# Appendix A
# Design Criteria and Guidelines

## A.1 Minimise Materials Consumption

Minimise material content:

- *Dematerialise* the product or some of its components
- Digitalise the product or some of its components
- Miniaturise
- Avoid over-sized dimensions
- Reduce thickness
- Apply ribbed structures to increase structural stiffness
- Avoid extra components with little functionality

Minimise scraps and discards:

- Select processes that reduce scraps and discarded materials during production
- Engage simulation systems to optimise transformation processes

Minimise or avoid packaging:

- Avoid packaging
- Apply materials only where absolutely necessary
- Design the package to be part (or to become a part) of the product

Engage more consumption-efficient systems:

- Design for more efficient consumption of operational materials
- Design for more efficient supply of raw materials
- Design for more efficient use of maintenance materials
- Design systems for consumption of passive materials

- Design for cascading recycling systems
- Facilitate the user to reduce materials consumption
- Set the product's default state at minimal materials consumption

Engage systems of flexible materials consumption:

- Engage digital support systems with dynamic configuration
- Design dynamic materials consumption for different operational stages
- Engage sensors to adjust materials consumption according to differentiated operational stages
- Reduce resource consumption in the product's default state

Minimise materials consumption during the product development phase:

- Minimise the consumption of stationery goods and their packages
- Engage digital tools in designing, modelling and prototype creation
- Engage digital tools for documentation, communication and presentation

## A.2 Minimising Energy Consumption

Minimise energy consumption during pre-production and production:

- Select materials with low energy intensity
- Select processing technologies with the lowest energy consumption possible
- Engage efficient machinery
- Use heat emitted in processes for preheating other determined process flows
- Engage pump and motor speed regulators with dynamic configuration
- Equip the machinery with intelligent power-off utilities
- Optimise the overall dimensions of the engines
- Facilitate engine maintenance
- Define accurately the tolerance parameters
- Optimise the volumes of required real estate
- Optimise stocktaking systems
- Optimise transportation systems and scale down the weight and dimensions of all transportable materials and semi-products
- Engage efficient general heating, illumination and ventilation in buildings

Minimise energy consumption during transportation and storage:

- Design compact products with high storage density
- Design concentrated products
- Equip products with onsite assembly
- Scale down the product weight
- Scale down the packaging weight

- Decentralise activities to reduce transportation volumes
- Select local material and energy sources

Select systems with energy-efficient operation stage:

- Design attractive products for collective use
- Design for energy-efficient operational stages
- Design for energy-efficient maintenance
- Design systems for consumption of passive energy sources
- Engage highly efficient energy conversion systems
- Design/engage highly efficient engines
- Design/engage highly efficient power transmission
- Use highly caulked materials and technical components
- Design for localised energy supply
- Scale down the weight of transportable goods
- Design energy recovery systems
- Design energy-saving systems

Engage dynamic consumption of energy:

- Engage digital dynamic support systems
- Design dynamic energy consumption systems for differentiated operational stages
- Engage sensors to adjust consumption during differentiated operational stages
- Equip machinery with intelligent power-off utilities
- Program product's default state at minimal energy consumption

Minimise energy consumption during product development:

- Engage efficient workplace heating, illumination and ventilation
- Engage digital tools for communicating with remote working sites

## A.3 Minimising Toxic Emissions

Select non-toxic and harmless materials:

- Avoid toxic or harmful materials for product components
- Minimise the hazard of toxic and harmful materials
- Avoid materials that emit toxic or harmful substances during pre-production
- Avoid additives that emit toxic or harmful substances
- Avoid technologies that process toxic and harmful materials
- Avoid toxic or harmful surface treatments
- Design products that do not consume toxic and harmful materials
- Avoid materials that emit toxic or harmful substances during usage
- Avoid materials that emit toxic or harmful substances during disposal

Select non toxic and harmless energy resources:

- Select energy resources that reduce dangerous emissions during pre-production and production
- Select energy resources that reduce dangerous emissions during distribution
- Select energy resources that reduce dangerous emissions during usage
- Select energy resources that reduce dangerous residues and toxic and harmful waste

## A.4 Renewable and Bio-compatible Resources

Select renewable and bio-compatible materials:

- Use renewable materials
- Avoid exhaustive materials
- Use residual materials of production processes
- Use retrieved components from disposed products
- Use recycled materials, alone or combined with primary materials
- Use bio-degradable materials

Select renewable and bio-compatible energy resources:

- Use renewable energy resources
- Engage the cascade approach
- Select energy resources with high second-order efficiency

## A.5 Optimisation of Product Lifespan

Design appropriate lifespan:

- Design components with co-extensive lifespan
- Design lifespan of replaceable components according to scheduled duration
- Select durable materials according to the product performance and lifespan
- Avoid selecting durable materials for temporary products or components

Reliability design:

- Reduce overall number of components
- Simplify products
- Eliminate weak *liaisons*

Facilitate upgrading and adaptability:

- Enable and facilitate software upgrading
- Enable and facilitate hardware upgrading

- Design modular and dynamically configured products to facilitate their adaptability for changing environments
- Design multifunctional and dynamically configured products to facilitate their adaptability for changing cultural and physical individual backgrounds
- Design onsite upgradeable and adaptable products
- Design complementary tools and documentation for product upgrading and adaptation

Facilitate maintenance:

- Simplify access and disassembly to components to be maintained
- Avoid narrow slits and holes to facilitate access for cleaning
- Prearrange and facilitate the substitution of short-lived components
- Equip the product with easily usable tools for maintenance
- Equip products with diagnostic and/or auto-diagnostic systems for maintainable components
- Design products for easy on-site maintenance
- Design complementary maintenance tools and documentation
- Design products that need less maintenance

Facilitate repairs:

- Arrange and facilitate disassembly and re-attachment of easily damageable components
- Design components according to standards to facilitate substitution of damaged parts
- Equip products with automatic damage diagnostics system
- Design products for facilitated onsite repair
- Design complementary repair tools, materials and documentation

Facilitate re-use:

- Increase the resistance of easily damaged and expendable components
- Arrange and facilitate access and removal of retrievable components
- Design modular and replaceable components
- Design components according to standards to facilitate replacement
- Design re-usable auxiliary parts
- Design the re-filling and re-usable packaging
- Design products for secondary use

Facilitate re-manufacture:

- Design and facilitate removal and substitution of easily expendable components
- Design structural parts that can be easily separated from external/visible ones
- Provide easier access to components to be re-manufactured
- Calculate accurate tolerance parameters for easily expendable connections
- Design for excessive use of materials in places more subject to deterioration
- Design for excessive use of material for easily deteriorating surfaces

## A.6 Improve Lifespan of Materials

Adopt the cascade approach:

- Arrange and facilitate recycling of materials in components with lower mechanical requirements
- Arrange and facilitate recycling of materials in components with lower aesthetical requirements
- Arrange and facilitate energy recovery from materials throughout combustion

Select materials with most efficient recycling technologies:

- Select materials that easily recover after recycling the original performance characteristics
- Avoid composite materials or, when necessary, choose easily recyclable ones
- Engage geometrical solutions like ribbing to increase polymer stiffness instead of reinforcing fibres
- Prefer thermoplastic polymers to thermosetting
- Prefer heat-proof thermoplastic polymers to fireproof additives
- Design considering the secondary use of the materials once recycled

Facilitate end-of-life collection and transportation:

- Design in compliance with product retrieval system
- Minimise overall weight
- Minimise cluttering and improve stackability of discarded products
- Design for the compressibility of discarded products
- Provide the user with information about the disposing modalities of the product or its parts

Material identification:

- Codify different materials to facilitate their identification
- Provide additional information about the material's age, number of times recycled in the past and additives used
- Indicate the existence of toxic or harmful materials
- Use standardised materials identification systems
- Arrange codifications in easily visible places
- Avoid codifying after component production stages

Minimise the number of different incompatible materials:

- Integrate functions to reduce the overall number of materials and components
- *Monomaterial* strategy: only one material per product or per sub-assembly
- Use only one material, but processed in sandwich structures
- Use compatible materials (that could be recycled together) within the product or sub-assembly
- For joining use the same or compatible materials as in components (to be joined)

Facilitate cleaning:

- Avoid unnecessary coating procedures
- Avoid irremovable coating materials
- Facilitate removal of coating materials
- Use coating procedures that comply with coated materials
- Avoid adhesives or choose ones that comply with materials to be recycled
- Prefer the dyeing of internal polymers, rather than surface painting
- Avoid using additional materials for marking or codification
- Mark and codify materials during moulding
- Codify polymers using lasers

Facilitate composting:

- Select materials that degrade in the expected end-of-life environment
- Avoid combining non-degradable materials with products that are going to be composted
- Facilitate the separation of non-degradable materials

Facilitate combustion:

- Select high energy materials for products that are going to be incinerated
- Avoid materials that emit dangerous substances during incineration
- Avoid additives that emit dangerous substances during incineration
- Facilitate the separation of materials that would compromise the efficiency of combustion (with low energy value)

## A.7 Design for Disassembly

Reduce and facilitate operations of disassembly and separation:

*Overall architecture:*

- Prioritise the disassembly of toxic and dangerous components or materials
- Prioritise the disassembly of components or materials with higher economic value
- Prioritise the disassembly of more easily damageable components
- Engage modular structures
- Divide the product into easily separable and manipulatable sub-assemblies
- Minimise overall dimensions of the product
- Minimise hierarchically dependent connections between components
- Minimise different directions in the disassembly route of components and materials
- Increase the linearity of the disassembly route
- Engage a sandwich system of disassembly with central joining elements

*Shape of components and parts:*

- Avoid difficult-to-handle components
- Avoid asymmetrical components, unless required
- Design leaning surfaces and grabbing features in compliance with standards
- Arrange leaning surfaces around the product's centre of gravity
- Design for easy centring on the component base

*Shape and accessibility of joints:*

- Avoid joining systems that require simultaneous interventions for opening
- Minimise the overall number of fasteners
- Minimise the overall number of different fastener types (that demand different tools)
- Avoid difficult-to-handle fasteners
- Design accessible and recognisable entrances for dismantling
- Design accessible and controllable dismantling points

*Engage reversible joining systems*

- Employ two-way snap-fit
- Employ joints that are opened with common tools
- Employ joints that are opened with special tools, when opening could be dangerous
- Design joints made of materials that become reversible only in determined conditions
- Use screws with hexagonal heads
- Prefer removable nuts and clips to self-tapping screws
- Use screws made of materials compatible with joint components, to avoid their separation before recycling
- Use self-tapping screws for polymers to avoid using metallic inserts

Engage easily collapsible permanent joining systems:

- Avoid rivets on incompatible materials
- Avoid staples on incompatible materials
- Avoid additional materials while welding
- Weld with compatible materials
- Prefer ultrasonic and vibration welding with polymers
- Avoid gluing with adhesives
- Employ easily removable adhesives

Co-design special technologies and features for crushing separation:

- Design thin areas to enable the taking off of incompatible inserts, by pressurised demolition
- Co-design cutting or breaking paths with appropriate separation technologies for incompatible materials separation

- Equip the product with a device to separate incompatible materials
- Employ joining elements that allow their chemical or physical destruction
- Make the breaking points easily accessible and recognisable
- Provide the products with information for the user about the characteristics of crushing separation

  Use materials that are easily separable after being crushed.
  Use additional parts that are easily separable after crushing of materials.

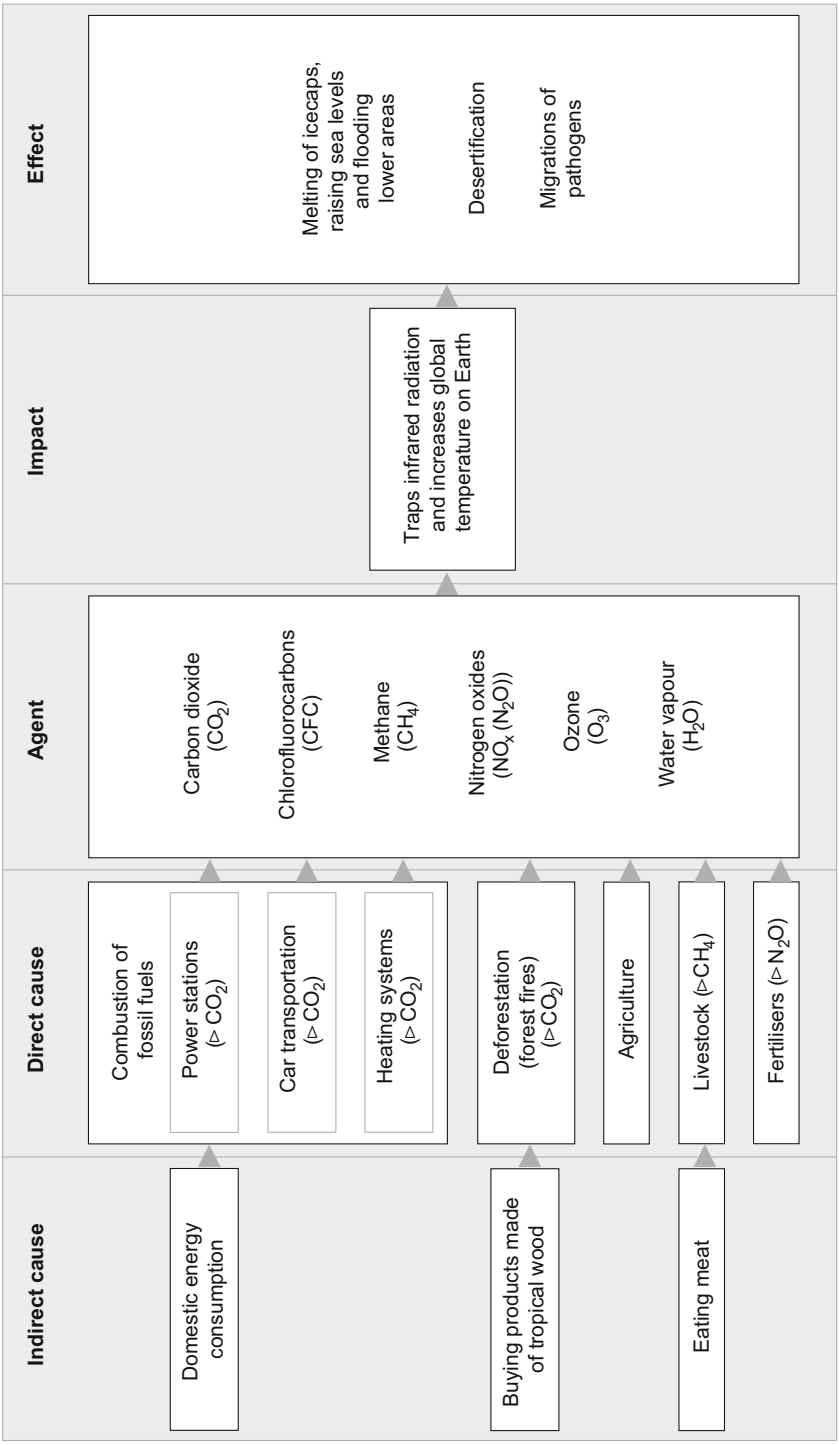
# Appendix B
# Diagrams of Environmental Impacts

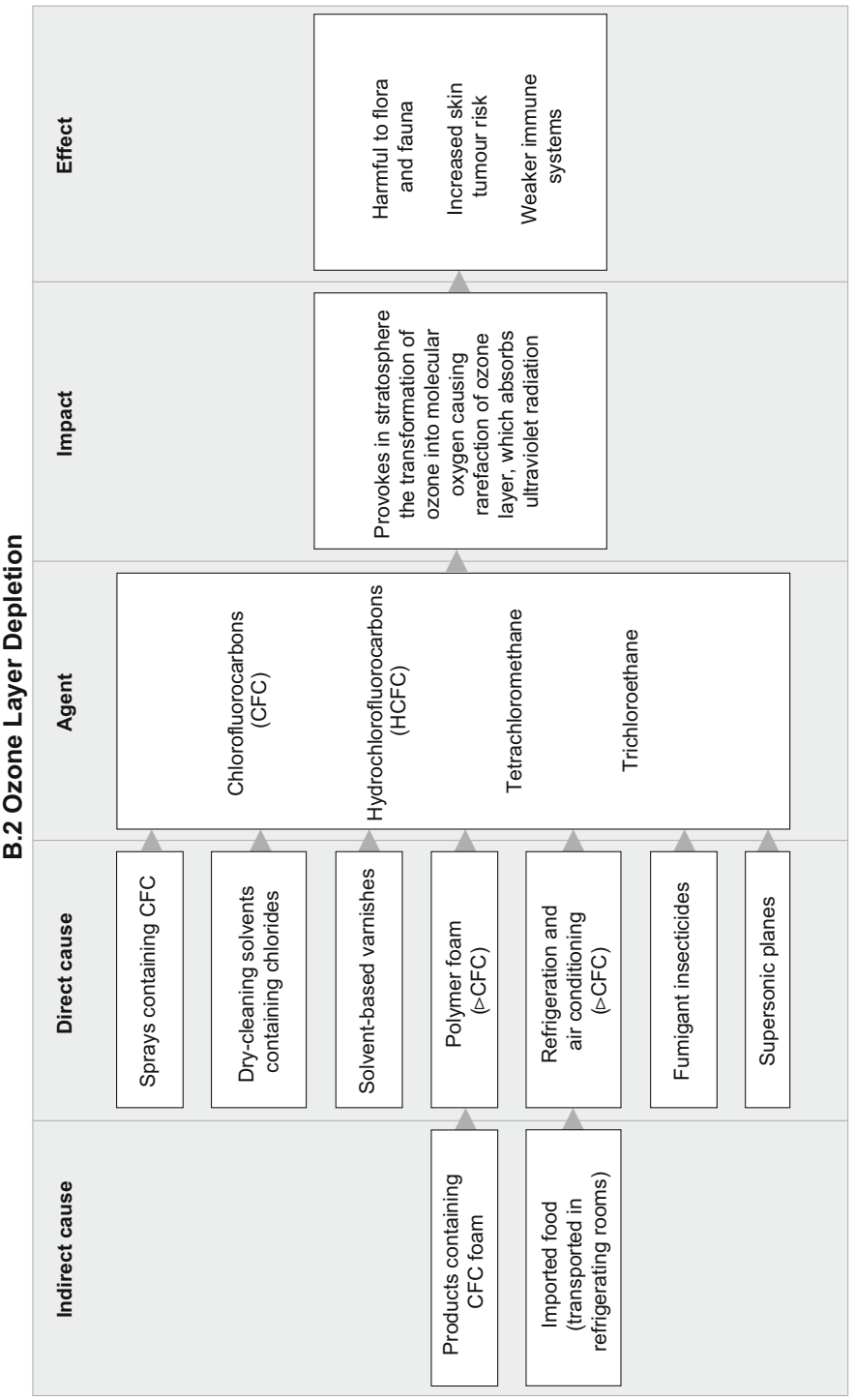
The following pages present diagrams of the following environmental effects.

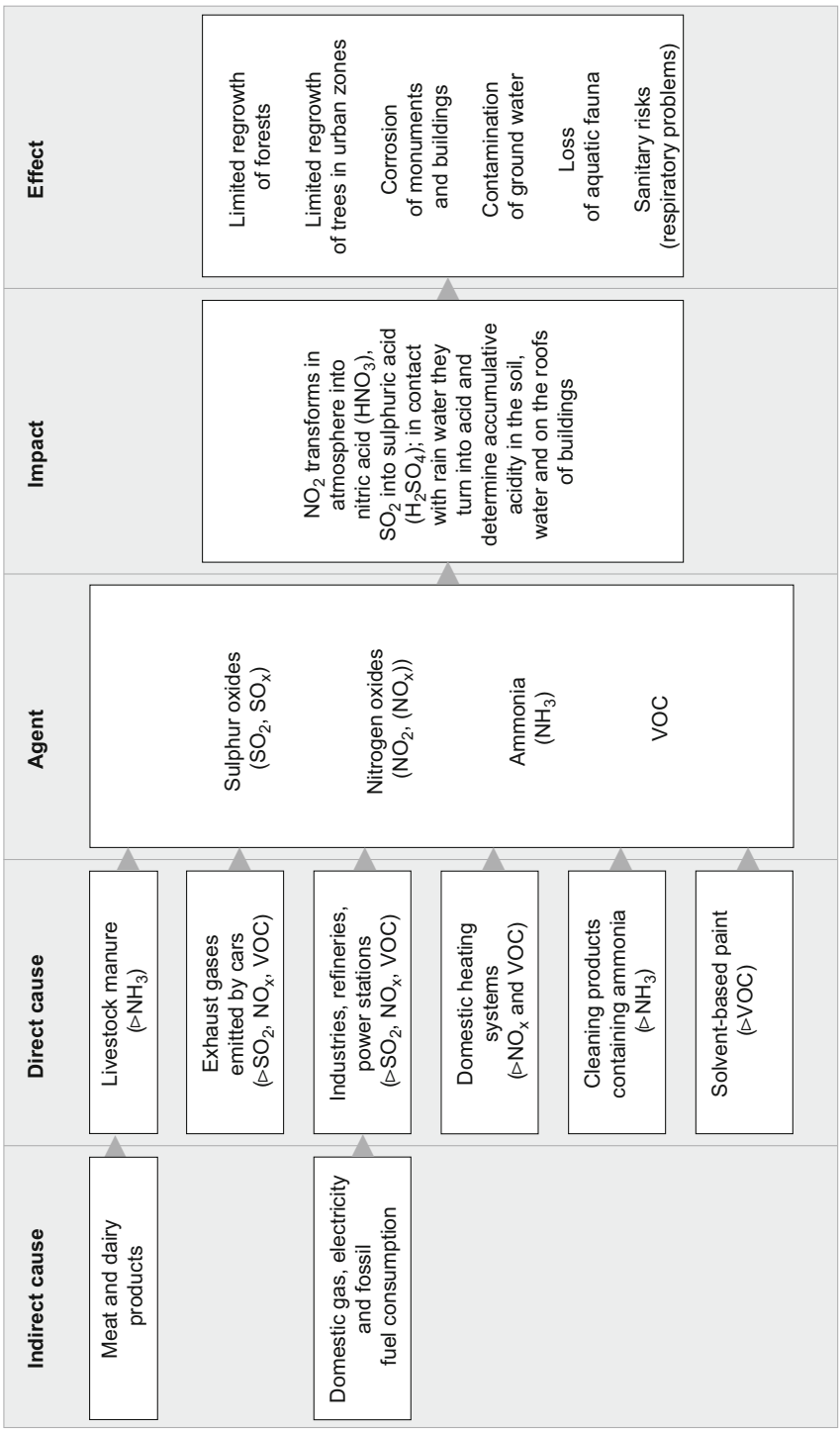
1. Global warming
2. Ozone layer depletion
3. Acidification
4. Eutrophication
5. Summer smog
6. Winter smog
7. Toxic air pollution
8. Toxic water and ground pollution
9. Landfills

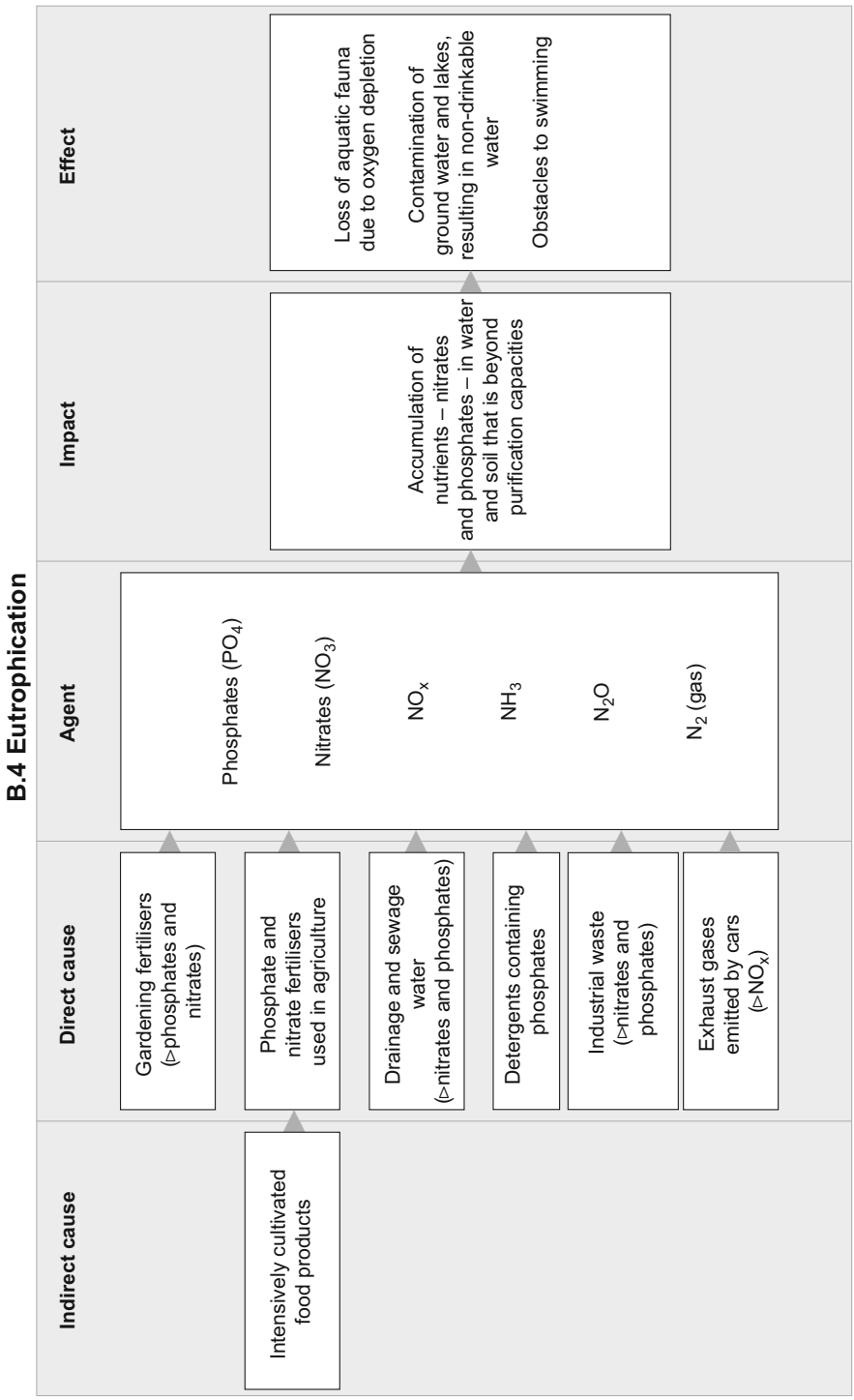
Every diagram presents the *agents* (emissions) and their *impact* on the geosphere and biosphere, and the detrimental *effects* that can occur. Likewise, the direct and indirect causes of these emissions are presented.

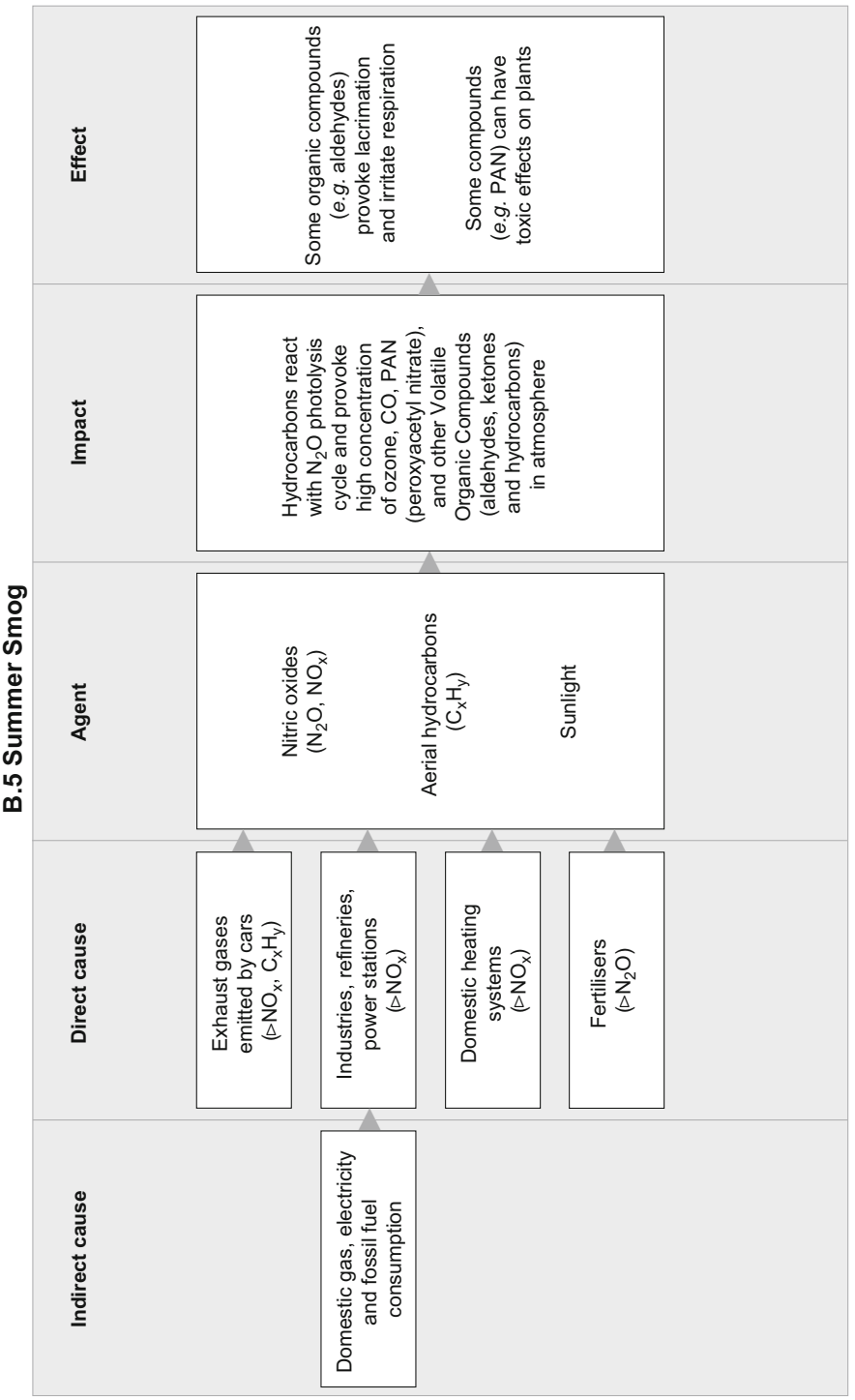
## B.1 Global warming: greenhouse effect

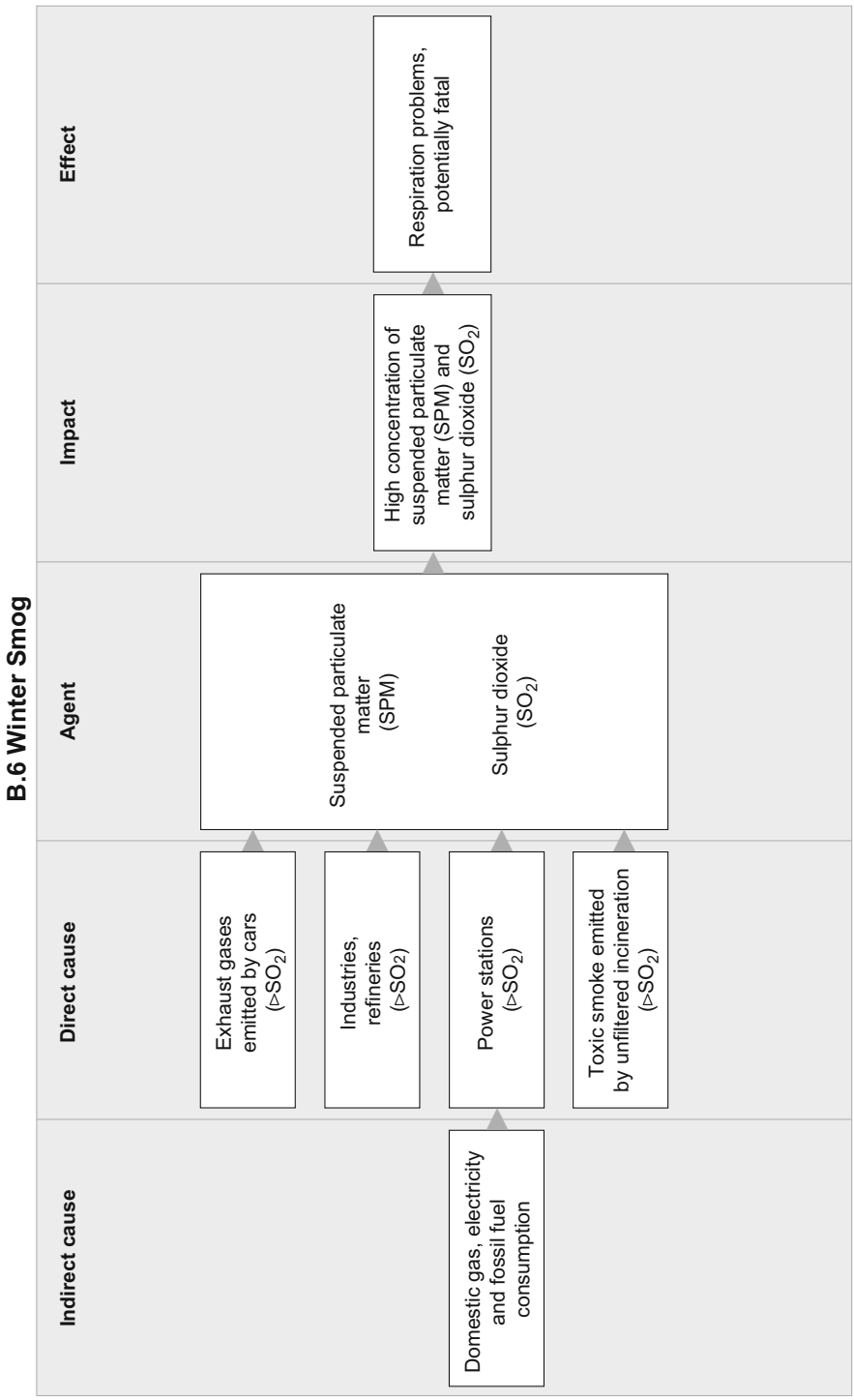


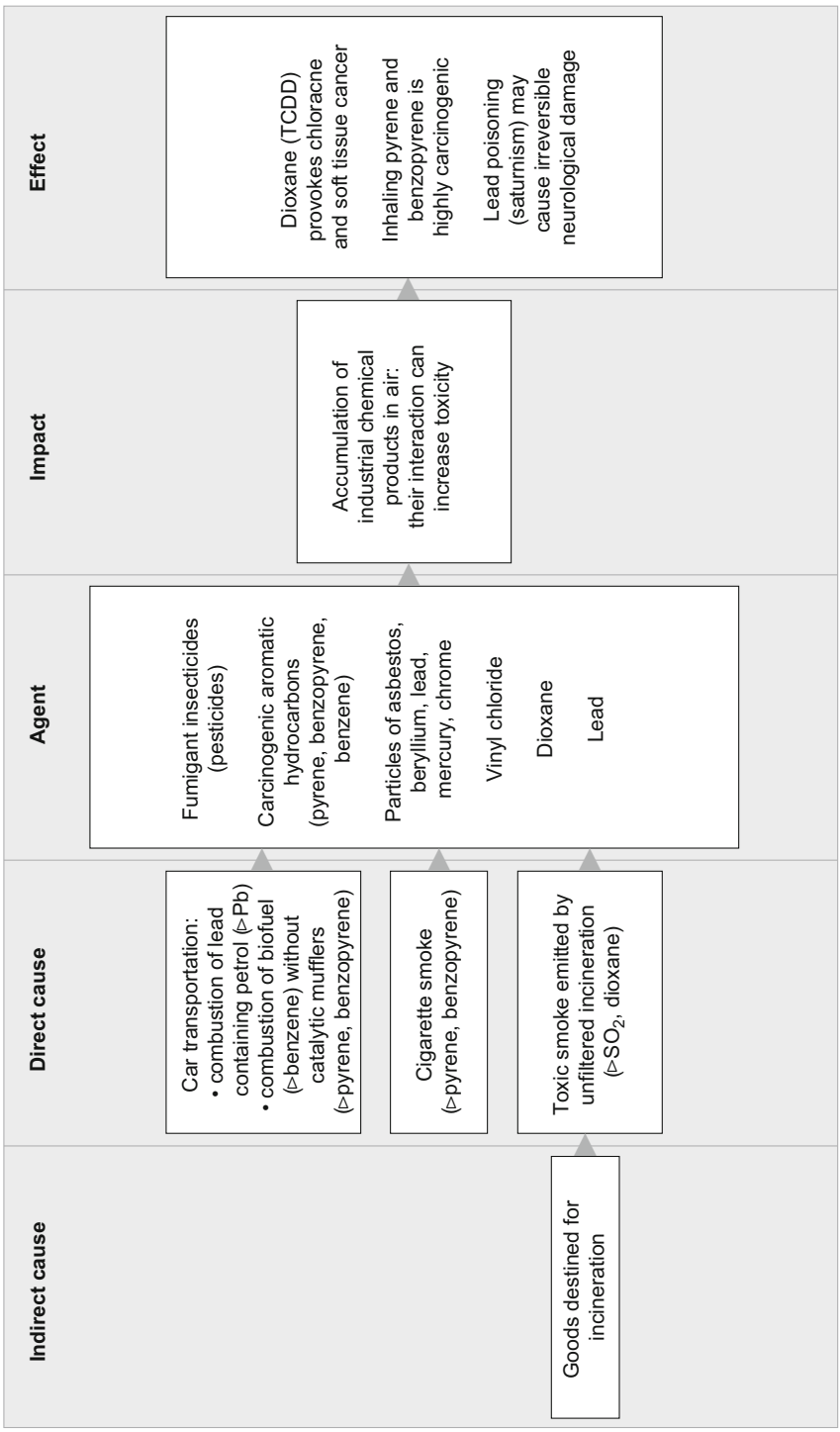

B.2 Ozone Layer Depletion
Indirect cause
Direct cause
Agent
Impact
Effect
Products containing CFC foam
Imported food (transported in refrigerating rooms)
Sprays containing CFC
Dry-cleaning solvents containing chlorides
Solvent-based varnishes
Polymer foam (>CFC)
Refrigeration and air conditioning (>CFC)
Fumigant insecticides
Supersonic planes
Chlorofluorocarbons (CFC)
Hydrochlorofluorocarbons (HCFC)
Tetrachloromethane
Trichloroethane
Provokes in stratosphere the transformation of ozone into molecular oxygen causing rarefaction of ozone layer, which absorbs ultraviolet radiation
Harmful to flora and fauna
Increased skin tumour risk
Weaker immune systems

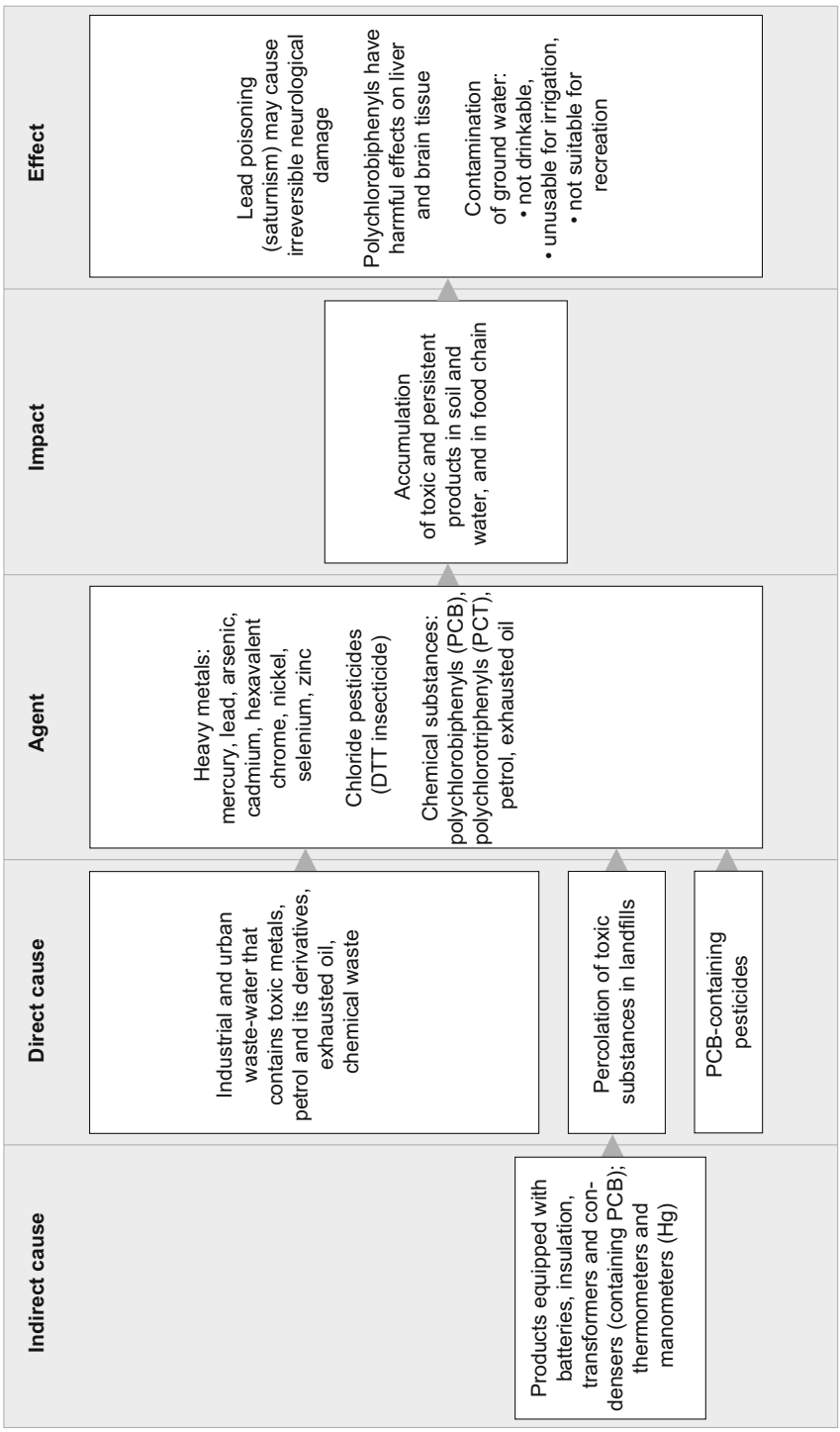

B.3 Acidification
Indirect cause
Direct cause
Agent
Impact
Effect
Meat and dairy products
Livestock manure (>NH3)
Domestic gas, electricity and fossil fuel consumption
Exhaust gases emitted by cars (>SO2, NOx, VOC)
Industries, refineries, power stations (>SO2, NOx, VOC)
Domestic heating systems (>NOx and VOC)
Cleaning products containing ammonia (>NH3)
Solvent-based paint (>VOC)
Sulphur oxides (SO2, SOx)
Nitrogen oxides (NO2, (NOx))
Ammonia (NH3)
VOC
NO2 transforms in atmosphere into nitric acid (HNO3), SO2 into sulphuric acid (H2SO4); in contact with rain water they turn into acid and determine accumulative acidity in the soil, water and on the roofs of buildings
Limited regrowth of forests
Limited regrowth of trees in urban zones
Corrosion of monuments and buildings
Contamination of ground water
Loss of aquatic fauna
Sanitary risks (respiratory problems)

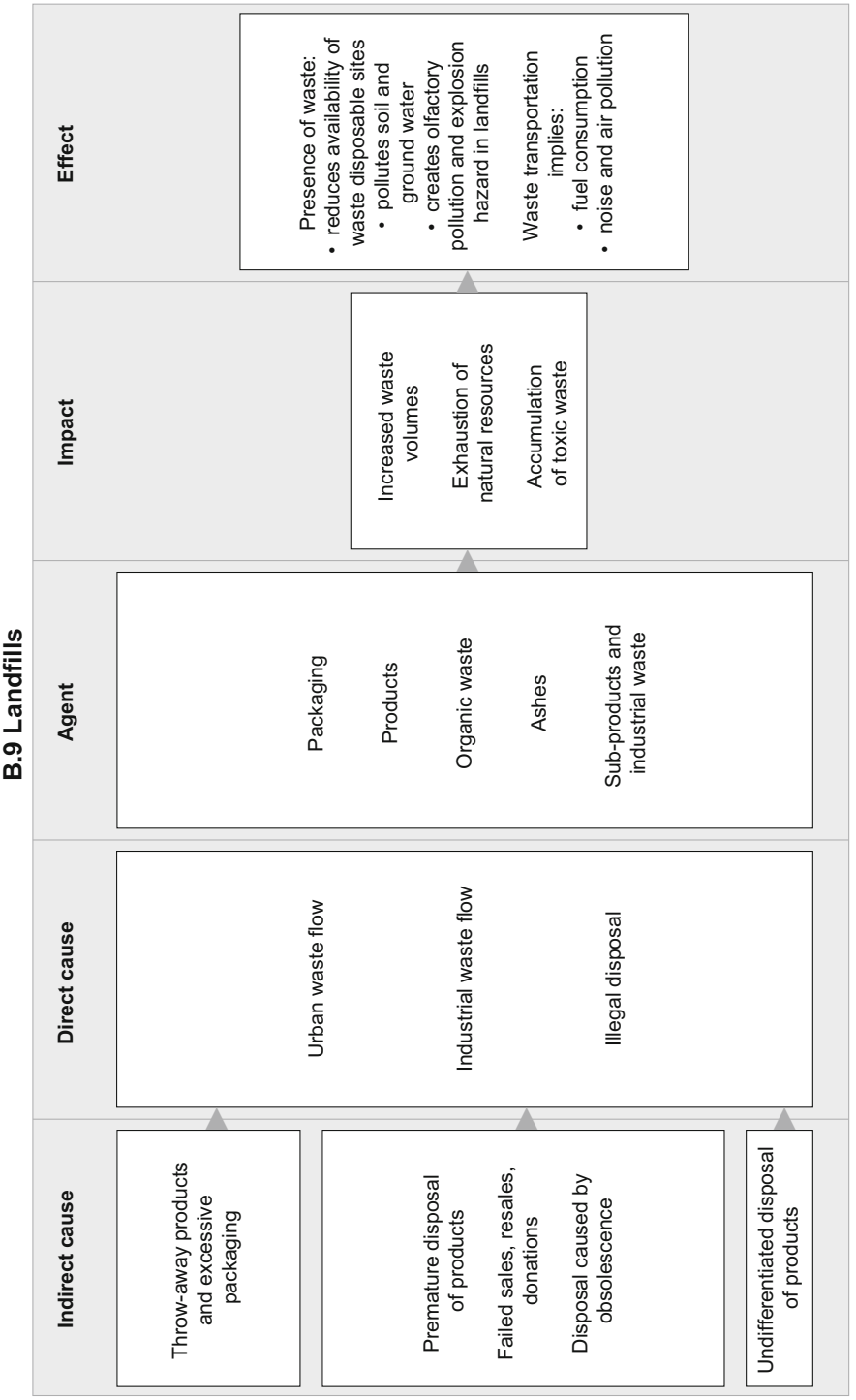

B.4 Eutrophication
Indirect cause
Direct cause
Agent
Impact
Effect
Intensively cultivated food products
Gardening fertilisers (>phosphates and nitrates)
Phosphate and nitrate fertilisers used in agriculture
Drainage and sewage water (>nitrates and phosphates)
Detergents containing phosphates
Industrial waste (>nitrates and phosphates)
Exhaust gases emitted by cars (>$NO_X$)
Phosphates ($PO_4$)
Nitrates ($NO_3$)
$NO_x$
$NH_3$
$N_2O$
$N_2$ (gas)
Accumulation of nutrients – nitrates and phosphates – in water and soil that is beyond purification capacities
Loss of aquatic fauna due to oxygen depletion
Contamination of ground water and lakes, resulting in non-drinkable water
Obstacles to swimming


B.5 Summer Smog
Indirect cause
Direct cause
Agent
Impact
Effect
Domestic gas, electricity and fossil fuel consumption
Exhaust gases emitted by cars (▷$NO_x$, $C_xH_y$)
Industries, refineries, power stations (▷$NO_x$)
Domestic heating systems (▷$NO_x$)
Fertilisers (▷$N_2O$)
Nitric oxides ($N_2O$, $NO_x$)
Aerial hydrocarbons ($C_xH_y$)
Sunlight
Hydrocarbons react with $N_2O$ photolysis cycle and provoke high concentration of ozone, CO, PAN (peroxyacetyl nitrate), and other Volatile Organic Compounds (aldehydes, ketones and hydrocarbons) in atmosphere
Some organic compounds (*e.g.* aldehydes) provoke lacrimation and irritate respiration
Some compounds (*e.g.* PAN) can have toxic effects on plants


B.6 Winter Smog
Indirect cause
Direct cause
Agent
Impact
Effect
Domestic gas, electricity and fossil fuel consumption
Exhaust gases emitted by cars (>SO2)
Industries, refineries (>SO2)
Power stations (>SO2)
Toxic smoke emitted by unfiltered incineration (>SO2)
Suspended particulate matter (SPM)
Sulphur dioxide (SO2)
High concentration of suspended particulate matter (SPM) and sulphur dioxide (SO2)
Respiration problems, potentially fatal


B.7 Toxic Air Pollution
Indirect cause
Direct cause
Agent
Impact
Effect
Goods destined for incineration
Car transportation:
• combustion of lead containing petrol (>Pb)
• combustion of biofuel (>benzene) without catalytic mufflers (>pyrene, benzopyrene)
Cigarette smoke (>pyrene, benzopyrene)
Toxic smoke emitted by unfiltered incineration (>$SO_2$, dioxane)
Fumigant insecticides (pesticides)
Carcinogenic aromatic hydrocarbons (pyrene, benzopyrene, benzene)
Particles of asbestos, beryllium, lead, mercury, chrome
Vinyl chloride
Dioxane
Lead
Accumulation of industrial chemical products in air: their interaction can increase toxicity
Dioxane (TCDD) provokes chloracne and soft tissue cancer
Inhaling pyrene and benzopyrene is highly carcinogenic
Lead poisoning (saturnism) may cause irreversible neurological damage


B.8 Toxic Water and Ground Pollution
Indirect cause
Direct cause
Agent
Impact
Effect
Products equipped with batteries, insulation, transformers and con-densers (containing PCB); thermometers and manometers (Hg)
Percolation of toxic substances in landfills
PCB-containing pesticides
Industrial and urban waste-water that contains toxic metals, petrol and its derivatives, exhausted oil, chemical waste
Heavy metals: mercury, lead, arsenic, cadmium, hexavalent chrome, nickel, selenium, zinc
Chloride pesticides (DTT insecticide)
Chemical substances: polychlorobiphenyls (PCB), polychlorotriphenyls (PCT), petrol, exhausted oil
Accumulation of toxic and persistent products in soil and water, and in food chain
Lead poisoning (saturnism) may cause irreversible neurological damage
Polychlorobiphenyls have harmful effects on liver and brain tissue
Contamination of ground water:
• not drinkable,
• unusable for irrigation,
• not suitable for recreation


B.9 Landfills
Indirect cause
Direct cause
Agent
Impact
Effect
Throw-away products and excessive packaging
Premature disposal of products
Failed sales, resales, donations
Disposal caused by obsolescence
Undifferentiated disposal of products
Urban waste flow
Industrial waste flow
Illegal disposal
Packaging
Products
Organic waste
Ashes
Sub-products and industrial waste
Increased waste volumes
Exhaustion of natural resources
Accumulation of toxic waste
Presence of waste:
• reduces availability of waste disposable sites
• pollutes soil and ground water
• creates olfactory pollution and explosion hazard in landfills
Waste transportation implies:
• fuel consumption
• noise and air pollution

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