Data Article

Multi-period optimal design of an aerospace CFRP waste management supply chain: Data set, variables and criteria for the development of a multi-objective MILP model

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A B S T R A C T

This paper presents the data set, variables and criteria for the development of a multi-objective and multi-period Mixed Integer Linear Programming (MILP) model for the deployment and design of an aerospace CFRP (Carbon Fibre Reinforced Polymer) waste supply chain. It involves $\varepsilon$-constraint, lexicographic techniques and Multiple Criteria Decision Making (MCDM) tools. In this model, the deployment of new recycling sites (Grinding, Pyrolysis, Supercritical Water, Microwave) is established. The system is optimised by bi-criteria optimisation including an economic objective based on cost minimisation or Net Present Value (NPV) maximisation and an environmental one (minimisation of Global Warming Potential). The presentation of the global strategy, the results and their discussion have been presented in a companion paper (Vo Dong, P.A., Azzaro-Pantel, C., Boix, A multi-period optimisation approach for deployment and optimal design of an aerospace CFRP waste management supply chain, Waste Management, Volume 95, 2019, Pages 201–216 [1]). The data were acquired by literature analysis, by use of Simapro v7.3 software tool and EcoInvent database, by use of institutional sources (Eurostat for energy prices) or from Airbus and Boeing websites for aircraft deliveries and calculation of CFRP content. The model was created by the authors within the framework of SEARRCH (Sustainability Engineering Assessment Research for Recycling Composite with High value) project supported by ANR (Agence Nationale de la Recherche Scientifique).

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The case study of CFRP waste supply chain in France has supported the deployment analysis.
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# MILP model formulation

## Indices/Sets

- **c ∈ C, C** = {Market $i$, $i = 1, 4$} Market of Recovered Product
- **e ∈ E, E** = {Landfill, Incineration, Co – incineration} No-fibre Recovery Pathways
- **i ∈ I, I** = {Cured and chopped composite} Intermediate product
- **l, l’ ∈ L, L** = {ACAL, ALPC, ARA, BFC, BRE, CVL, IDF, LRMP, NOR, NPCP, PACA, PL} Location/region

| Abbreviation | Description |
|--------------|-------------|
| ACAL         | Alsace-Champagne-Ardenne-Lorraine |
| ALPC         | Aquitaine-Limousin-Poitou-Charentes |
| ARA          | Auvergne-Rhône-Alpes |
| BFC          | Bourgogne-France-Comté |
| BRE          | Bretagne |
| CVL          | Centre-Val de Loire |
| IDF          | Île-de-France |
| LRMP         | Languedoc-Roussillon-Midi-Pyrénées |
| NOR          | Normandie |
| NPCP         | Nord Pas-de-Calais Picardie |
| PACA         | Provence-Alpes-Côte d'Azur |
| PL           | Pays de la Loire |

| Parameter | Description |
|-----------|-------------|
| p ∈ P, P  | (Powdered, Fibrous, Fibre, Oligomers) Recovered Product from Fibre Recycling Technique |
| r ∈ R, R  | (grinding, pyrolysis, SCW, microwave) Fibre recycling technique |
| s ∈ S, S  | {small, medium, large} Plant scale |
| t ∈ T, T  | [0; 20] Year |
| w ∈ W, W  | {dry fibre, uncured production, cured production, EOL} Waste type |

## Parameters

- **CAPEL_{el}**: Capacity of no-fibre recovery technique $e$ at region $l$, (tonnes of waste/year)
- **CAPR0_{rs}**: Standard maximum recycling capacity of deployed recovery of technique $r$ at scale $s$
- **CAPROL_{rl}**: Recycling capacity of the existing recovery site of technique $r$ at region $l$, (tonnes of waste/year)
- **CQL_{cp}**: Minimum quality of product $p$ accepted by sector $c$ (%) |
- **DIST_{ll}**: Distance between region $l$ and region $l'$, (km)
- **ECOM**: Energy for compression (kWh/tonne)
- **EPR_{w}**: Energy used for pre-treatment of waste $w$ (kWh/tonne)
- **GWPE**: GWP impacts of electricity (tonnes CO2 eq./MJ)
- **GWPNRAU_{we}**: Avoided GWP impact of no-fibre recovery pathway $e$ from waste $w$ (tonnes CO2 eq./tonne of waste)
- **GWPNRU_{e}**: GWP impacts of treatment by no-fibre recovery pathway $e$ (tonnes CO2 eq./tonne of waste)
- **GWPP_{p}**: GWP impacts of conventional production of product $p$ (tonnes CO2 eq./tonne of product)
| Symbol | Description |
|--------|-------------|
| GWPTRU | GWP impacts of transport (tonnes CO₂ eq./tkm) |
| GWPWR_w | GWP impacts of treatment of waste \( w \) by fibre recycling technique \( r \) (tonnes CO₂ eq./tonne of waste) |
| INV0S | Unit investment cost for a deployed recovery site of technique \( r \) at scale \( s \) (€) |
| OCOSTrs | Other direct cost (labour, maintenance) of deployed recovery site \( r \) at scale \( s \) (€/year) |
| PCOM | Cost of compression (€/tonne) |
| PE | Unit cost of electricity (€/kWh) |
| PIRri | Unit cost of treatment of recycling technique \( r \) for intermediate product \( i \) (€/tonne) |
| PNR_e | Unit cost of no-fibre recovery technique \( e \) for waste \( w \) (€/tonne) |
| PPp | Price of recovered product \( p \) (€/tonne) |
| PSTW_w | Unit cost of transport for waste (€/tonne of waste) |
| PTR0 | Cost of normal transport for recovered product (same for all type product \( p \)) (€/tkm) |
| PTRw | Cost of transport for waste \( w \) (€/tkm) |
| FWRrw | Unit cost of treatment of recycling technique \( r \) for waste \( w \) (€/tonne) |
| QLPRPwp | Quality of recovered product \( p \) from waste \( w \) by pretreatment (%) |
| QLRP1iwp | Quality of recovered product \( p \) from intermediate \( i \) by recycling technique \( r \) (%) |
| QLRPW_wrp | Quality of recovered product \( p \) from waste \( w \) by recycling technique \( r \) (%) |
| QW_wri | Waste quantity \( w \) generated at region \( l \) at year \( t \), (tonnes of waste) |
| RIRP_wri | Conversion ratio from intermediate product \( i \) to final product \( p \) by fibre recycling technique \( r \) (%), 0 otherwise |
| RN_e | Revenue from no-fibre recovery pathway \( e \) (€/tonne of waste) |
| RWRP_rpw | Conversion ratio from waste \( w \) to final product \( p \) by fibre recycling technique \( r \) (%) |
| XDP_cpl | Index of existence of sector \( c \) for product \( p \) at region \( l \) |
| XIR_r | Acceptance index of fibre recycling technique \( r \) for intermediate product \( i \), 1 if the technique \( r \) can treat the intermediate product \( i \), 0 otherwise |
| XPRrpwp | Conversion rate of waste \( w \) to product \( p \) after pretreatment |
| XPR_w | Index for waste \( w \) which does not need recycling process after pretreatment step for recovery, 1 if the waste \( w \) does not go to the recycling process for recovery, 0 otherwise |
| XTR_Il | Factor of transport, 1 if two regions \( (I \) and \( I' \)) are different; 0 otherwise |
| XWIR_wri | Index of conversion waste \( w \) to intermediate product \( i \) after pretreatment |
| XWNR_wre | Acceptance index of no-fibre recovery technique \( e \) for waste \( w \), 1 if the technique \( e \) can treat the waste \( w \), 0 otherwise |
| XWPR_w | Index for waste \( w \) which can go to pre-treatment step separately from processing, 1 if the separated pretreatment step is opened for the waste \( w \), 0 otherwise |
| XWR_wrf | Acceptance index of fibre recycling technique \( r \) for waste \( w \), 1 if the technique \( r \) can treat the waste \( w \), 0 otherwise |
| \( \omega \) | Ratio of maximum storage capacity to maximum recycling capacity at a deployed recovery site |

**Continuous/Integer variables**

| Symbol | Description |
|--------|-------------|
| FIIR_tirl | Flow of intermediate product \( i \) transported from pretreatment deployed site at \( l \) to deployed recycling site of technique \( r \) at \( l' \) in year \( t \), (tonnes) |
| FIOR_tirl | Flow of intermediate product \( i \) transported from pretreatment existing site at \( l \) to existing recycling site of technique \( r \) at \( l' \) in year \( t \), (tonnes) |
| FPIDR_wrpctll | Flow of product \( p \) recovered from waste \( w \) by direct recycling from deployed recovery site of technique \( r \) at \( l \) and then distributed to market \( c \) at \( l' \) in year \( t \), (tonnes) |
| FPIIR_repc | Flow of product \( p \) recovered from \( i \) by deployed recovery site of technique \( r \) at \( l \) and then distributed to market \( c \) at \( l' \) in year \( t \), (tonnes) |
| FPIPR_wrpctll | Flow of product \( p \) obtained from pretreatment of waste \( w \) by deployed recovery site of technique \( r \) at \( l \) and then distributed to market \( c \) at \( l' \) in year \( t \), (tonnes) |
| FPODR_wrpctll | Flow of product \( p \) recovered from waste \( w \) by direct recycling from existing recovery site of technique \( r \) at \( l \) and then distributed to market \( c \) at \( l' \) in year \( t \), (tonnes) |
| Symbol | Description |
|--------|-------------|
| FPOIR_{rptl} | Flow of product $p$ recovered from $i$ by existing recovery site of technique $r$ at $l$ and then distributed to market $c$ at $l'$ in year $t$, (tonnes) |
| FPOPWR_{rptl} | Flow of product $p$ obtained from pretreatment of waste $w$ by existing recovery site of technique $r$ at $l$ and then distributed to market $c$ at $l'$ in year $t$ (tonnes) |
| FWNWR_{rwtl} | Flow of waste $w$ to no-fibre recovery technique $e$ in year $t$ at region $l$, (tonnes) |
| FWIRDR_{rwtl} | Flow of waste $w$ for directly recovery at deployed recycling site of technique $r$ at $l$ in year $t$, (tonnes) |
| FWIRPR_{rwtl} | Flow of waste $w$ for pretreatment at deployed site of technique $r$ at $l$ in year $t$, (tonnes) |
| FWIRD_{rwtl} | Flow of waste $w$ from waste source $l$ transported directly to deployed recycling site of technique $r$ at $l'$ in year $t$, (tonnes) |
| FWIOPR_{rwtl} | Flow of waste $w$ for pretreatment at existing site of technique $r$ at $l$ in year $t$, (tonnes) |
| FWPRODR_{rwtl} | Flow of waste $w$ for directly recovery at existing recycling site of technique $r$ at $l$ in year $t$, (tonnes) |
| FWPROPR_{rwtl} | Flow of waste $w$ for pretreatment at existing site of technique $r$ at $l$ in year $t$, (tonnes) |
| FWPRO_{rwtl} | Flow of waste $w$ from waste source $l$ transported directly to existing recycling site of technique $r$ at $l'$ in year $t$, (tonnes) |
| QWRS_{rwtl} | Quantity of waste $w$ stored at a deployed recycling site $r$ in year $t$ at region $l$, (tonnes) |
| YRSTl_{rs} | Binary variable for implementation of new recycling site of technique $r$ at scale $s$ in year $t$ at region $l$ |

### Specifications Table

| Subject | Modelling and Simulation |
|---------|--------------------------|
| Specific subject area | Multi-period Mixed Integer Linear Programming (MILP) model, Process Systems Engineering, Supply Chain Optimisation |
| Type of data | Table |
| How data were acquired | MILP model formulation: Parameters, Variables, Constraints, Objective functions. The data were acquired by literature analysis, by use of Simapro v7.3 software tool and EcoInvent database, by use of institutional sources (Eurostat for energy prices) or from Airbus and Boeing websites for aircraft deliveries and calculation of CFRP content. The model was created by the authors within the framework of SEARRCH (Sustainability Engineering Assessment Research for Recycling Composite with High value) project supported by ANR (Agence Nationale de la Recherche Scientifique). |
| Data format | Raw |
| Parameters for data collection | Analyzed, MILP model formulation: Variables, Constraints, Objective functions, Parameters |
| Description of data collection | The parameters include the main features of the supply chain dedicated to CFRP waste management, the key parameters, constraints and objective functions to be considered, i.e., environmental and economic criteria. |
| Data source location | European (mainly French) sources |
| Data accessibility | Case study of France for CFRP waste supply chain deployment |
| Related research article | With the article, Anh Vo Dong, Catherine Azzaro-Pantel, Marianne Boix, A multi-period optimisation approach for deployment and optimal design of an aerospace CFRP waste management supply chain, Waste Management, Volume 95, 2019, Pages 201–216, ISSN 0956-053X, [https://doi.org/10.1016/j.wasman.2019.05.002](https://doi.org/10.1016/j.wasman.2019.05.002). |
1. Data

The dataset contains:

- the list of parameters and the set of integer/continuous variables that are involved in the MILP model formulation through the constraints and objective functions i.e., the environmental and economic criteria that have been considered. Many of the variables are continuous (e.g. flows of wastes), but there is a set of discrete variables that represent design choices (e.g. choice of a recycling technology).
- the aircraft deliveries for each model (Airbus and Boeing) from 1991 to 2010 (pieces) (Table 1) that have been used for the identification of CFRP waste potential either after their End-Of-Life or as production scrap (see the companion paper).
- the distances between regions for road transportation (km) that have been considered in the distribution echelon of the supply chain model (see Table 2).
- The data used in the bicriteria formulation, i.e. for the determination of CFRP waste treatment Unit Cost and GWP impact (see Table 3).
- The Investment Cost for Recovery Pathways (Table 4).

2. Experimental design, materials, and methods

This section presents the constraints and objectives used in the model which is part and parcel of the methodological framework developed to design the network of CFRP waste management. The model encompasses the dynamic variation of waste quantity by a bi-criteria optimisation including economic objective and environmental objectives.

The parameters (see Section Data) correspond to the data that must be collected to model the waste supply chain and analyse its dynamic behaviour. The list of data that is presented constitutes the supplementary materials for the companion paper of this article [1] (to avoid redundancy, the other parameters that are not explicitly mentioned here can be found in Ref. [1]). The model that was developed creates the links between this set of data and the integer and continuous variables that have also been presented through constraints as well as the objective functions that have been involved in the MILP model. This model could also be viewed as a tool to acquire data for supply chain management, i.e. the results of the optimisation model that are the values of the variables that are computed as optimal solutions of the optimisation model that was developed by the authors [1]. The reader must refer to the base paper to have information about the assumptions related to CFRP recycling/recovery technologies, the spatio-temporal availability of CFRP sources and demand scenarios. The results of the optimisation model have been presented and discussed in detail in Ref. [1].

The model can solve problems of the following type:

**Given:**
Spatio-temporal demands for resources and energy services.
Spatio-temporal availability of CFRP sources.
Characteristics of each CFRP recycling/recovery technology.

**Determine:**
Network design.
### Table 1
Aircraft deliveries for each model from 1991 to 2010 (pieces).

| Year | A300 | A310 | A318 | A319 | A320 | A321 | A330 | A340 | A341 | A380 | MD-80 | MD-90 | MD-11 | B707 | B717 | B737 NG | B737 (Original & Classic) | B747 | B757 | B767 | B777 | Total | Average wt% CFRP per plane |
|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|-------|--------------------------|------|------|------|------|-------|--------------------------|
| 1991 | 25   | 19   |      | 18   | 119  | 16   | 1    | 22   | 31   | 119  | 140  | 13   | 31   | 31   | 14   |      | 215               | 64   | 80   | 62   | 13   | 769   | 1.18                     |
| 1992 | 22   | 24   | 47   | 18   | 111  | 22   | 9    | 25   | 21   | 117  | 84   | 25   | 56   | 61   | 5    |      | 218               | 61   | 99   | 63   | 13   | 729   | 1.26                     |
| 1993 | 23   | 22   | 53   | 48   | 71   | 16   | 10   | 19   | 41   | 21   | 43   | 26   | 40   | 76   | 5    |      | 152               | 40   | 71   | 51   | 12   | 547   | 1.77                     |
| 1994 | 17   | 22   | 88   | 34   | 48   | 22   | 14   | 28   | 37   | 41   | 76   | 26   | 25   | 56   | 17   |      | 119               | 25   | 40   | 43   | 13   | 435   | 2.10                     |
| 1995 | 14   | 33   | 85   | 38   | 53   | 35   | 33   | 46   | 43   | 61   | 35   | 53   | 54   | 55   | 37   |      | 116               | 47   | 46   | 42   | 13   | 380   | 2.91                     |
| 1996 | 6    | 33   | 72   | 58   | 53   | 37   | 33   | 47   | 42   | 74   | 47   | 47   | 47   | 47   | 43   |      | 116               | 25   | 45   | 42   | 13   | 557   | 3.17                     |
| 1997 | 13   | 28   | 87   | 80   | 101  | 28   | 37   | 47   | 44   | 74   | 55   | 55   | 55   | 55   | 43   |      | 101               | 27   | 45   | 42   | 13   | 557   | 3.47                     |
| 1998 | 8    | 33   | 142  | 101  | 101  | 33   | 33   | 47   | 44   | 74   | 55   | 55   | 55   | 55   | 43   |      | 119               | 27   | 45   | 42   | 13   | 557   | 4.04                     |
| 1999 | 11   | 22   | 142  | 119  | 116  | 33   | 33   | 47   | 44   | 74   | 55   | 55   | 55   | 55   | 43   |      | 119               | 27   | 45   | 42   | 13   | 557   | 4.26                     |
| 2000 | 9    | 8    | 142  | 116  | 119  | 33   | 33   | 47   | 44   | 74   | 55   | 55   | 55   | 55   | 43   |      | 101               | 27   | 45   | 42   | 13   | 557   | 4.46                     |
| 2001 | 8    | 12   | 142  | 101  | 101  | 33   | 33   | 47   | 44   | 74   | 55   | 55   | 55   | 55   | 43   |      | 121               | 27   | 45   | 42   | 13   | 557   | 4.87                     |
| 2002 | 12   | 9    | 142  | 121  | 101  | 33   | 33   | 47   | 44   | 74   | 55   | 55   | 55   | 55   | 43   |      | 101               | 27   | 45   | 42   | 13   | 557   | 5.10                     |
| 2003 | 9    | 12   | 142  | 121  | 101  | 33   | 33   | 47   | 44   | 74   | 55   | 55   | 55   | 55   | 43   |      | 101               | 27   | 45   | 42   | 13   | 557   | 5.04                     |
| 2004 | 6    | 12   | 142  | 121  | 101  | 33   | 33   | 47   | 44   | 74   | 55   | 55   | 55   | 55   | 43   |      | 121               | 27   | 45   | 42   | 13   | 557   | 5.30                     |
| 2005 | 8    | 12   | 142  | 121  | 101  | 33   | 33   | 47   | 44   | 74   | 55   | 55   | 55   | 55   | 43   |      | 101               | 27   | 45   | 42   | 13   | 557   | 5.44                     |
| 2006 | 9    | 12   | 142  | 121  | 101  | 33   | 33   | 47   | 44   | 74   | 55   | 55   | 55   | 55   | 43   |      | 121               | 27   | 45   | 42   | 13   | 557   | 5.44                     |
| 2007 | 8    | 12   | 142  | 121  | 101  | 33   | 33   | 47   | 44   | 74   | 55   | 55   | 55   | 55   | 43   |      | 121               | 27   | 45   | 42   | 13   | 557   | 5.44                     |
| 2008 | 10   | 12   | 142  | 121  | 101  | 33   | 33   | 47   | 44   | 74   | 55   | 55   | 55   | 55   | 43   |      | 121               | 27   | 45   | 42   | 13   | 557   | 5.44                     |
| 2009 | 8    | 12   | 142  | 121  | 101  | 33   | 33   | 47   | 44   | 74   | 55   | 55   | 55   | 55   | 43   |      | 121               | 27   | 45   | 42   | 13   | 557   | 5.44                     |
| 2010 | 6    | 12   | 142  | 121  | 101  | 33   | 33   | 47   | 44   | 74   | 55   | 55   | 55   | 55   | 43   |      | 121               | 27   | 45   | 42   | 13   | 557   | 5.44                     |

https://www.airbus.com/aircraft/market/orders-deliveries.html
http://www.boeing.com/commercial/market/long-term-market/
http://www.boeing.com/commercial/#/orders-deliveries
https://www.planespotters.net/deliveries

GAO, 2011, Aviation Safety-Status of FAA's Actions to Oversee the Safety of Composite Airplanes. GAO-11-849 (for CFRP content).
Table 2
Distance between regions for road transportation (km)

|                | NPCP    | NOR     | BRE     | ACAL    | IDF     | PL      | CVL     | BFC     | ALPC    | ARA     | LRMP    | PACA    |
|----------------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|
| NPCP           | 0       | 256     | 569     | 554     | 225     | 600     | 348     | 502     | 800     | 691     | 895     | 1001    |
| NOR            | 256     | 0       | 311     | 638     | 142     | 387     | 241     | 444     | 655     | 594     | 787     | 904     |
| BRE            | 569     | 311     | 0       | 830     | 349     | 107     | 302     | 617     | 461     | 738     | 700     | 1046    |
| ACAL           | 554     | 638     | 830     | 0       | 490     | 865     | 587     | 330     | 970     | 493     | 972     | 800     |
| IDF            | 225     | 142     | 349     | 490     | 0       | 384     | 130     | 313     | 582     | 464     | 678     | 773     |
| PL             | 600     | 387     | 107     | 865     | 384     | 0       | 334     | 638     | 347     | 685     | 586     | 986     |
| CVL            | 348     | 241     | 302     | 587     | 130     | 334     | 0       | 315     | 469     | 465     | 555     | 758     |
| BFC            | 502     | 444     | 617     | 330     | 313     | 638     | 315     | 0       | 724     | 194     | 727     | 504     |
| ALPC           | 800     | 655     | 461     | 970     | 582     | 347     | 469     | 724     | 0       | 556     | 246     | 645     |
| ARA            | 691     | 594     | 738     | 493     | 464     | 685     | 465     | 194     | 556     | 0       | 537     | 314     |
| LRMP           | 895     | 787     | 700     | 972     | 678     | 586     | 555     | 727     | 246     | 537     | 0       | 403     |
| PACA           | 1001    | 904     | 1046    | 800     | 773     | 986     | 758     | 504     | 645     | 314     | 403     | 0       |

Table 3
Data for Unit Cost and GWP impact in the modelled system.

| Material/Activity                  | Unit Cost | GWP Impact |
|------------------------------------|-----------|------------|
| Input Electricity                  | 0.091 €/kWh [5] | 0.0262 kg CO₂ eq./MJ (Electricity, medium voltage, at grid/FR – Ecoinvent v2.2/ReCiPe Midpoint (H) v.1.06) |
| Input Natural Gas                  | 0.16 €/m³ [6] | 0.38 kg CO₂ eq./m³ (Natural gas, at long-distance pipeline/RER – Ecoinvent v2.2/ReCiPe Midpoint (H) v.1.06) |
| Input Pure Water                   | 2.20 €/tonne [6] | 0.000679 kg CO₂ eq./kg (Water, ultrapure, at plant/GLO – Ecoinvent v2.2/ReCiPe Midpoint (H) v.1.06) |
| Input Cooling Water                | 13.27 €/1000 m³ [6] | 0.0132 kg CO₂ eq./kg (Limestone, milled, loose, at plant/CH U – Ecoinvent v2.2/ReCiPe Midpoint (H) v.1.06) |
| Limestone                          | 90.91 €/tonne [7] | 0.131 kg CO₂/MJ (Heat, at hard coal, burned industrial furnace, 1–10 MW/MJ/RER – Ecoinvent v2.2/ReCiPe Midpoint (H) v.1.06) |
| Clinker                            | /          | 0.901 kg CO₂ eq./kg (Clinker, at plant/CH – Ecoinvent v2.2/ReCiPe Midpoint (H) v.1.06) |
| Heat from coal                     | /          | 0.131 kg CO₂/MJ (Heat, at hard coal, burned industrial furnace, 1–10 MW/MJ/RER – Ecoinvent v2.2/ReCiPe Midpoint (H) v.1.06) |
| Electricity (valorised from heat in incineration) | / | 0.0256 kg CO₂ eq./MJ (Electricity, medium voltage, production FR, at grid/FR – Ecoinvent v2.2/ReCiPe Midpoint (H) v.1.06) |
| Virgin ex-PAN Carbon Fibre         | /          | 31 kg CO₂ eq./kg [8] |
| Virgin Glass Fibre                 | 1-30 €/kg [9] | 2.6 kg CO₂/kg [10] |
| Recycled Glass fibre               | 0.25 €/kg [11] | / |
| Oligomers                          | 1.52 €/kg [7] | 3.86 kg CO₂/kg (Phenol, at plant/RER – Ecoinvent v2.2/ReCiPe Midpoint (H) v.1.06) |
| CFRP waste landfill                | 95 €/tonne [12] | 0.0897 kg CO₂ eq./kg (Disposal, plastics, mixture, 15.3% water, to sanitary landfill/CH – Ecoinvent v2.2/ReCiPe Midpoint (H) v.1.06) |
| Ash landfill (in incineration)      | 95 €/tonne [12] | 0.0122 kg CO₂ eq./kg (Disposal, inert material, 0% water, to sanitary landfill/CH – Ecoinvent v2.2/ReCiPe Midpoint (H) v.1.06) |
| Matrix combustion (in pyrolysis)    | /          | 2.35 kg CO₂ eq./kg (Disposal, plastics, mixture, 15.3% water, to municipal incineration/CH – Ecoinvent v2.2/ReCiPe Midpoint (H) v.1.06) |
Location, number and capacity of recycling technologies.
Structure of transport infrastructure network.
When and where to/install the technologies.

Network operation.
Which resources to convert, store and transport (how much, where and when).
Which technologies to use at different times.
Transport flows between different regions.

Subject to:
Demand satisfaction.
Conservation and other physical laws.
Technological constraints (e.g. availability of technologies).

Objective:
Minimise cost.
Minimise environmental impact (e.g. GWP Global Warming Potential).
Maximise value (e.g. profit).
Any combination of the above.

2.1. Constraints

2.1.1. Deployment of new recycling sites

For the waste scenarios that have been considered (see Ref. [1]) (except the as “Business as usual” (BAU) scenario where the quantity of wastes is constant over the years), the production wastes have been varied by an annual variation rate ($\delta$) (see Eq. (1)); the end-of-life waste is estimated similarly to the assumptions made in Ref. [2] and based on the projection of retired aircraft (from 2016 to 2035) from delivered aircraft of Airbus and Boeing from 1991 to 2010 (see Table 1) over an average 25-year lifespan of airplane.

$$QW_{t \in T, l \in L, w \in W \setminus \{EOL\}} = QW_{t=1, l \in L, w \in W \setminus \{EOL\}} \times (1 + \delta)^{t-1}$$ (1)

The implementation of a new recycling site is expressed by a binary variable ($YRSTL_{rstl}$) and depends on the recovery technique ($r$), the scale ($s$), the year of investment ($t$) and its location ($l$). Each new site can be created at different scales corresponding to different capacities of recycling ($CAPR0_{rs}$).

Eqs. (2)–(4) describe the formulation of recycling capacity of new recovery plants. Storage capacity in the new sites follows a linear relationship according to recycling capacity Eq. (5).

$$CAPRTU_{rstl} = CAPRO_{rs} \times YRSTL_{rstl}^{t-1}, \forall r \in R, \forall s \in S, \forall t \in T, \forall l \in L$$ (2)

$$CAPRTU_{rstl}^{t=0} = 0, \forall r \in R, \forall s \in S, \forall l \in L$$ (3)

Table 4

| Technique               | Investment Cost for Process in literature | CAPEX used in Economic Assessment |
|-------------------------|------------------------------------------|----------------------------------|
| Grinding                | 200,000 € for a shredder of capacity of 4000 tonnes/year [13] | 265,000 € of capacity of 4000 tonnes/year |
| Pyrolysis               | 10,000,000 € for capacity of 20,000 tonnes/year | 1,450,000 € of capacity of 2000 tonnes/year |
| Microwave               | 9,400,000 € for capacity of 50,000 tonnes/year (tyres application) [15] | 2,550,000 € of capacity of 2000 tonnes/year |
| Supercritical water     | 5,770,000 £ for capacity of 150 kg/hour [6] | 6,430,000 € of capacity of 1000 tonnes/year |

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2.2. Waste quantity conservation

All the wastes generated at source \( l \) have to be treated completely through either Non recovery (\( \text{FWNR}_{\text{wrtl}} \)) or Fibre Recovery pathways. In the Fibre Recovery pathways, wastes can go to the existing sites (\( \text{FWRO}_{\text{wrtl}} \)) or to the new sites (\( \text{FWRI}_{\text{wrtl}} \)). Each output flow of each waste type \( w \) at source \( l \) at time \( t \) has to be equal to the waste quantity of that waste type at the same location and period Eq. (6).

\[
\sum_{e \in E} \text{FWNR}_{\text{wrtl}} + \sum_{r \in R} \sum_{l' \in L} \text{FWRO}_{\text{wrtl}} + \sum_{r \in R} \sum_{l' \in L} \text{FWRI}_{\text{wrtl}} = QW_{\text{wrtl}}, \forall w \in W, \forall t \in T, \forall l \in L
\]  

(6)

The waste flows into Non recovery techniques are treated on site because they are considered available at all regions and there is no transportation of these streams according to the results in Ref. [1]. The recycling process is the same as already presented with two options:

- Pretreatment step and recycling process are separated for \( \text{FWROPR}_{\text{wrtl}} \) (existing sites) and \( \text{FWRIPR}_{\text{wrtl}} \) (new sites);
- Direct recycling in which pretreatment can be integrated in function of the adaptability of process \( r \) with waste \( w \) for \( \text{FWRODR}_{\text{wrtl}} \) (existing sites) and \( \text{FWRIDR}_{\text{wrtl}} \) (new sites).

Eq. (1) expresses the mass balance of waste flows in the existing sites. In the deployed sites, wastes can be pre-treated, directly recycled or stored (Eq. (8) and Eq. (9)).

\[
\text{FWROPR}_{\text{wrtl}} + \text{FWRODR}_{\text{wrtl}} = \sum_{l \in L} \text{FWRO}_{\text{wrtl}}, \forall w \in W, \forall r \in R, \forall t \in T, \forall l' \in L
\]  

(7)

\[
QWR^{t+1}_{\text{wrtl}} = QWR^{t}_{\text{wrtl}} + \sum_{l \in L} \text{FWRI}^{t+1}_{\text{wrtl}} - \text{FWRIPR}^{t+1}_{\text{wrtl}} - \text{FWRIDR}^{t+1}_{\text{wrtl}},
\forall w \in W, \forall r \in R, \forall t \in T, \forall l' \in L
\]  

(8)

\[
\sum_{l \in L} \text{FWRI}^{t}_{\text{wrtl}} = \text{FWRIPR}^{t}_{\text{wrtl}} + \text{FWRIDR}^{t}_{\text{wrtl}} + QWR^{t}_{\text{wrtl}}, \forall w \in W, \forall r \in R, \forall l' \in L
\]  

(9)

2.3. Capacity constraints

The inputs of all waste types are taken into account in the waste treatment capacity of each plant. Therefore, the total waste streams that go into Non recovery techniques are constrained by a maximal value determined by the capacity of these techniques Eq. (10). The flow of waste, which is pre-treated separately, is lower than the capacity of pre-treatment which is equal to the total of capacity of all recycling techniques at the same location Eq. (11) and Eq. (13). All input streams of each recycling plant are inferior to its capacity Eq. (12) and Eq. (14). The total quantity of stored wastes has to be under the storage capacity for each deployed site Eq. (15).
2.4. Non negativity constraints

All streams of wastes, intermediate products and recovered final products can only take positive values.

2.5. Acceptability constraints

In this approach, the wastes can be accepted in a waste treatment pathway depending on their relevance to the treatment technique and waste type. Therefore, according to the acceptability index which is a binary parameter (value 1 = accept otherwise 0) waste to technique, the waste streams to each treatment route are restricted by the constraints Eq. (16)–(18) and Eq. (26), Eq. (27). Similarly, the adaptability of intermediate products after pre-treatment step in recycling technique is under the constraints Eq. (19) and Eq. (28).

The constraints Eq. (20)–(22) and Eq. (29)–(31) show the acceptability of recovered product streams to the corresponding market. Besides the types of recovered products, each market requires a minimum quality of products so that they can be accepted to that market. These constraints are shown by Eq. (23)–(25) and Eq. (32)–(34).

Flows of wastes in the Non-Recovery paths:

\[ \sum_{w \in W} FWR_{\text{wetl}} \leq W_{\text{we}} \times Q_{\text{wetl}}, \forall w \in W, \forall e \in E, \forall t \in T, \forall l \in L \] (16)

Flows of wastes/recovered products in the existing recovery sites:

Constraints of recycling techniques and waste types:

\[ \sum_{w \in W} \sum_{r \in R} FWR_{\text{roprl}} \leq \sum_{r \in R} CAP_{\text{rol}}, \forall r \in R, \forall t \in T, \forall l \in L \] (11)

\[ \sum_{w \in W} FWR_{\text{rodrl}} + \sum_{i \in I} FIOR_{\text{irtl}} \leq CAP_{\text{rol}}, \forall r \in R, \forall t \in T, \forall l \in L \] (12)

\[ \sum_{w \in W} \sum_{r \in R} \sum_{s \in S} FWR_{\text{rip}, r} \leq \sum_{r \in R} CAP_{\text{rol}}, \forall r \in R, \forall t \in T, \forall l \in L \] (13)

\[ \sum_{w \in W} \sum_{r \in R} \sum_{i \in I} FWR_{\text{rid}, r} + \sum_{i \in I} FIO_{\text{irtl}} \leq \sum_{s \in S} CAP_{\text{rol}}, \forall r \in R, \forall t \in T, \forall l \in L \] (14)

\[ \sum_{w \in W} QWR_{\text{rsl}} \leq \sum_{s \in S} CAP_{\text{rsl}}, \forall r \in R, \forall t \in T, \forall l \in L \] (15)
\[\text{FWROPR}_\text{wrtl} \leq M \times XWPR_w, \forall w \in W, \forall r \in R, \forall t \in T, \forall l \in L\] (18)

\[\sum_{r \in L} \text{FIOR}_\text{rirl} \leq QIOR_\text{rl} \times XIR_r, \forall i \in I, \forall r \in R, \forall t \in T, \forall l \in L\] (19)

with

\[QIOR_\text{rl} = \sum_{r \in R} \left[\frac{\text{FWROPR}_\text{wrtl} \times \left(1 - XPR_w\right)}{XWI_{wi}}\right], \forall i \in I, \forall t \in T, \forall l \in L\]

Constraints of market locations for the distribution of recovered products:

\[\sum_{w \in W} \sum_{r \in R} \sum_{l \in L} \text{FPOPR}_\text{wrpl} \leq M \times XDP_{cpl}, \forall c \in C, \forall p \in P, \forall t \in T, \forall l \in L\] (20)

with

\[\sum_{c \in C} \sum_{l \in L} \text{FPOPR}_\text{wrpl} = \text{FWROPR}_\text{wrtl} \times XPR_w \times XPRP_{wp}, \forall w \in W, \forall r \in R, \forall p \in P, \forall t \in T, \forall l \in L\]

\[\sum_{w \in W} \sum_{r \in R} \sum_{l \in L} \text{FPODR}_\text{wrpl} \leq M \times XDP_{cpl}, \forall c \in C, \forall p \in P, \forall t \in T, \forall l \in L\] (21)

with

\[\sum_{c \in C} \sum_{l \in L} \text{FPODR}_\text{wrpl} = \frac{\text{FWRODR}_\text{wrtl} \times WRPR_{pw}}{100}, \forall w \in W, \forall r \in R, \forall p \in P, \forall t \in T, \forall l \in L\]

\[\sum_{i \in I} \sum_{r \in R} \sum_{l \in L} \text{FPOIR}_\text{rirp} \leq M \times XDP_{cpl}, \forall c \in C, \forall p \in P, \forall t \in T, \forall l \in L\] (22)

with

\[\sum_{c \in C} \sum_{l \in L} \text{FPOIR}_\text{rirp} = \sum_{r \in R} \text{FIOR}_\text{rl} \times RI_{rpi}/100, \forall i \in I, \forall r \in R, \forall p \in P, \forall t \in T, \forall l \in L\]

Constraints of minimum quality for acceptability in each market for recovered products from recycling techniques:

\[\text{FPODR}_\text{wrpl} \times QLRPW_{wp} \geq \text{FPODR}_\text{wrpl} \times CQL_{cp}, \forall w \in W, \forall r \in R, \forall p \in P, \forall c \in C, \forall t \in T, \forall l, l' \in L\] (23)

\[\text{FPOIR}_\text{rirp} \times QLRPI_{rp} \geq \text{FPOIR}_\text{rirp} \times CQL_{cp}, \forall i \in I, \forall r \in R, \forall p \in P, \forall c \in C, \forall t \in T, \forall l, l' \in L\] (24)


\[
FPOP_{\text{wrptll}} \times QLPRP_{\text{wp}} \geq FPOP_{\text{wrptll}} \times CQL_{cp}
\]
\[\forall w \in W, \forall r \in R, \forall p \in P, \forall c \in C, \forall t \in T, \forall l, \forall l' \in L\]  

(25)

### Flows of wastes/recovered products in the deployed recovery sites:

#### Constraints of recycling techniques and waste types:

\[
FWRIRD_{\text{wrtl}} \leq M \times XWR_{wr}, \forall w \in W, \forall r \in R, \forall t \in T, \forall l \in L
\]

(26)

\[
FWRIPR_{\text{wrtl}} \leq M \times XWP_{rpw}, \forall w \in W, \forall r \in R, \forall t \in T, \forall l \in L
\]

(27)

\[
\sum_{l \in L} FIIR_{\text{rtl}} \leq QIIR_{\text{rtl}} \times XIR_{rl}, \forall i \in I, \forall r \in R, \forall t \in T, \forall l \in L
\]

(28)

**with**

\[
QIIR_{\text{rtl}} = \sum_{w \in W} \sum_{r \in R} [FWRIPR_{\text{wrtl}} \times (1 - XPR_{w})] \times XWL_{wi}, \forall i \in I, \forall t \in T, \forall l \in L
\]

#### Constraints of market locations for the distribution of recovered products:

\[
\sum_{w \in W} \sum_{r \in R} \sum_{l \in L} FPIPR_{\text{wrptll}} \leq M \times XDP_{cp}, \forall c \in C, \forall p \in P, \forall t \in T, \forall l' \in L
\]

(29)

**with**

\[
\sum_{c \in C} \sum_{l' \in L} FPIPR_{\text{wrptll}} = FWRIPR_{\text{wrtl}} \times XPR_{w} \times XPRP_{wp},
\]
\[\forall w \in W, \forall r \in R, \forall p \in P, \forall t \in T, \forall l \in L\]

\[
\sum_{w \in W} \sum_{r \in R} \sum_{l \in L} FPIDR_{\text{wrptll}} \leq M \times XDP_{cp}, \forall c \in C, \forall p \in P, \forall t \in T, \forall l' \in L
\]

(30)

**with**

\[
\sum_{c \in C} \sum_{l' \in L} FPIDR_{\text{wrptll}} = FWRIRD_{\text{wrtl}} \times RWPR_{rpw} \div 100,
\]
\[\forall w \in W, \forall r \in R, \forall p \in P, \forall t \in T, \forall l \in L\]

\[
\sum_{l \in L} \sum_{r \in R} FPIIR_{\text{rptll}} \leq M \times XDP_{cp}, \forall c \in C, \forall p \in P, \forall t \in T, \forall l' \in L
\]

(31)

**with**

\[
\sum_{c \in C} \sum_{l' \in L} FPIIR_{\text{rptll}} = \sum_{l \in L} FIIR_{\text{rtl}} \times RIRP_{rpl} / 100,
\]
\[\forall i \in I, \forall r \in R, \forall p \in P, \forall t \in T, \forall l \in L\]
Constraints of minimum quality for acceptability in each market for recovered products from recycling techniques:

\[
\begin{align*}
FPIDR_{w, r, p, c, t, l} \times QLRP_{w} & \geq FPIDR_{w, r, p, c, t, l} \times CQL_{c, r, p, c, c, r, c, t, c, t, c, l, l, l} \\
FPIDR_{i, r, p, c, t, l} \times QLRP_{i, r, p, c, t, l} & \geq FPIDR_{i, r, p, c, t, l} \times CQL_{c, r, p, c, c, r, c, t, c, t, c, l, l, l} \\
FPIDR_{w, r, p, c, t, l} \times QLRP_{w} & \geq FPIDR_{w, r, p, c, t, l} \times CQL_{c, r, p, c, c, r, c, t, c, t, c, l, l, l}
\end{align*}
\]  

(32)

(33)

(34)

2.6. Objective functions

2.6.1. Minimisation of total cost (COST)

The total cost of the system (COST) depends on the investment cost for new recycling sites and on all the costs of the system activities Eq. (35). In each period, the investment cost (CINVT) is calculated by Eq. (36). Besides the costs of transportation, operation and distribution of recovered products, labour and maintenance costs of deployed sites are included in the cost of activities per year (CACT). Its components are presented in detail in Eq. (37)

\[
COST = \sum_{t \in T} CINVT_t + \sum_{t \in T} CACT_t
\]  

(35)

\[
CINVT_t = \sum_{r \in R} \sum_{s \in S} \sum_{l \in L} (INV_{r, s, l} \times YRSTL_{r, s, l, t}) \quad \forall t \in T
\]  

(36)

\[
CACT_t = + \left[ \sum_{r \in R} \sum_{s \in S} \sum_{l \in L} (OCOST_{r, s, l} \times YRSTL_{r, s, l, t}) \right] + (Other \ costs(labour, \ maintenance...))
\]  

(37)

\[
YRSTL_{r, s, l, t} = \sum_{l' = 0}^{l-1} YRSTL_{r, s, l, l'}
\]

\[
YRSTL_{r, s, l, 0} = 0
\]

\[
\forall r \in R, \forall s \in S, \forall l \in L, \forall t, t' \in T
\]

with

\[
+ \left[ \sum_{w \in W} \sum_{e \in E} \sum_{l \in L} (FWNR_{w, e, l} \times PN_{w, e}) \right] + (Cost \ of \ Non \ recovery \ pathways)
\]

\[
+ \left\{ \sum_{w \in W} \sum_{l \in L} \sum_{t \in T} \sum_{l' \in L} \left[ (FWRO_{w, r, t, l} + FWRI_{w, r, t, l}) \times PTR_{w, r, t, l} \right] \times DIST_{l,l'} \right\} + (Transport \ cost)
\]
\[
\text{Compression cost} = \sum_{w \in W} \sum_{r_i \in R} \sum_{l \in L} \left( \left( \text{FWRO}_{\text{wrtl}} + \text{FWR}_{\text{wrtl}} + \text{FIOR}_{\text{irtl}} + \text{FIIR}_{\text{irtl}} \right) \times \text{XTR}_{\text{ltl}} \times \text{PCOM} \right) + \text{(Pretreatment cost)}
\]

\[
\text{Cost of recycling process} = \sum_{w \in W} \sum_{r_i \in R} \sum_{l \in L} \left( \left( \sum_{r \in R} \left( \text{FWRO}_{\text{drwl}} + \text{FWR}_{\text{drwl}} \right) \times \text{PWR}_{\text{rw}} \right) + \sum_{i \in I} \left( \text{FIOR}_{\text{irtl}} + \text{FIIR}_{\text{irtl}} \right) \times \text{PIR}_{\text{rl}} \right) + \text{(Cost of pretreatment)}
\]

\[
\text{Cost of distribution of recovered product} = \sum_{w \in W} \sum_{r \in R} \sum_{l \in L} \left( \text{QWRS}_{\text{wrtl}} \times \text{PST}_{Ww} \right) + \text{(Cost of storage)}
\]

See Tables 3 and 4 for the related costs.

### 2.6.2. Maximisation of Net Present Value

The Net Present Value is maximised at the end of the project, i.e. the end of the 20th year \( (\text{NPV}) \) Eq. (38). The Net Present Value for each year in the horizon time \( (\text{NPVT}_{st}) \) Eq. (39) is calculated by the revenue before tax \( (\text{RBT}_{st}) \) expressed by Eq. (41), a tax rate \( (\alpha) \) and a discount rate \( (\beta) \). In function of the profitability at each year, the revenue can be taxed Eq. (39) or not Eq. (40), i.e. if recycling activities generate revenue (positive profit), they have to pay tax; if they have no revenue, no tax is imposed.

As the imposed lifespan of a new recycling site is 10 years, the depreciation cost \( (\text{DEP}_t) \) is calculated by equations Eq. (42). The profits from recovered products \( (\text{REVT}_t) \) are presented in detail in Eq. (43).

\[
\text{NPV} = \text{NPVT}_{st=20}
\]

\[
\text{NPVT}_t = \sum_{t=0}^{T} \frac{\text{RBT}_{st} \times (1 - \alpha) + \text{DEP}_{st} - \text{CACT}_{st}}{(1 + \beta)^t}, \quad \forall t \in T, \text{ if } \text{RBT}_{st} \geq 0
\]

\[
\text{NPVT}_t = \sum_{t=0}^{T} \frac{\text{RBT}_{st} + \text{DEP}_{st} - \text{CACT}_{st}}{(1 + \beta)^t}, \quad \forall t \in T, \text{ if } \text{RBT}_{st} < 0
\]

\[
\text{RBT}_{st} = \text{REVT}_t - \text{CACT}_t - \text{DEP}_t
\]
\[ \text{DEP}_{t=0} = 0 \]
\[ \text{DEP}_{1 \leq t \leq 10} = \sum_{t=0}^{t-1} \frac{\text{CINV}_t}{10} \]
\[ \text{DEP}_{11 \leq t \leq 20} = \sum_{t=0}^{t-11} \frac{\text{CINV}_t}{10} - \sum_{t=0}^{t-11} \frac{\text{CINV}_t}{10} \]

\[ \text{REV}_t = \left\{ \sum_{w \in \text{WR}} \sum_{r \in \text{RP}} \sum_{p \in \text{PC}} \sum_{e \in \text{EL}} \left[ \left( \text{FPOD}_{\text{wrpctl}} + \text{FPI}_{\text{wrpctl}} \right) \times PP_p \times \text{QLRPW}_{\text{wp}} / 100 \right] \right\} \]
\[ + \left\{ \sum_{i \in \text{IR}} \sum_{r \in \text{RP}} \sum_{p \in \text{PC}} \sum_{e \in \text{EL}} \left[ \left( \text{FPOI}_{\text{irpctl}} + \text{FPII}_{\text{irpctl}} \right) \times PP_p \times \text{QLRPI}_{\text{irp}} / 100 \right] \right\} + \text{(revenue from recovered products from directed recycling)} \]
\[ + \left\{ \sum_{w \in \text{WR}} \sum_{r \in \text{RP}} \sum_{p \in \text{PC}} \sum_{e \in \text{EL}} \left[ \left( \text{FPOPR}_{\text{wrpctl}} + \text{FPIPR}_{\text{wrpctl}} \right) \times PP_p \times \text{QLPRP}_{\text{wp}} / 100 \right] \right\} + \text{(revenue from recovered products through intermediate step)} \]
\[ + \left\{ \sum_{w \in \text{WE}} \sum_{e \in \text{EL}} \left( \text{FWNR}_{\text{wetl}} \times \text{RNR}_e \right) \right\} \text{(revenue from non recovery pathways)} \]

### 2.6.3. Minimisation of GWP impact (GWP)

The GWP impact of the system is evaluated from Simapro v7.3 [3] with ReCiPe Midpoint (H) v.1.06 [4] assessment method and collected from literature and can be computed by Eq. (44) as follows:

\[ \text{GWP} = \left\{ \sum_{w \in \text{WE}} \sum_{e \in \text{EL}} \left( \text{FWNR}_{\text{wetl}} \times \text{GWP}_{\text{RNU}_e} \right) \right\} + \text{(Non recovery activities impacts)} \]
\[ + \left\{ \sum_{i \in \text{IR}} \left\{ \sum_{r \in \text{RP}} \sum_{p \in \text{PC}} \sum_{e \in \text{EL}} \left( \text{FWRO}_{\text{wrtl}} + \text{FWRI}_{\text{wrtl}} + \text{FIOR}_{\text{irtl}} + \text{FIIR}_{\text{irtl}} \right) \times \text{DIST}_{\text{it}} \times \text{GWPR}_{\text{ru}} \right\} \right\} \]
\[ + \text{(Transport impacts)} \]
For transportation, the geographic unit of the model is based on a regional grid. The distance between the regions corresponds to the average distance between their two prefectures (Table 2). The model does not consider the intra-mobility in each region. Although each waste type is generated by specific plants, e.g. end-of-life waste from aircraft dismantling site, uncured waste from prepreg/composite production plants, etc., the collection of all waste type in each region is not considered in the model and all of waste in each region is assumed to be available at the same location, i.e. its prefecture. In the same way, the transportation of waste from source to treatment plant and the distribution of the recovered product to market at the same region are not considered in the model.

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Conflict of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.
References

[1] P.A. Vo Dong, C. Azzaro-Pantel, Boix, Anh Vo Dong, Catherine Azzaro-Pantel, Marianne Boix, A multi-period optimisation approach for deployment and optimal design of an aerospace CFRP waste management supply chain, Waste Manag. 95 (2019) 201–216, https://doi.org/10.1016/j.wasman.2019.05.002. ISSN 0956–053X.

[2] P.A. Vo Dong, C. Azzaro-Pantel, M. Boix, L. Jacquemin, A.-L. Cadène, A bicriteria optimisation approach for waste management of carbon fibre reinforced polymers used in aerospace applications: application to the case study of France, Waste Biomass Valorization (2016) 1–22, https://doi.org/10.1007/s12649-016-9669-z.

[3] Simapro v7.3, https://simapro.com. Product of Pré Consultants (Accessed 22 November 2019).

[4] M. Goedkoop, R. Heijungs, M. Huijbregts, A. De Schryver, J. Struijs, R. van Zelm, ReCiPe 2008 A Life Cycle Impact Assessment Method Which Comprises Harmonised Category Indicators at the Midpoint and the Endpoint Level, 2009.

[5] Eurostat, Energy price statistics [WWW Document]. URL http://ec.europa.eu/eurostat/statistics-explained/index.php/Energy_price_statistics (Accessed 22 November 2019).

[6] C.C. Knight, Recycling High-Performance Carbon Fiber Reinforced Polymer Composites Using Sub-critical and Supercritical Water, Ph.D.-The Florida State University, 2013, ISBN 9781303433146. Publication Number: AAT 3596525.

[7] ICIS, https://www.icis.com/explore/services/market-intelligence/price-reports/?intcmp=mega-menu-explore-services-market-intelligence-price-reports (Accessed 22 November 2019).

[8] S. Das, Life cycle assessment of carbon fiber-reinforced polymer composites, Int. J. Life Cycle Assess. 16 (2011) 268–282, https://doi.org/10.1007/s11367-011-0264-z.

[9] G. Dupupet, Fibres de carbone. Tech. Ing. Gd. Évén. Année base documentaire , 2008, p. 42625210.

[10] D. Kellenberger, H.-J. Althaus, N. Jungbluth, T. Künniger, M. Lehmann, P. Thalmann, Life cycle inventories of building products, Final Rep. Ecoinvent Data (2007) 7. V2 0.

[11] S. Job, Recycling glass fibre reinforced composites — history and progress, Reinf. Plast. 57 (2013) 19–23, https://doi.org/10.1016/S0034-3617(13)70151-6.

[12] C. Fischer, M. Lehner, D. Lindsay Mckinnon, Overview of the Use of Landfill Taxes in Europe, European Topic Centre on Sustainable Consumption and Production, 2012 (ETC/SCP Working Paper 1/2012).

[13] S. Halliwell, End of Life Options for Composite Waste—Recycle, Reuse or Dispose, National Composite Network Best Practice Guide, 2006.

[14] P. Krawczak, Recyclage des composites. Tech. Ing. Plasturgie Procédés Spécifiques Aux Compos. base documentaire : TIB474DUO, in: https://www.techniques-ingenieur.fr/base-documentaire/materiaux-th11/plasturgie-procedes-specifiques-aux-composites-42474210/recyclage-des-composites-am5895/, 2011.

[15] T.J. Appleton, R.I. Colder, S.W. Kingman, I.S. Lowndes, A.G. Read, Microwave technology for energy-efficient processing of waste, Appl. Energy 81 (2005) 85–113, https://doi.org/10.1016/j.apenergy.2004.07.002.