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1. Executive summary

In pursuit of stable financial growth, corporates will bring about varying degrees of impact (also known as externalities) in the course of creating products or service value. Their operational activities will take natural resources from the environment and emit pollutants, henceforth creating risks or opportunities. Environmental Profit & Loss (EP&L) is a management tool that measures a corporate’s environmental footprint in economic terms and offers us a plain and straightforward monetary interpretation of the social costs resulting from our operations. This will allow us to consider environmental externalities during our decision-making process and create a Net Positive Impact.

In 2018, TSMC developed EP&L methodology in collaboration with academic institutes and began conducting environmental impact assessments on all TSMC operations sites globally. In order to accurately reflect local environment characteristics, TSMC also developed localized coefficients appropriate for Taiwan.

In 2019, we continued to advance our methodology and extend the assessments to the upstream supply chain. In the complex inter-industry supply and demand relationship, we attempt to analyze and evaluate the environmental externalities brought onto the entire value chain by TSMC’s procurement with the environmentally extended input-output analysis (EEIOA). So we can identify ways to reduce its environmental footprint and increase social welfare. We hope that a supply chain transition can increase our positive impact on sustainability.

In 2019, the environmental externalities in TSMC operations was estimated to have a monetary value of around NT$ 14,562 million. Greenhouse gas (GHG) is the major source of impact, accounting for 97% and around NT$ 14,115 million. The primary source of greenhouse gas emissions was from electricity and gases used in the manufacturing process. In recent years, the environmental externalities of TSMC operations have been trending upwards because of new fabs and the growing demand on electricity, water, and raw materials because of advancement of process technology. In addition to promoting the applications of renewable energies and improving technologies for water reclamation, TSMC is also actively trying to develop optimal, viable technologies for pollution prevention and source reduction, finding the most
success in air pollution and waste externalities with 17% and 7% reductions respectively from the last year.

As a growing amount of procurement from TSMC drives the growth of supply chain, a focus on environmental issues in the supply chain has also been emphasized. In 2019, environmental externalities derived from TSMC procurement was estimated to have a monetary value of around NT$ 6,679 million of which chemical materials and products accounted for 60% and around NT$ 3,980 million of total externalities in the supply chain. In the face of the supply chain’s environmental impact, we will be actively promoting a responsible supply chain in order to reduce the resulting environmental and societal impact.

We hope that our tireless efforts can drive a more comprehensive sustainability management for TSMC. Through the four major principles of Insight, Collaboration, Transformation, and Impact, we want to prepare ourselves to meet the risks and opportunities brought on by environmental challenges and offer the society more added value.

Note: EEIOA is a common methodology to assess the correlation between economic activities and downstream environmental impact (Kitzes, 2013).
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 the Tier 1 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.

<table>
<thead>
<tr>
<th>Upstream Procurement</th>
<th>TSMC Operations</th>
<th>Customer Usage</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Input (Resource)</strong></td>
<td><strong>Input (Resource)</strong></td>
<td><strong>Final Product</strong></td>
</tr>
<tr>
<td>Material 1</td>
<td>Electricity</td>
<td></td>
</tr>
<tr>
<td>Material 2</td>
<td>Water</td>
<td></td>
</tr>
<tr>
<td>Material 3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Supplier A</td>
<td>Raw material</td>
<td></td>
</tr>
<tr>
<td>Output (Emission)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Supplier B</td>
<td>Service</td>
<td></td>
</tr>
<tr>
<td>Output (Emission)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Spatial boundary**
Tier 1 suppliers with annual transactions of over NT$ 10 million

*Note: Tier 1 suppliers are suppliers trading with TSMC directly with more than two orders of expenses in a year, and where the transactions exceeded NT$ 10 million in value; 441 suppliers meet the criteria.*

**Temporal boundary**
2019/01/01 to 2019/12/31

**Scope**
Greenhouse gases (GHGs), air pollution, water pollution, waste, and water consumption

**Externalities**
Social cost of carbon and human health cost
3. Methodology

Environmental profit and loss (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) 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: 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.

<table>
<thead>
<tr>
<th>Input/Output</th>
<th>Outputs</th>
<th>Impacts</th>
<th>Valuation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Activity data</td>
<td>Midpoint CFs</td>
<td>Endpoint CFs</td>
<td>VFs</td>
</tr>
</tbody>
</table>

- **GHGs**
  - Social cost of carbon

- **Water consumption**
  - Malnutrition and waterborne diseases

- **Air pollution**
  - Particulate matter formation potential (PMFP)

- **Water pollution**
  - Photochemical oxidant formation potential (HOFP)

- **Waste**
  - Human toxicity potential (HTP)
  - Disability-Adjusted Life Years (DALYs)

*Note: Data from TSMC is results of actual inventory; data from Tier 1 suppliers are derived by importing actual purchase amount into EIOBASE 2.*
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 DALY as a quantitative metric (refer to Sections 4.1 to 4.5 for further information).

VF$s$ 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: One DALY can be considered as one lost year of “healthy” life (WHO).*

<table>
<thead>
<tr>
<th></th>
<th>Activity data (Input)</th>
<th>Activity data (Output)</th>
<th>CFs</th>
<th>VFs</th>
</tr>
</thead>
<tbody>
<tr>
<td>TSMC</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>Tier 1 suppliers</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
</tbody>
</table>

○ Primary Data:
- Data on resource use and pollutant emissions in TSMC operations
- TSMC purchases (in NT$) from Tier 1 suppliers

○ Secondary Data:
- Pollutant emissions data are derived from purchase amount by applying EEIOA, which is referenced from EXIOBASE 2 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.

### 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).

<table>
<thead>
<tr>
<th>Year</th>
<th>Social cost of carbon (in 2007 USD/ton-CO₂)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>5% discount rate</td>
</tr>
<tr>
<td>2015</td>
<td>11</td>
</tr>
<tr>
<td>2016</td>
<td>11</td>
</tr>
<tr>
<td>2017</td>
<td>11</td>
</tr>
<tr>
<td>2018</td>
<td>12</td>
</tr>
<tr>
<td>2019</td>
<td>12</td>
</tr>
</tbody>
</table>

Note¹: 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.

Note²: 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).

Note³: 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.

$$\text{Human health cost} = \frac{VSL}{\text{Number of DALYs loss}}$$
<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>Value</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Life expectancy</td>
<td>Year</td>
<td>78</td>
<td></td>
</tr>
<tr>
<td>Proportion of life loss</td>
<td>%</td>
<td>23.4</td>
<td></td>
</tr>
<tr>
<td>Number of DALYs loss</td>
<td>Year</td>
<td>18.3</td>
<td></td>
</tr>
<tr>
<td>VSL</td>
<td>2005 USD</td>
<td>3,000,000</td>
<td></td>
</tr>
<tr>
<td>Human health cost</td>
<td>2005 USD/DALY</td>
<td>164,366</td>
<td></td>
</tr>
</tbody>
</table>

**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).

\[ E_i = \left( \frac{Y_i}{Y_{ref}} \right) ^\epsilon \]

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
- \( \epsilon \): 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

<table>
<thead>
<tr>
<th>Value factor</th>
<th>Original</th>
<th>Adjusted</th>
</tr>
</thead>
<tbody>
<tr>
<td>Social cost of carbon</td>
<td>41</td>
<td>1,503</td>
</tr>
<tr>
<td>(Unit : 2007 USD/ton-CO$_2$)</td>
<td></td>
<td>(Unit : 2018 NTD/ton-CO$_2$)</td>
</tr>
<tr>
<td>Human health cost</td>
<td>164,366</td>
<td></td>
</tr>
<tr>
<td>(Unit : 2005 USD/DALY)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note: CO$_2$ emissions cause a global impact of rising GHG concentrations and will not vary by region.

### 4. EP&L valuation: TSMC operations

In 2019, the environmental externalities in TSMC operations was estimated to have a monetary value of around NT$ 14,562 million. Greenhouse gas (GHG) is the main source of impact accounting for 97% and around NT$ 14,115 million, while other types of air pollution, water pollution, waste, and water consumption comprise 3%. In recent years, the environmental externalities of TSMC operations have been trending upwards because of new facilities and the growing demand on electricity, water, and raw materials because of improved and advanced processing technologies. In the production stages, we 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.
EP&L analysis for TSMC operations

<table>
<thead>
<tr>
<th>Year</th>
<th>Greenhouse gases</th>
<th>Water Consumption</th>
<th>Air Pollution</th>
<th>Water Pollution</th>
<th>Waste</th>
</tr>
</thead>
<tbody>
<tr>
<td>2015</td>
<td>8,865</td>
<td>23</td>
<td>163</td>
<td>62</td>
<td>48</td>
</tr>
<tr>
<td>2016</td>
<td>10,463</td>
<td>24</td>
<td>179</td>
<td>92</td>
<td>63</td>
</tr>
<tr>
<td>2017</td>
<td>11,664</td>
<td>24</td>
<td>190</td>
<td>107</td>
<td>96</td>
</tr>
<tr>
<td>2018</td>
<td>13,336</td>
<td>25</td>
<td>253</td>
<td>102</td>
<td>93</td>
</tr>
<tr>
<td>2019</td>
<td>14,115</td>
<td>28</td>
<td>210</td>
<td>123</td>
<td>86</td>
</tr>
</tbody>
</table>

Unit: NT$ million

Note 1: The monetary value is the relative value produced by the formula and the scenario analysis rather than the absolute value.

Note 2: The GNI (PPP) per capita has been updated to the year 2018. The damage cost on human health for various regions and the calculations for 2015 to 2018 have also been updated accordingly.

Note 3: The CFs for water consumption has been updated. Calculations for 2015 to 2018 have also been updated accordingly, please refer to 4.2.

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 (CO₂), methane (CH₄), nitrous oxide (N₂O), sulphur hexafluoride (SF₆), nitrogen trifluoride (NF₃), 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 × 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 2019 was around NT$ 14,115 million which was 96.9% of the overall external cost. CO₂ emissions, at 80%, 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.

We will continue to promote measures to mitigate the social costs and impact brought on by consuming significant amounts of energy and resources:

1) Promote Low-Carbon Manufacturing: adopt the optimal, viable technology for reducing emissions of greenhouse gases and become an industry benchmark for low-carbon manufacturing.

2) Renewable Energies: purchase renewable energies and set up a solar power system to increase the use of renewable energies.

3) Increase Energy Efficiency: outline the new annual energy conservation measures, carry out the measures, and increase energy efficiency.

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**

![Impact pathways diagram]

**Calculation**

Externalities of water consumption

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

- **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 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.

**Updates to the methodology:**

- Updated CFs for water consumption; the CFs was previously a national average and has now been adjusted to local average for areas with TSMC facilities.
Results

According to EP&L analysis, the external cost of water consumption at all TSMC operation sites globally in 2019 was around NT$ 28 million, which is 0.2% of the overall external cost on the environment; malnutrition from agricultural water scarcity is the primary effect. The evolution of advanced technologies and new fabs becoming operational is why external costs of water consumption grew in 2019.

We will be expanding sources and conserving energy, integrating internal and external resources to promote risk management of water resources, finding diverse water sources, recycling and reusing water, and implementing various water conservation measures. TSMC will also be working with external agencies to develop the Green Energy Smart Floodgate technology to help increase the irrigation efficiency of our local agricultural industry, thereby reducing water demands on our reservoirs and building a sustainable manufacturing model where we coexist and thrive with our environments.

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

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)

Calculation

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

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 2019 was around NT$ 210 million, which is 1.4% 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 2019, TSMC has been able to reduce the external costs of air pollution for TSMC operations by 17% from the last year as we witness the most significant reductions in nitric acid pollutants. We will continue to adopt optimal viable technologies to minimize air pollutant emissions produced in operations to reduce the social costs and impacts that the pollutants cause as it spreads 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 (CH₄) and nitrous oxide (N₂O) derived from wastewater discharge at various operation sites to estimate the social cost of carbon.

**Impact pathways**

![Impact pathways diagram]

**Calculation**

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

- 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)
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.
   - CO₂ 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 2019 was around NT$ 123 million of which the social cost of carbon and human health cost from heavy metals arising from the wastewater management process are the primary sources. In 2019, the external costs of wastewater have risen because of new fabs becoming operational, a greater demand on cleaning for the new processes, and optimization for operational systems.

We strive to expand applications of source management with diversion and recycling system as we hope to transform wastewater components into
recycled industrial grade materials. TSMC is also researching effective dosage in order to carry out various measures and effectively reduce pollutants while also recycling and reusing.

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 CO₂, CH₄, and N₂O. 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. CH₄ 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

Externalities of waste

\[ = (\text{Waste incineration} \times \text{Emission factor of air pollution} \times \text{Health damage factor} \times \text{Human health cost}) \]
\[+ (\text{Waste incineration} \times \text{GHGs emission factor} + \text{Waste landfill} \times \text{GHGs emission factor}) \times \text{Social cost of carbon} \]

- 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-CO₂/ton)
- Social cost of carbon: long-term economic damage indicators caused by GHG emissions in a given year (2018 NTD/ton-CO₂) (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
   - CH₄ 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 2019 was around NT$ 86 million of which the social cost of carbon from waste incineration is the primary source of impact. In recent years, TSMC has been deploying source reduction and resource regeneration strategies and in 2019, we have been able to witness a 7% reduction in the external costs of waste from TSMC operations from the previous year. We are presenting a year-on-year reduction and we see our greatest success in reducing liquid wastes.

We continue to stay true to our management principle of "Minimizing Waste and Maximizing Resources" to carry out our commitment to source reduction. We are researching various technologies for resource regeneration in hopes that TSMC can transform from a waste producer into an actor in the circular economy and minimize our environmental impact.
5. EP&L valuation: upstream procurement

In 2019, TSMC extended the scope of its EP&L analysis to the upstream supply chain by analyzing procurement to find our indirect environmental footprint and social costs. We hope to identify more opportunities to reduce environmental footprint and increase social welfare so we can build a more sustainable 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 EEIOA offers a simple and comprehensive method for evaluating the relationship between consumer activity and its environmental impact. In this study, we apply the EEIOA to Tier 1 suppliers with annual transactions exceeding NT$ 10 million to evaluate the indirect environmental footprint and social costs that our procurement have resulted on our supply chain. The scope of our assessment include 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; 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
Calculation

**Externalities of supply chain**

= purchase amount (in NT$) × EEIO characterization factors × valuation factors

- Externalities of supply chain: external costs on the environment from TSMC’s procurement (2018 NTD/year)
- Purchase amount (in NT$): the monetary value of procurement made by TSMC from Tier 1 suppliers (NTD/year)
- EEIO characterization factor: environmental externalities from pollutants indirectly caused by TSMC's procurement and subsequent impact on supply and demand in various industries; includes human health costs from air pollution and global warming from greenhouse gas emissions (DALY/NTD and ton-CO$_2$e/NTD, respectively)
- Valuation factor: includes human health costs and social cost of carbon (2018 NTD/DALY and 2018 NTD/ton-CO$_2$e, respectively); please refer to 3.2.

Assumptions and limitations

1) EEIOA combines pollutants from various industries with inter-industry supply and demand to estimate the environmental impact indirectly caused by purchasing expenses. The EEIOA 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) Some TSMC suppliers were located in countries not included in the EXIOBASE 2, therefore an average of all the country coefficients in the same continent were calculated to serve as replacement which may unwittingly result in inaccurate calculations; an Asia coefficient, for example, was adopted for Malaysia.

Results

In 2019, environmental externalities as a result from TSMC procurement are estimated to have a monetary value of around NT$ 6,679 million. Chemical, transportation & storage, and plastic industries have the most significant environmental impacts when offering their products or services, with each industry’s external cost estimated at around NT$ 3,980 million (60%), NT$ 1,061 million (16%), and NT$ 733 million (11%), respectively. 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$ 4,544 million (68%) and NT$ 1,505 million (23%), 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. We will conduct a comprehensive evaluation from our purchasing strategies to seek opportunities to reduce impacts on society and the environment.

**EP&L analysis for TSMC Upstream Procurement in 2019**

- Chemical materials & products
- Transportation & Storage
- Plastics products
- Fabricated metal products
- Electronic components
- Machinery & Equipment
- Supporting services
- Others

(NT$ million)

- Health damage by Ozone
- Health damage by Carcinogens
- Social cost of carbon by GHGs
- Health damage by Particulate matter
6. Bibliography


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   https://www.usetox.org/model/download/usetox2.1


Kingdom