Comparing North American and European Methods to Characterize the Environmental Effects of Common Processes

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This study examines the similarities and differences of environmental effects of four common processes characterized with Eco-Indicator 99 and TRACI.

- Production processes to be characterized
- Characterization methods and effect categories
- Influence of input-output data and characterization methods on resulting effect values
- Implications for LCA practitioners & developers

Production processes characterized

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Production processes characterized

The assessment employs chemical input/output data for common production processes:

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low-voltage electricity

We use separate chemical input/output data from a North American source and a European source for each process.

Production processes characterized

- **Franklin Associates** (Kansas, US) generated the original US inventory data. **Sylvatica** personnel (Maine, US) recorded and validated the data.
- No adjustments were made to the data for uncertainties.
- Average US technology was used including data from second order capital goods (material/energy flows including operations.)
- All data recorded and verified for consistency and reasonableness.
- Where possible, specific unit processes have been identified for the product of interest.
- Where this could not be done, allocation was performed on a mass basis. Cut off rules (less than 1%) were applied using physical criteria.

FRANKLIN Associates

Production processes characterized

Polypropylene

Time period: 1995-1999

Geography: North America

Process: Data for the material and energy requirements and process emissions for the production of polypropylene.

Production processes characterized

Steel, low-alloy

Time period:	2000
Geography:	North America
Process:	Data for the material and energy requirements and and process emissions for the production of steel using a basic oxygen furnace.

FRANKLIN Associates

Production processes characterized

Paper

Time period:	1995-1999
Geography:	North America
Process:	Data for the material and energy requirements and process emissions for the production of bleached Kraft paper (for white paper sacks), with no recycled content.

FRANKLIN Associates

Production processes characterized

Electricity, low voltage

Time period:	2000
Geography:	 North America
Process:	Data for the fuel consumption associated with the generation and delivery of an average kilowatt-hour in the USA. Includes adjustment to account for line losses.
Sampling:	Drawn from a variety of 57 public and private USA statistical sources, reports, and telephone conversations.

Production processes characterized

- **EcoInvent** generated the original European inventory data with detailed information inherent to EcoInvent documentation.
- EcoInvent personnel in Switzerland recorded and validated the data.
- No adjustments were made to the data for uncertainties.
- System process data was used (not unit process data).

Production processes characterized

Polypropylene

Time period:	Late 1990's
Geography:	15 European production sites
Processes:	Aggregated data for all processes from raw material extraction until delivery at plant. Data are from the Eco-profiles of the European plastics industry (APME). Mercaptan emission to air and unspecified CFC/HCFC emission to air are not included.
Sampling:	Literature values based on company surveys

Production processes characterized

Steel, low-alloy

Time period:	Late 1990’s
Geography:	European
Processes:	Mix of differently produced steels that represent average European production.
Sampling:	Literature and statistics

Production processes characterized

Paper

Time period:	Early 1990's
Geography:	One Swiss producer
Processes:	Production of bleached Kraft paper (for white paper sacks), including transports to paper mill, pulp handling, paper production, energy production on-site and internal wastewater treatment.

Production processes characterized

Electricity, European

Time period:	2000
Geography:	Infrastructure demand is based on Swiss data. SF6-Emissions are mainly based on German data.
Processes:	Data for production, transformation and distribution of low voltage electricity. Electricity losses and direct SF6-emissions are included. Average technology includes underground and overhead lines, as well as SF6-insulated medium-to-low voltage switching stations. SF6 is greenhouse gas 23,900 times more effective at trapping infrared radiation than CO_2.
Sampling:	Statistics were used. Attribution of total losses was based on assumptions.

Characterization methods and effect categories

Characterization methods and effect categories

The United States Environmental Protection Agency oversaw development of TRACI.

Eco-Indicator 99 is a familiar European effect characterization method.

TRACI

The U.S. EPA developed the Tool for the Reduction and Assessment of Chemical and other environmental Impacts (**TRACI**) in 2002. **http://epa.gov/ORD/NRMRL/std/sab/iam_traci.htm**

TRACI measures the capacity to create each environmental impact at it's **mid-point**. Mid-point measurements have a higher level of modeling certainty than end-point measurements that rely on complex models based on extrapolations.

For instance, characterization of Ozone layer depletion occurs at the midpoint level of Ozone depletion potential, not at endpoints such as skin cancer, crop damage, immune system suppression, damage to materials like plastics, marine life damage and cataracts.

Characterization methods and effect categories

TRACI

In 2002 TRACI allowed the characterization of potential effects in eleven categories, including land use. In 2004 the land use effect category was dropped because the characterization method needs further development.

2004 effects category	**equivalency unit/yr/capita**
acidification	H+
ecotoxicity	2,4-D
eutrophication	N
global warming	CO_2
human health cancer	benzene
human health non-cancer	toluene
human health respiratory	PM2.5
ozone depletion	CFC-11
photochemical smog	NO_x
fossil fuel depletion	surplus mega-Joules

Characterization methods and effect categories

TRACI

TRACI allows for regional and local impact modeling of acidification and smog formation. In this study I use default US average values, because as a designer, I am not often sure which supplier I will use.

Eco-Indicator 99

26 European experts from academia and industry developed **Eco-Indicator 99**. EI99 measures effects at the **end-point**. It measures units of damage to human health and environmental health – instead of measuring the capacity to create a unit if a specific type of environmental effect.

EI99 employs **damage analysis** to define the relationship between an environmental effect and end-point damage to human health or end-point damage to the ecosystem.

Eco-Indicator 99

EI99 uses European (old EU12 countries plus Switzerland and Norway) for regional effect categories, such as eco-toxicity, respiratory health, carcinogens, radiation, acidification, eutrophication and land-use.

Other effects such as climate change, ozone layer depletion, resource depletion, very persistent pollutants and radioactive isotopes are on a world scale.

Eco-Indicator 99

EI99 units for damage in the three meta-categories and respective effect categories are listed.

Metacategory	Effect category	Damage name (unit)
Human health damage	Climate change	DALY (disability adjusted life year)
	Ozone depletion	DALY
	Ionizing radiation	DALY
	Human respiratory	DALY
	Human carcinogen	DALY
Ecological damage	Ecotoxicity	PDF (%vascular plant species/km^2 –yr.)
	Acidification/eutroph.	PDF
	Local land-use effects	PDF
	Regional land-use effects	PDF
Resource depletion	Energy fossil fuel extract.	MJ surplus energy
	Energy mineral extraction	MJ surplus energy

Characterization methods and effect categories

The tabulation of TRACI and EI99 effect categories in the table below shows the many-shared categories of the two methods. TRACI does not model Ionizing radiation, land use (local or regional) nor does it model mineral depletion. EI99 does not model non-cancer human health damage. EI99 aggregates acidification with eutrophication and aggregates smog with human respiratory.

	TRACI	**EI99**
Metacategory	**Effect category**	**Effect category**
Human health	Climate change	Climate change
	Ozone layer depletion	Ozone layer depletion
		Ionizing radiation
	Photochemical smog	Human respiratory/smog
	Human respiratory	Human respiratory/smog
	Human cancer	Human Cancer
	Human non-cancer	
Ecological health	Ecotoxicity	Ecotoxicity
	Acidification	Acidification/Eutrophication
	Eutrophication	Acidification/Eutrophication
		Local & Regional land use
Resource depletion	Fossil fuel depletion	Fossil fuel depletion
	Mineral depletion	

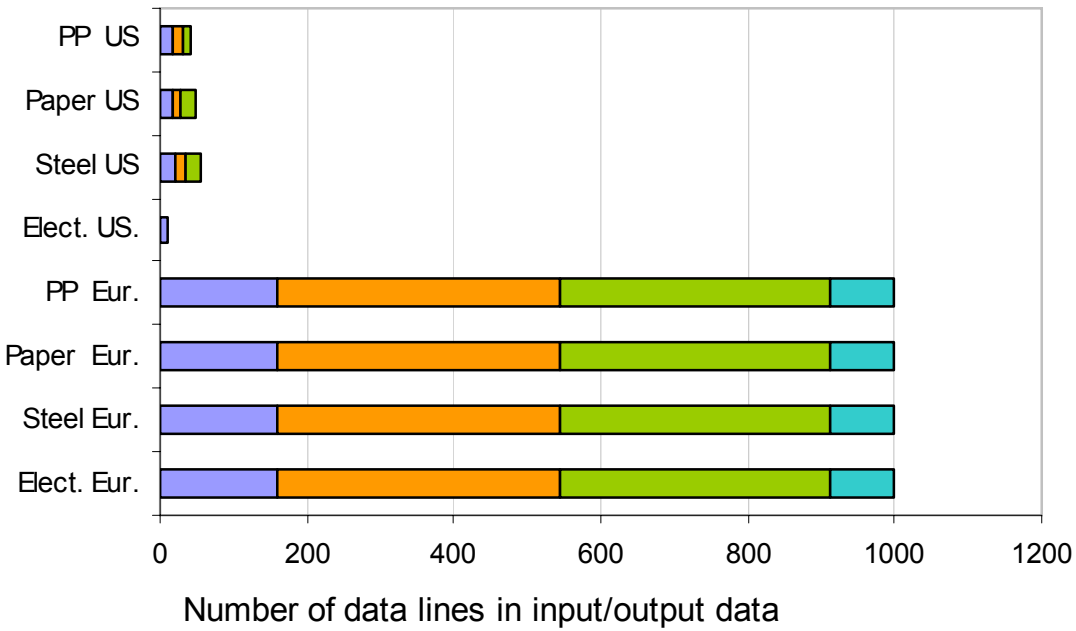
Influence of input/output data and characterization methods on resulting effect values

Influence of input/output data and characterization methods on resulting effect values

One way to asses the thoroughness of inventory data is to sum the number of substances and resources listed in the input/output table.

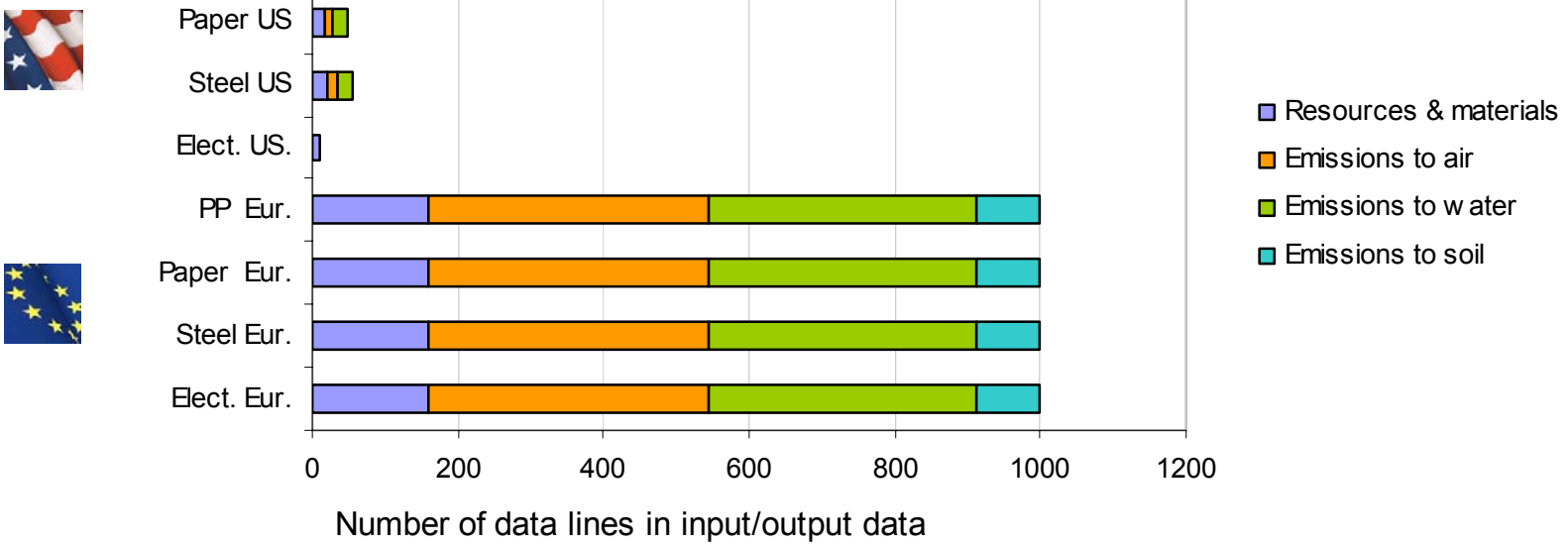
The chart below lists the data entries per process. Those documented in Ecoinvent each have 1002 data lines, while those documented by FAL have an average of 44 data lines.

Overall, this Ecoinvent data is more thorough than this FAL data.



Influence of input/output data and characterization methods on resulting effect values

The FAL electricity only lists resource inputs, with no output emissions data. We should be cautious about interpreting the characterized results from this US Electricity data because it lacks emissions data.



Characterized effect values

Larger characterized values per process type and impact category are in **bold**.
Those larger by an order of magnitude or more are in **bold purple**.




Method: **EI99 H/A**

Impact category	Unit	Elec. US 10kV	Elec. Eur.10kV	Steel US 1kg	Steel Eur. 1kg	Paper US 1kg	Paper Eur.1kg	PP US 1kg	PP Eur. 1kg
Climate change	DALY	**1.549E-06**	1.124E-06	**5.898E-07**	3.412E-07	**1.025E-06**	-9.101E-08	**7.788E-07**	4.175E-07
Carcinogens	DALY	9.571E-08	**5.923E-07**	3.122E-08	**1.083E-06**	**7.454E-08**	2.406E-07	**2.963E-07**	1.4E-08
Human Respiratory	DALY	**6.50E-06**	3.01E-06	2.04E-06	**3.16E-06**	**3.55E-06**	1.59E-06	**5.09E-06**	2.06E-06
Ozone layer	DALY	1.769E-10	**2.344E-10**	1.526E-11	**8.556E-11**	1.86E-11	**1.713E-10**	**1.539E-11**	1.35E-13
Ecotoxicity	PDF*m2yr	0.01275	**0.1546**	0.002266	**0.2886**	**0.04776**	0.04284	**0.025**	0.001472
Fossil Fuel depletion	MJ surplus	**4.427**	3.782	**1.743**	1.364	**2.899**	2.759	**11.58**	9.657
Acidif./Eutrophication	PDF*m2yr	0.2024	0.076	0.03934	0.03435	0.1215	0.04361	0.1324	0.06821
Land use	PDF*m2yr	0	0.03789	0	0.05201	0	1.206	0	0.0001972
Mineral depletion	MJ surplus	0	0.2055	0.03465	**1.693**	0	0.04883	0	0.001711
Radiation	DALY	0	1.091E-07	0	1.171E-08	0	1.249E-08	0	6.995E-12

Method: **TRACI**

Impact category	Unit eq.	Elec. US 10kV	Elec. Eur.10kV	Steel US 1kg	Steel Eur. 1kg	Paper US 1kg	Paper Eur.1kg	PP US 1kg	PP Eur. 1kg
Climate change	CO_2	**0.3706**	0.07822	**0.159**	0.01382	**0.08676**	0.02142	**0.3064**	0.00004026
Carcinogens	benzene	0.0029	**0.0201**	0.000283	**0.017**	0.00399	**0.00928**	**0.0052**	0.000408
Human Respiratory	PM2.5	0.002331	**0.01747**	0.000423	**0.010711**	0.001532	**0.005425**	0.001064	**0.00843**
Ozone Depletion	CFC-11	1.025E-07	**2.433E-07**	8.844E-09	**8.679E-08**	1.078E-08	**1.775E-07**	**8.919E-09**	1.287E-10
Ecotoxicity	2,4-D	0.0128	**10.36**	0.002845	**6.324**	0.05719	**2.13**	0.02047	**0.3591**
Fossil Fuel Depletion	MJ surplus	**4.427**	3.782	**1.743**	1.364	**2.899**	2.759	**11.58**	9.657
H. Health damage	toluene	3.508	**246.5**	0.997	**224**	5.358	**208.7**	8.079	12
Smog	NOx	0.02551	0.009233	0.004961	0.004649	0.01707	0.00666	0.01175	0.009588
Acidification	H+ moles	3.82	1.458	0.796	0.4453	1.912	0.5044	3.688	1.041
Eutrophication	N	0.001219	0.001113	0.0002213	**0.002857**	0.001294	0.003521	0.0007348	0.0005679

Influence of input/output data and characterization methods on resulting effect values

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Method:	**TRACI**								
Impact category	Unit eq.	Elec. US 10kV	Elec. Eur.10kV	Steel US 1kg	Steel Eur. 1kg	Paper US 1kg	Paper Eur.1kg	PP US 1kg	PP Eur. 1kg
Climate change	CO_2	**0.3706**	0.07822	**0.159**	0.01382	**0.08676**	0.02142	**0.3064**	0.00004026

Climate change values are larger from US processes than from European processes when characterized by both EI99 and TRACI.

The characterized substance data indicates that US processes produce greater quantities of climate change emissions – primarily fossil derived CO_2 and fossil derived methane – which are also reported in the European process data at lower quantities..

Influence of input/output data and characterization methods on resulting effect values

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Fossil Fuel depletion	MJ surplus	**4.427**	3.782	**1.743**	1.364	**2.899**	2.759	**11.58**	9.657

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Impact category	Unit eq.	Elec. US 10kV	Elec. Eur.10kV	Steel US 1kg	Steel Eur. 1kg	Paper US 1kg	Paper Eur.1kg	PP US 1kg	PP Eur. 1kg
Fossil Fuel depletion	MJ surplus	**4.427**	3.782	**1.743**	1.364	**2.899**	2.759	**11.58**	9.657

Because the characterization method for **fossil fuel depletion** in TRACI is identical to that of EI99, characterized effects from both methods are identical.

Fossil fuel depletion values are larger from **US processes** than the European data – but none of the values are larger by an order of magnitude. US processes create larger fossil fuel depletion effects for the same reasons it creates large climate change effects.

Influence of input/output data and characterization methods on resulting effect values

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Method: **TRACI**

Impact category	Unit eq.	Elec. US 10kV	Elec. Eur.10kV	Steel US 1kg	Steel Eur. 1kg	Paper US 1kg	Paper Eur.1kg	PP US 1kg	PP Eur. 1kg
Human Respiratory	PM2.5	0.002331	**0.01747**	0.000423	**0.010711**	0.001532	**0.005425**	0.001064	**0.00843**
Ecotoxicity	2,4-D	0.0128	**10.36**	0.002845	**6.324**	0.05719	**2.13**	0.02047	**0.3591**

TRACI calculated the European data to have higher values in two effect categories. **Ecotoxicity** measures an order of magnitude larger in all four processes, while **Human Respiratory** measures an order of magnitude larger two out of four data sets.

Detailed characterized process data for each of these effect categories may offer clues about the origins of these values.

Influence of input/output data and characterization methods on resulting effect values

Larger characterized values per process type and impact category are in **bold**.
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Substance	Medium	Unit eq.	Elec US 10kW	Elec Eur10kW	Steel US 1kg	Steel Eur1kg	Paper US 1kg	Paper Eur1kg	PP US 1kg	PP Eur1kg
Total		2,4-D	0.0128	10.36	0.002845	7.292	0.05719	2.13	0.02047	0.3591
Aluminum	Water	2,4-D	x	8.716	x	1.317	x	1.631	x	0.3053
Copper, ion	Water	2,4-D	x	0.1391	x	0.6759	x	0.265	x	0.0519
Aluminum	Air	2,4-D	x	1.352	x	5.059	x	0.1934	x	0.001528

Characterized European process data (above) report emissions of Aluminum to water and air, and Copper-ion to water that US processes data does not report. **TRACI** registers these substances as creating **Ecotoxicity** effects.

Given the comparative thoroughness of the European data, I assume these missing substance values were not measured.

According to the Appeldoorn Declaration 2004, metals are extremely persistent and difficult to model for ETP and HTP. Jane bare of the US EPA noted “In the new version of TRACI we are still discussing how and whether these metals are properly handled.”

Influence of input/output data and characterization methods on resulting effect values

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Substance	Medium	Unit eq.	Elec US 10kW	Elec Eur10kW	Steel US 1kg	Steel Eur1kg	Paper US 1kg	Paper Eur1kg	PP US 1kg	PP Eur1kg
Total		PM2.5	0.001055	0.008686	0.0001913	0.006703	0.0006933	0.002682	0.0004815	0.004167
SO2	Air	PM2.5	x	0.005034	x	0.001083	x	0.001095	x	0.003107
PM<2.5um	Air	PM2.5	x	0.001298	x	0.002438	x	0.0008643	x	0.0003732
PM> 10um	Air	PM2.5	x	0.001974	x	0.002985	x	0.0004482	x	0.0002895

Likewise, characterized European process data report emissions of SO_2, 2.5 PM and 10 PM to air that US processes data do not report. **TRACI** registers these substances as creating **Human Respiratory** effects.

Similarly, given the substantial thoroughness of the European data, I assume these missing substance values were not measured. This should be verified with the process data providers.

Influence of input/output data and characterization methods on resulting effect values

	 US processes	 Euro Processes
EI99	Larger Climate Change Larger FF Depletion	
TRACI	Larger Climate Change Larger FF Depletion	Larger Ecotoxicity Larger HH Respiratory

US processes created larger effects than European processes in the categories of **Climate change** (by at least one order of magnitude) and **Fossil fuel depletion** when characterized by both EI99 and TRACI due to larger resource use and emissions.

European processes created larger effects than US processes in the categories of **Ecotoxicity** and **Human Respiratory** when characterized by **TRACI**, apparently due to un-measured substance emissions in the the US process data.

Implications for LCA practitioners & developers

Implications for LCA practitioners




Practitioners should select process data that have clearly defined boundary conditions.

Practitioners can select process data based on geography – but thoroughness of the data set is also a crucial selection criteria. For instance, process data with no output emissions should usually be avoided.

Implications for LCA Developers




Different teams of scientists developed the EI99 and TRACI characterization methods. These methods calculate environmental effects in different ways, resulting in different effect units and end-values.

As methods develop in the future, it will be constructive for the international scientific community to define standard characterization methods - such as all ready exist for climate change - for other for global effects (such as ozone layer depletion, resource depletion, persistent bioaccumulative toxins, and ionizing radiation.)

Likewise, the international scientific community need to develop standards and flexible software systems for the regionalized characterization of regional and local effects (such as acidification, eutrophication, smog, land use and water use.)

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