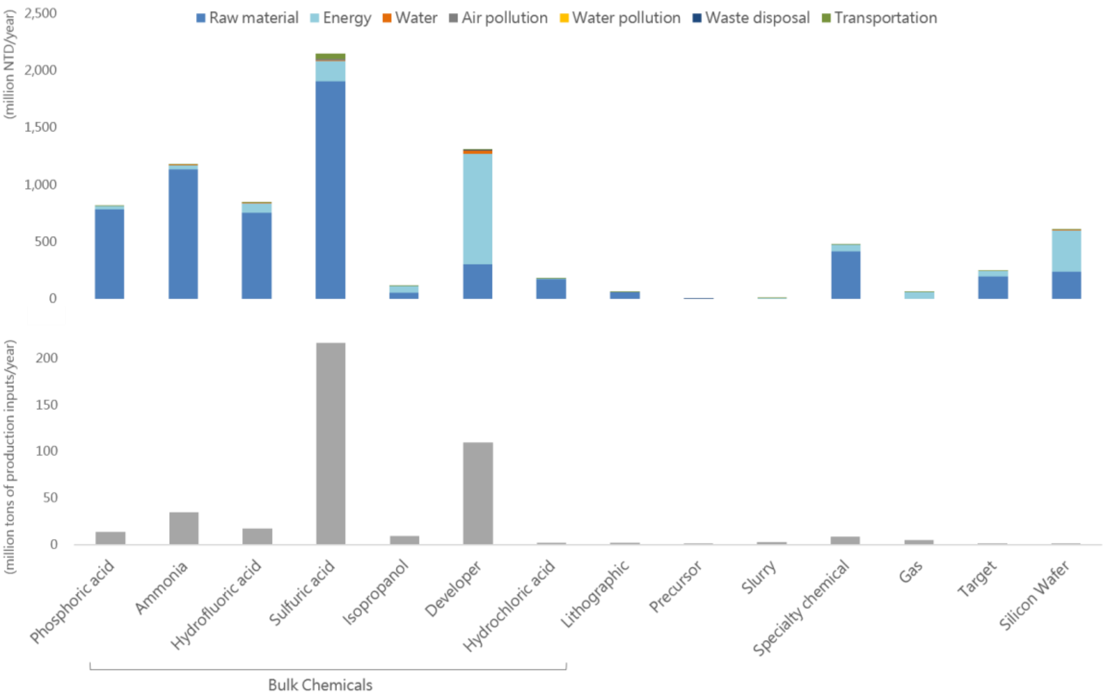
Results from analysis show that: 1) silicon wafers and targets generate the largest environmental externality by each unit of raw material input into TSMC processes. Primary impacts are caused by energy consumed in suppliers’ processes and the raw material supply chain. In terms of chemicals, lithographic and specialty chemicals have higher environmental externalities per unit product. 2) sulfuric acid, developers, and ammonia solution have the most significant environmental externalities in terms of annual production input.

Environmental externalities from evaluated suppliers (by unit material input)



Note: Weighted average of the supplier's raw material type and output volume

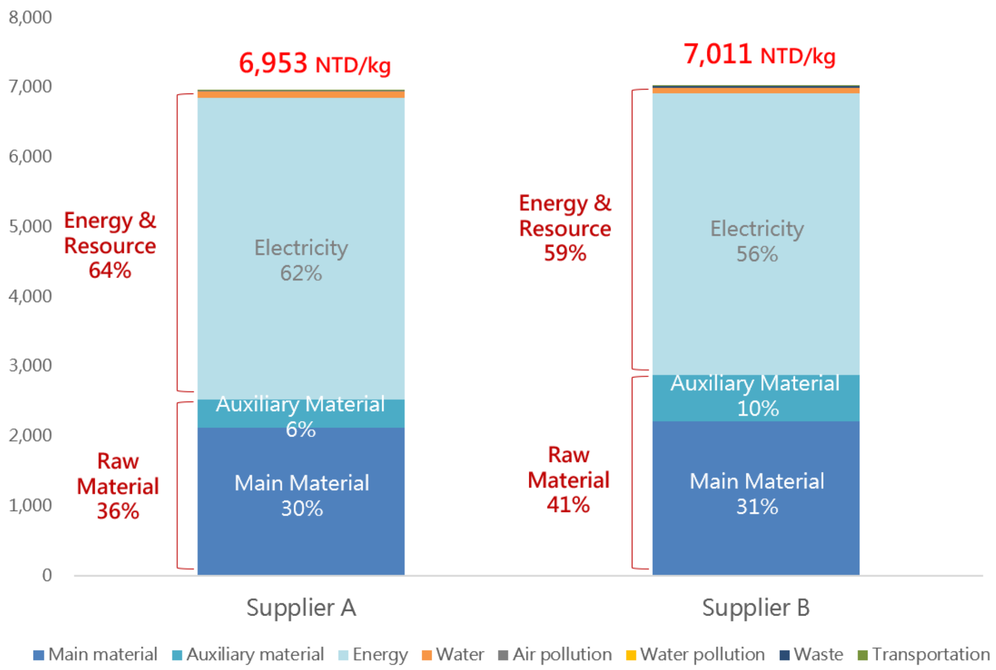
Environmental externalities from evaluated suppliers (by annual production input)



Note: Results derived solely from the supplier's annual output volume and subsequent external costs on the environment.

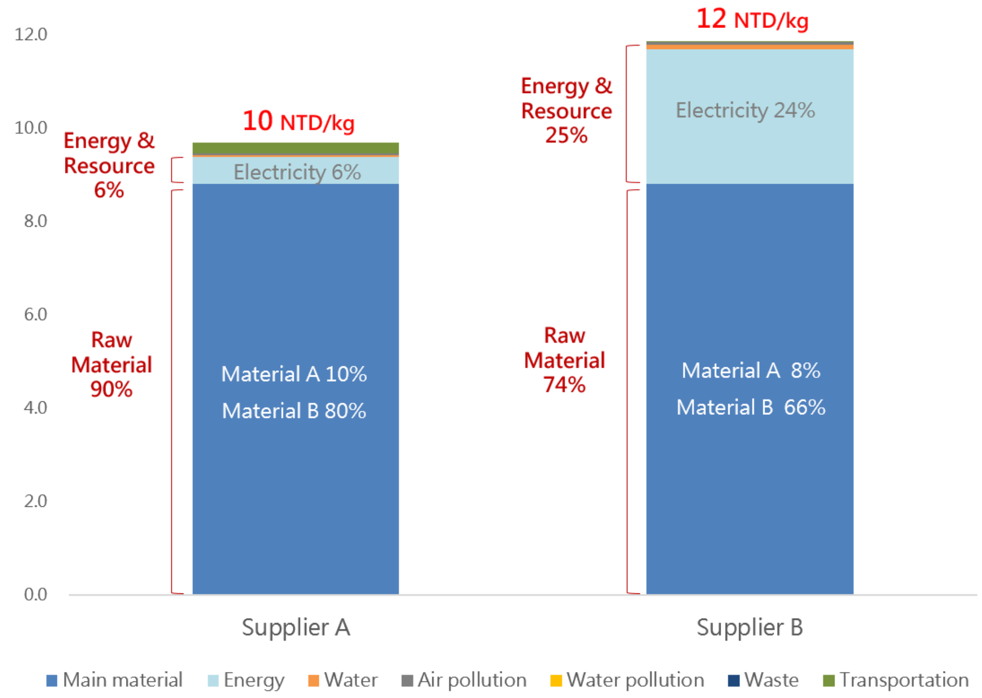
Case Study 1: Silicon Wafers

Environmental externalities from silicon wafers are primarily derived from energy consumption from manufacturing processes and secondly from the raw material supply chain. Results have shown that raw material use in processes, the type and use of auxiliary materials, and the energy consumed by equipment are the primary impact factors. As such, TSMC will collaborate with suppliers to create a more sustainable production model by working to increase efficiency in production, introduce substitute materials, make equipment more energy efficient, and adopt renewable energies.



Case Study 2: Sulfuric Acid

Sulfuric acid is one of the biggest raw materials consumed by TSMC processes. Results show that energy consumption varies drastically across unit product processes in different facilities. In the future, TSMC will assist suppliers in creating a more energy-efficient production model. TSMC has also commenced construction for the industry's first Zero Waste Manufacturing Center. The center is slated to be operational in 2023 and will effectively increase the reuse rate of sulfuric acid waste, thereby reducing the external costs on the environment introduced from the supply chain.



In the future, TSMC will continue to survey and analyze raw material suppliers and construct a supply chain EP&L database. TSMC also plans to carry out a supplier audit program on the environment in 2021. Through differential analysis against peer industries, TSMC aims to collaborate with suppliers to find ways to optimize processes, minimize our environmental footprint, facilitate sustainability across the supply chain, and together create a positive impact on society.

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