Model documentation.

Variable/Parameter	Value	Units	Reference
Accumulation 2020-2050	IF THEN ELSE(Time>=2019, IF THEN ELSE(Time<=2050, Yearly GWP-Yearly GWP primary import	Tonnes CO_2/year	
Accumulating GWP	IF THEN ELSE(Time>=2019, IF THEN ELSE(Time<=2050, Yearly GWP , 0) , 0)	Tonnes CO_2/year	
AL usage rate per square meter (residential Bldg.)	$5*10^{-6}$	Dmnl	TUD & CBS study experts
Alumina	1.908	Tonnes	European Aluminium (2017)
Alumina inventory	Integ(Yearly alumina production-Alumina needed for primary, LEADTIME TO RECEIVE ORDERED ALUMINA*Yearly alumina production)	Tonnes	
Aluminum Ore	1	Dmnl	Environmental Profile Report from European Aluminium (2017)
Annual average price of imported primary Al	Annual average price of Primary Al*(1+"Tax percentage for importing carbon-intensive aluminum")	USD/Tonnes	
Annual average price of Post-consumer scrap	500	USD/Tonnes	
Annual average price of Pre-consumer scrap	700	USD/Tonnes	H&S Metals (n.a.)
Annual forecasted demand of Alumina	(Annual forecasted demand of primary AL-yearly Primary AL import)*ALUMINA	Tonnes/year	
Annual forecasted demand of Bauxite	Annual forecasted demand of Alumina*BAUXITE	Tonnes/year	
Annual forecasted demand of Ingot AL	MAX(("Annual forecasted demand of Rolled Al (Market)"*INGOT AL)-("yearly Ingot AL production rate from Post-consumer scrap" +"yearly Ingot AL production rate from Pre-consumer scrap"),0)	Tonnes/year	
Annual forecasted demand of primary AL	MAX(Annual forecasted demand of Ingot AL*PRIMARY AL,0)	Tonnes/year	
Annual forecasted demand of Rolled Al (Market)	Total demand of Rolled Al	Tonnes/year	

Annual revenue (Rolled Al)	"Annual revenue from high-carbon products (Rolled Al)"+"Annual revenue from low-carbon products (Rolled Al)"	USD/year	
"Annual revenue from high-carbon products (Rolled Al)"	"Yearly High-carbon Rolled Al production"*"Average annual price (Rolled AL)"	USD/year	
"Annual revenue from low-carbon products (Rolled Al)"	"Yearly Low-carbon Rolled Al production"*"Average annual price (Rolled AL)"	USD/year	
Annual average price of Primary Al	1060	USD/Tonne	EAA expert on economics
Availability of low-carbon aluminum RP outside Europe for import	IF THEN ELSE("European aluminum competitors' behavior to produce low-carbon Al"=1, "Production of low-carbon AL outside Europe (steady increase)" , IF THEN ELSE ("European aluminum competitors' behavior to produce low-carbon Al"=2, "Production of low-carbon AL outside Europe (slow increase)" (Time) , IF THEN ELSE("European aluminum competitors' behavior to produce low-carbon Al" =0, "Production of low-carbon AL outside Europe (Constant)" ,"Production of low-carbon AL outside Europe (fast increase) (Time))))	Dmnl	
"Average Al used per square meter (non-residential)"	INTEG ("AL usage rate per square meter (non-residential Bldg.)", 0.0033)	Tonnes/Square meters	
"Average Al used per square meter (residential)"	INTEG ("AL usage rate per square meter (residential Bldg.)", 1e-05)	Tonnes/Square meters	
Average annual price (Rolled AL)	1530	USD/Tonnes	EAA expert on economics
Average lifespand of aluminum (Automotive Ind.)	12	year	ACEA (2023)
Average lifespan of aluminum (Construction Ind.)	60	Year	European Aluminium (2018b)
Average lifespan of aluminum (Other Ind.)	20+STEP(1,10)	Year	European Aluminium (2018b)

Average lifespan of aluminum (Packaging Ind.)	1+STEP(1,10_	Year	European Aluminium (2018b)
Average renovation rate in the EU (Non-residential Bldgs)	INTEG("yearly renovation rate (non-residential Bldgs)", 0.0074)	Dmnl	
Average weight of AL in a new car	INTEG(yearly increase rate of AL in car, 0.095)	Tonnes/cars	DuckerFrontier (2019)
Carrying Capacity (Bldg & Const)	98	Square meters/People	
Carrying Capacity (Packaging)	80	Square meters/People	
Consumer usage of AL packages	INTEG(0+STEP (Consumer usage rate of Al packages, 2020),1)	Dmnl	
Convert MJ to KWH	0.278	kWh/MJ	
Cost of imported primary AL (rolled AL)	Annual average price of imported primary Al*yearly Primary AL import	USD/year	
Cost of other primary AL (rolled Al)	(Yearly rolled AL production-("yearly Ingot AL production rate from Post-consumer scrap",0)	MEUR	
Cumulative investment primary 2021-2030	195+1535+25+15	MEUR	Le Den et al., (2023)
Cumulative investment primary 2031-2040	500+19480+215+115	MEUR	Le Den et al., (2023)
Cumulative investment primary 2041-2050	110+8200+15+10	MEUR	Le Den et al., (2023)
Cumulative investment refining	INTEG(incoming investment refining,0)	MEUR	
Cumulative investment refining 2021-2030	55	MEUR	Le Den et al., (2023)
Cumulative investment refining 2031-2040	500	MEUR	Le Den et al., (2023)
Cumulative investment refining 2041-2050	115	MEUR	Le Den et al., (2023)
Cumulative investment remelting	INTEG(incoming investment remelting,0)	MEUR	
Cumulative investment remelting 2021-2030	110	MEUR	Le Den et al., (2023)
Cumulative investment remelting 2031-2040	1035	MEUR	Le Den et al., (2023)
Cumulative investment remelting 2041-2050	230	MEUR	Le Den et al., (2023)
Cumulative investment sheet	INTEG(incoming investment sheet, 0)	MEUR	
Cumulative investment sheet 2021-2030	30	MEUR	Le Den et al., (2023)
Cumulative investment sheet 2031-2040	300	MEUR	Le Den et al., (2023)

Cumulative investment sheet 2041-2050	15	MEUR	Le Den et al., (2023)
Customers' behavior on requesting low carbon Al	1	Dmnl	
Decision investment method primary aluminum	0	Dmnl	1- constant, 2 – slow, 3- fast
Decision investment refining	0	Dmnl	1- constant, 2 – slow, 3- fast
Decision investment remelting	0	Dmnl	1- constant, 2 – slow, 3- fast
Decision investment sheet	0	Dmnl	1- constant, 2 – slow, 3- fast
Decision on the substitution trend	1	Dmnl	1- No, 2 – slow, 3 - fast
Demand for rolled AL in Auto industry	(New cars*Average weight of AL in a new car)	Tonnes/Year	
Demand for Rolled AL in Const Ind.	Demand for Rolled AL in non-residential Bldgs + demand fro Rolled AL in residential Bldgs	Tonnes/year	
Demand for Rolled AL in non-residential Bldgs	("newly built floor space (non-residential Bldgs)"+"Renovated floor space (non-residential Bldgs)")*"Average Al used per square meter (non-residential)"	Tonnes/year	
Demand for Rolled AL in other Inds.	1.095*10^6*(1+"Yearly Rolled Al demand (Other Ind.)")	Tonnes/year	IAI (2020a)
Demand for Rolled AL in Packaging Ind.	Average weight of square meter of Al package*newly built Al packages*Consumer usage of Al packages	Tonnes/year	
Demand for Rolled AL in residential Bldgs	("newly built floor space (residential Bldgs)"+"Renovated floor space (residential Bldgs)")*"Average Al used per square meter (residential)"	Tonnes/year	
Demand growth rate (Other Ind.)	(0.038)+STEP(0.03,2020)	Tonnes/year/year	IAI (2020a)
Demolished Al packages	Yearly Al package stock difference/"Average lifespan of aluminum (Packaging Ind.)"	Square meters/year	
Demolished floor space=	Yearly floor space stock difference/"Average lifespan of aluminum (Construction Ind.)"	Square meters/year	

Discarded cars=	Yearly car stock difference/"Average lifespan of aluminum (Automotive Ind.)"	cars/year	
"Disposed Post-consumer scrap"=	"Post-consumer scrap inventory"*Fraction of disposed scrap	Tonnes/year	
EU Al packages stock	"EU stock per capita (square meter of Al packages)"*Population	Square meters	
EU building floor space stock	EU Building floor space stock per capita*Population	Square meters	
EU Building floor space stock per capita= INTEG (	"Net increase (Bldg & Const)", 41)	Square meters/People	
EU GDP	INTEG(EU GDP * GDP increase rate+STEP(0.0016,2020))*0.87, 21420)	EUR/year	
EU passenger car stock	EU passenger car stock per capita*Population	Cars	
EU passenger car stock per capita	INTEG(Net increase, 0.5562)	Cars/people	Statista (2020)
EU stock per capita (square meter of Al packages)	INTEG(Net increase (Packaging),19)	Square meters/People	
European aluminum competitors' behavior to produce low-carbon Al	1	Dmnl	0- constant, 1 – steady, 2 - slow, 3 – fast
Final time	2050	year	The final time for the simulation.
Fraction of disposed scrap	0.37	1/year	IAI (2020a)
Fraction of low-carbon aluminum RP (SC level)	Reduction in emissions extrusion*Reduction in emissions primary aluminum* Reduction in emissions refining*Reduction in emissions remelting*Reduction in emissions sheet	Dmnl	
Fraction of Primary Al import	0.5	Dmnl	European Aluminium (2019b)
FRACTION OF RESIDENTIAL BUILDINGS	0.75	Dmnl	BPIE (2015)
FRACTION PRE-CONSUMER SCRAP (Auto Ind.)	0.15	Dmnl	IAI (2020a)
FRACTION PRE-CONSUMER SCRAP (Bldg & Const Ind.)	0.15	Dmnl	IAI (2020a)

FRACTION PRE-CONSUMER SCRAP (Other Ind.)	0.15	Dmnl	IAI (2020a)
FRACTION PRE-CONSUMER SCRAP (Packaging Ind.)	0.15	Dmnl	IAI (2020a)
GDP increase rate	0.0154	1/year	Eurostat (2020)
Gross profit (Rolled Al)	IF THEN ELSE(("Annual revenue (Rolled Al)"-"Total cost (Rolled AL)"<=0), 0, ("Annual revenue (Rolled Al)"-"Total cost (Rolled AL)"))*0.87	EUR/year	
Growth rate EU Al packages stock	Net increase (Packaging)*Population	Square meters/year	
Growth rate EU building floor space stock	Net increase (Bldg & Const) * Population	Square meters/year	
Growth rate EU car stock	Net increase * Population	Cars/year	
Growth rate slow investment extrusion 2021-2030	1.03	Dmnl	
Growth rate slow investment extrusion 2031-2040	1.11	Dmnl	
Growth rate slow investment extrusion 2041-2050	1.116	Dmnl	
Growth rate slow investment primary 2021-2030	1.2	Dmnl	
Growth rate slow investment primary 2031-2040	1.256	Dmnl	
Growth rate slow investment primary 2041-2050	1.239	Dmnl	
Growth rate slow investment refining 2021-2030	1.1	Dmnl	
Growth rate slow investment refining 2031-2040	1.175	Dmnl	
Growth rate slow investment refining 2041-2050	1.128	Dmnl	
Growth rate slow investment remelting 2021-2030	1.127	Dmnl	
Growth rate slow investment remelting 2031-2040	1.194	Dmnl	
Growth rate slow investment remelting 2041-2050	1.152	Dmnl	
Growth rate slow investment sheet 2021-2030	1.07	Dmnl	
Growth rate slow investment sheet 2031-2040	1.16	Dmnl	
Growth rate slow investment sheet 2041-2050	1.03	Dmnl	
GWP extrustion production	0.312	Tonnes CO_2/Tonnes	European Aluminium (2017)

GWP primary aluminum produced in Europe	1.192+3.628+0.281+0.15	Tonnes CO_2/Tonnes	European Aluminium (2017)
GWP primary aluminum used in Europe	8.32	Tonnes CO_2/Tonnes	European Aluminium (2017)
GWP refining production	0.343	Tonnes CO_2/Tonnes	European Aluminium (2017)
GWP remelting productin	0.273	Tonnes CO_2/Tonnes	European Aluminium (2017)
GWP rolling mill production	0.357	Tonnes CO_2/Tonnes	European Aluminium (2017)
Impact of substitution materials	1-(0.67*Substitution trend)	dmnl	low impact:0.33 high impact:0.67
Import of low-carbon Rolled Al	Required import fraction for low-carbon Al"*Total demand of Rolled Al	Tonnes/year	
Incoming investment extrusion	Investment extrusion	MEUR/year	
Incoming investment primary	Investment primary aluminum	MEUR/year	
Incoming investment refining	Inestment refining	MEUR/year	
Incoming investment remelting	Investment remelting	MEUR/year	
Incoming investment sheet	Investment sheet	MEUR/year	
Ingot AL	1	Tonnes	European Aluminium (2017)
Ingot AL inventory	INTEG((Yearly Ingot AL production+"yearly Ingot AL production rate from Pre-consumer scrap"+"yearly Ingot AL production rate from Post-consumer scrap"+yearly clean Internal scrap from Rolled AL production)-(Ingot needed for rolled (Yearly Ingot AL production+"yearly Ingot AL production rate from Pre-consumer scrap"+"yearly Ingot AL production rate from Post-consumer scrap" +yearly clean Internal scrap from Rolled AL production)*LEADTIME TO RECEIVE ORDERED INGOT AL)	Tonnes	
Ingot production capacity	$1.2*10^7$	Tonnes/year	
Ingot needed for rolled	MAX(Ingot AL inventory/LEADTIME TO RECEIVE ORDERED INGOT AL,0)	Tonnes/year	
Initial Time	1990	Year	The initial time for the simulation.
Interest rate	0.05	Dmnl	Pinto & Diemer (2020)

Internal Scrap (From rolled AL production)	1.019	Tonnes	European Aluminium (2017)
Internal scrap inventory	INTEG(yearly internal scrap during rolled al production – internal to ingot, 0)	Tonnes	
Internal to Ingot	Internal scrap inventory/LEADTIME TO RECEIVE ORDERED INGOT AL	Tonnes/year	
Inventory holding cost (rolled AL)	0.2*"Average annual price (Rolled AL)"	USD/Tonnes	
Investment extrusion	"Investment extrusion 2021-2030"+"Investment extrusion 2031-2040"+"Investment extrusion 2041-2050"	MEUR/year	
"Investment extrusion 2021-2030"=	IF THEN ELSE(Time>=2021, IF THEN ELSE(Time<=2030, IF THEN ELSE(Decision investment method extrusion=1, "Cumulative investment extrusion 2021-2030"/10 , IF THEN ELSE (Decision investment method extrusion=2, (("Cumulative investment extrusion 2021-2030" /10)/LOG("Cumulative investment extrusion 2021-2030" , 10))*"Growth rate slow investment extrusion 2021-2030"^(Time-2020), IF THEN ELSE (Decision investment method extrusion=3, ("Cumulative investment extrusion 2021-2030"/2.4*LN((Time-2020)+1))-("Cumulative investment extrusion 2021-2030"/2.4*LN ((Time-2020))) , 0))),0),0)	MEUR/year	
"Investment extrusion 2031-2040"=	IF THEN ELSE(Time>=2031, IF THEN ELSE(Time<=2040, IF THEN ELSE(Decision investment method extrusion=1, "Cumulative investment extrusion 2031-2040"/10 , IF THEN ELSE (Decision investment method extrusion=2, (("Cumulative investment extrusion 2031-2040"	MEUR/year	

	/10)/LOG("Cumulative investment extrusion 2031-2040" , 10))*"Growth rate slow investment extrusion 2031-2040"^(Time-2030), IF THEN ELSE (Decision investment method extrusion=3, ("Cumulative investment extrusion 2031-2040" /2.4*LN((Time-2030)+1))-("Cumulative investment extrusion 2031-2040"/2.4*LN((Time-2030))) , 0))), 0), 0)	
"Investment extrusion 2041-2050"=	IF THEN ELSE(Time>=2041, IF THEN ELSE(Time<=2050, IF THEN ELSE(Decision investment method extrusion =1, "Cumulative investment extrusion 2041-2050"/10 , IF THEN ELSE (Decision investment method extrusion=2, (("Cumulative investment extrusion 2041-2050" /10)/LOG("Cumulative investment extrusion 2041-2050" , 10))*"Growth rate slow investment extrusion 2041-2050"^(Time-2040), IF THEN ELSE (Decision investment method extrusion=3, ("Cumulative investment extrusion 2041-2050" /2.4*LN((Time-2040)+1))-("Cumulative investment extrusion 2041-2050"/2.4*LN ((Time-2040))) , 0))), 0), 0)	MEUR/year
Investment Primary aluminum	"Investment primary aluminum 2021-2030"+"Investment primary aluminum 2031-2040" +"Investment primary aluminum 2041-2050"	MEUR/year
"Investment primary aluminum 2021-2030"	IF THEN ELSE(Time>=2021, IF THEN ELSE(Time<=2030, IF THEN ELSE(Decision investment method primary aluminum =1, "Cumulative investment	MEUR/year

	primary 2021-2030"/10 , IF THEN ELSE (Decision investment method primary aluminum=2, (("Cumulative investment primary 2021-2030" /10)/LOG("Cumulative investment primary 2021-2030", 10))*"Growth rate slow investment primary 2021-2030"^(Time-2020), IF THEN ELSE (Decision investment method primary aluminum=3, ("Cumulative investment primary 2021-2030" /2.4*LN((Time-2020)+1))-("Cumulative investment primary 2021-2030"/2.4*LN((Time-2020))) , 0))),0),0)	
"Investment primary aluminum 2031-2040"	IF THEN ELSE(Time>=2031, IF THEN ELSE(Time<=2040, IF THEN ELSE(Decision investment method primary aluminum =1, "Cumulative investment primary 2031-2040"/10 , IF THEN ELSE (Decision investment method primary aluminum=2, (("Cumulative investment primary 2031-2040" /10)/LOG("Cumulative investment primary 2031-2040", 10))*"Growth rate slow investment primary 2031-2040"^(Time-2030), IF THEN ELSE (Decision investment method primary aluminum=3, ("Cumulative investment primary 2031-2040" /2.4*LN((Time-2030)+1))-("Cumulative investment primary 2031-2040"/2.4*LN((Time-2030))) , 0))), 0), 0)	MEUR/year
"Investment primary aluminum 2041-2050"	IF THEN ELSE(Time>=2041, IF THEN ELSE(Time<=2050, IF THEN ELSE(Decision investment method primary aluminum =1,	MEUR/year

	"Cumulative investment primary 2041-2050"/10 , IF THEN ELSE (Decision investment method primary aluminum=2, (("Cumulative investment primary 2041-2050" /10)/LOG("Cumulative investment primary 2041-2050" , 10))*"Growth rate slow investment primary 2041-2050"^(Time-2040), IF THEN ELSE (Decision investment method primary aluminum=3, ("Cumulative investment primary 2041-2050" /2.4*LN((Time-2040)+1))-("Cumulative investment primary 2041-2050"/2.4*LN((Time-2040))) , 0))), 0), 0)	
Investment refining	"Investment refining 2021-2030"+"Investment refining 2031-2040"+"Investment refining 2041-2050"	MEUR/year
Investment refining 2021-2030	IF THEN ELSE(Time>=2021, IF THEN ELSE(Time<=2030, IF THEN ELSE(Decision investment method refining =1, "Cumulative investment refining 2021-2030"/10 , IF THEN ELSE (Decision investment method refining=2, (("Cumulative investment refining 2021-2030" /10)/LOG("Cumulative investment refining 2021-2030", 10))*"Growth rate slow investment refining 2021-2030"^(Time-2020), IF THEN ELSE (Decision investment method refining=3, ("Cumulative investment refining 2021-2030" /2.4*LN((Time-2020)+1))-("Cumulative investment refining 2021-2030"/2.4*LN ((Time-2020))) , 0))),0),0)	

Investment refining 2031-2040	IF THEN ELSE(Time>=2031, IF THEN ELSE(Time<=2040, IF THEN ELSE(Decision investment method refining =1, "Cumulative investment refining 2031-2040"/10 , IF THEN ELSE (Decision investment method refining=2, (("Cumulative investment refining 2031-2040" /10)/LOG("Cumulative investment refining 2031-2040", 10))*"Growth rate slow investment refining 2031-2040"^(Time-2030), IF THEN ELSE (Decision investment method refining=3, ("Cumulative investment refining 2031-2040" /2.4*LN((Time-2030)+1))-("Cumulative investment refining 2031-2040"/2.4*LN ((Time-2030))) , 0))), 0), 0)	MEUR/year
Investment refining 2041-2050	IF THEN ELSE(Time>=2041, IF THEN ELSE(Time<=2050, IF THEN ELSE(Decision investment method refining =1, "Cumulative investment refining 2041-2050"/10 , IF THEN ELSE (Decision investment method refining=2, (("Cumulative investment refining 2041-2050" /10)/LOG("Cumulative investment refining 2041-2050", 10))*"Growth rate slow investment refining 2041-2050"^(Time-2040), IF THEN ELSE (Decision investment method refining=3, ("Cumulative investment refining 2041-2050" /2.4*LN((Time-2040)+1))-("Cumulative investment refining 2041-2050"/2.4*LN ((Time-2040))) , 0))), 0), 0)	MEUR/year

Investment remelting	"Investment remelting 2021-2030"+"Investment remelting 2031-2040"+"Investment remelting 2041-2050"	MEUR/year
Investment remelting 2021-2030	IF THEN ELSE(Time>=2021, IF THEN ELSE(Time<=2030, IF THEN ELSE(Decision investment method remelting =1, "Cumulative investment remelting 2021-2030"/10 , IF THEN ELSE (Decision investment method remelting=2, (("Cumulative investment remelting 2021-2030" /10)/LOG("Cumulative investment remelting 2021-2030", 10))*"Growth rate slow investment remelting 2021-2030"^(Time-2020), IF THEN ELSE (Decision investment method remelting=3, ("Cumulative investment remelting 2021-2030" /2.4*LN((Time-2020)+1))-("Cumulative investment remelting 2021-2030"/2.4*LN ((Time-2020))) , 0))),0),0)	MEUR/year
Investment remelting 2031-2040	IF THEN ELSE(Time>=2031, IF THEN ELSE(Time<=2040, IF THEN ELSE(Decision investment method remelting =1, "Cumulative investment remelting 2031-2040"/10 , IF THEN ELSE (Decision investment method remelting=2, (("Cumulative investment remelting 2031-2040" /10)/LOG("Cumulative investment remelting 2031-2040", 10))*"Growth rate slow investment remelting 2031-2040"^(Time-2030), IF THEN ELSE (Decision investment method remelting=3, ("Cumulative investment remelting 2031-	MEUR/year

	2040" /2.4*LN((Time-2030)+1))-("Cumulative investment remelting 2031-2040"/2.4*LN ((Time-2030))) , 0))), 0), 0)	
Investment remelting 2041-2050	IF THEN ELSE(Time>=2041, IF THEN ELSE(Time<=2050, IF THEN ELSE(Decision investment method remelting=1, "Cumulative investment remelting 2041-2050"/10 , IF THEN ELSE (Decision investment method remelting=2, (("Cumulative investment remelting 2041-2050" /10)/LOG("Cumulative investment remelting 2041-2050", 10))*"Growth rate slow investment remelting 2041-2050"^(Time-2040), IF THEN ELSE (Decision investment method remelting=3, ("Cumulative investment remelting 2041-2050" /2.4*LN((Time-2040)+1))-("Cumulative investment remelting 2041-2050"/2.4*LN ((Time-2040))) , 0))), 0), 0)	MEUR/year
Investment Sheet	"Investment sheet 2021-2030"+"Investment sheet 2031-2040"+"Investment sheet 2041-2050"	MEUR/year
Investment sheet 2021-2030	IF THEN ELSE(Time>=2021, IF THEN ELSE(Time<=2030, IF THEN ELSE(Decision investment method sheet=1, "Cumulative investment sheet 2021-2030"/10 , IF THEN ELSE (Decision investment method sheet=2, (("Cumulative investment sheet 2021-2030" /10)/LOG("Cumulative investment sheet 2021-2030", 10))*"Growth rate slow investment sheet 2021-2030"^(Time-2020), IF THEN ELSE (Decision investment method sheet=3,	MEUR/year

	("Cumulative investment sheet 2021-2030" /2.4*LN((Time-2020)+1))- ("Cumulative investment sheet 2021-2030"/2.4*LN((Time - 2020))) , 0))),0),0)	
Investment sheet 2031-2040	IF THEN ELSE(Time>=2031, IF THEN ELSE(Time<=2040, IF THEN ELSE(Decision investment method sheet=1, "Cumulative investment sheet 2031-2040"/10 , IF THEN ELSE (Decision investment method sheet=2, (("Cumulative investment sheet 2031-2040" /10)/LOG("Cumulative investment sheet 2031-2040", 10))*"Growth rate slow investment sheet 2031-2040"^(Time-2030), IF THEN ELSE (Decision investment method sheet=3, ("Cumulative investment sheet 2031-2040" /2.4*LN((Time-2030)+1))- ("Cumulative investment sheet 2031-2040"/2.4*LN((Time - 2030))) , 0))), 0), 0)	MEUR/year
Investment sheet 2041-2050	IF THEN ELSE(Time>=2041, IF THEN ELSE(Time<=2050, IF THEN ELSE(Decision investment method sheet=1, "Cumulative investment sheet 2041-2050"/10 , IF THEN ELSE (Decision investment method sheet=2, (("Cumulative investment sheet 2041-2050" /10)/LOG("Cumulative investment sheet 2041-2050", 10))*"Growth rate slow investment sheet 2041-2050"^(Time-2040), IF THEN ELSE (Decision investment method sheet=3, ("Cumulative investment sheet 2041-2050" /2.4*LN((Time-2040)+1))-	MEUR/year

	("Cumulative investment sheet 2041-2050"/2.4*LN((Time -2040))) , 0))), 0), 0)		
Labor cost	15	USD/Tonnes	Pinto & Diemer (2020)
Leadtime to receive ordered alumina	1	Year	
Leadtime to receive ordered bauxite	1	Year	
Leadtime to receive ordered Ingot AL	1	Year	
Leadtime to receive ordered Prim1ary AL	1	Year	
Net increase	EU passenger car stock per capita*Net increase fraction	Cars/People/year	
Net increase (Bldg & Const)	EU Building floor space stock per capita * Net increase fraction (Bldg & Const)	Square meters/People/year	
Net increase (Packaging)	EU stock per capita (square meter of Al packages)*Net increase fraction (Packaging)	Square meters/People/year	
Net increase fraction	GDP increase rate*(1-Resource adequacy	1/year	
Net increase fraction (Bldg & Const)	GDP increase rate*1-Resource adequacy(Bldg & Const)	1/year	
Net increase fraction (Packaging)	GDP increase rate*(1-"Resource adequacy (Packaging)")	1/year	
New cars	(Growth rate EU car stock+Discarded cars)*(1-"Car-sharing effect")	Cars/year	
newly built Al packages	growth rate EU Al packages stock+Demolished Al packages	Square meters/year	
newly built floor space	growth rate EU building floor space stock+Demolished floor space	Square meters/year	
newly built floor space (non-residential Bldgs)	(1-FRACTION OF RESIDENTIAL BUILDINGS)*newly built floor space	Square meters/year	
newly built floor space (residential Bldgs)	FRACTION OF RESIDENTIAL BUILDINGS*newly built floor space	Square meters/year	
Population	INTEG(yearly population increase rate, $2.393*10^8$)	People	Eurostat (2022)

Post to ingot	Post-consumer scrap inventory*(1-fraction of disposed scrap)	Tonnes/year	
Post-consumer scrap inventory	INTEG(Recyclability-"Disposed Post-consumer scrap"-Post to ingot,0)	Tonnes	
Post-Consumer scrap	1	Tonnes	European Aluminium (2017)
Pre-consumer scrap inventory	INTEG("yealy Pre-consumer scrap production (Bldg & Const Ind.)"+"yealy Pre-consumer scrap production (Other Inds.)" +"yealy Pre-consumer scrap production (Packaging Ind.)" +"yearly Pre-consumer scrap production (Auto Ind.)")-Pre to ingot,0)	Tonnes	
Primary AL	0.912	Tonnes	European Aluminium (2017)
Primary AL inventory	INTEG(Yearly Primary AL production-Primary needed for Ingot+yearly Primary AL import, Yearly Primary AL production*LEADTIME TO RECEIVE ORDERED PRIMARY AL)	Tonnes	
Primary needed for Ingot	MAX(Primary AL inventory/LEADTIME TO RECEIVE ORDERED PRIMARY AL,0)	Tonnes/year	
"Production of low-carbon AL outside Europe (Constant)"	0+STEP(0.1,2020)	Dmnl	
Production of low-carbon AL outside Europe (fast increase)	[(1990,0)-(2090,1)],(1990,0),(2020,0),(2023,0.3125),(2026,0.5),(2029,0.5975),(2032,0.685),(2035,0.75),(2038,0.8075),(2041,0.86),(2044,0.9125),(2047,0.9525),(2050,1),(2090,1))	Dmnl	
"Production of low-carbon AL outside Europe (slow increase)"	[(1990,0)-(2090,1)],(1990,0),(2020,0),(2025.47,0.0263158),(2029.14,0.0570176),(2031.59,0.0921053),(2034.95,0.157895),(2037.4,0.22807),(2039.24,0.302632),(2041.68,0.394737),(2044,0.5),(2047,0.6875),(2050,1),(2090,1))	Dmnl	

Production of low-carbon AL outside Europe (steady increase)	INTEG("Production rate of low-carbon AL outside Europe",0)	Tonnes	
Production rate of low-carbon AL outside Europe	0+STEP(0.0333, 2020)+STEP(-0.0333,2050)	Tonnes/year	
Recyclability	"RECYCLABILITY FRACTION (AUTOMOTIVE IND.)"*"yearly Post-consumer scrap production (Automotive Ind.)" +"RECYCLABILITY FRACTION (CONSTRUCTION IND.)"*"yearly Post-consumer scrap production (Construction Ind.)" "RECYCLABILITY FRACTION (AUTOMOTIVE IND.)"*"yearly Post-consumer scrap production (Automotive Ind.)" +"RECYCLABILITY FRACTION (CONSTRUCTION IND.)"*"yearly Post-consumer scrap production (Construction Ind.)"	Tonnes/year	
RECYCLABILITY FRACTION (AUTOMOTIVE IND.)	0.9	Dmnl	IAI experts
RECYCLABILITY FRACTION (CONSTRUCTION IND.)	0.9	Dmnl	IAI experts
RECYCLABILITY FRACTION (OTHER IND.)	0.5	Dmnl	IAI experts
RECYCLABILITY FRACTION (PACKAGING IND.)	0.7	Dmnl	IAI experts
Reduction in emissions extrusion	Cumulative investment extrusion/("Cumulative investment extrusion 2021-2030" +"Cumulative investment extrusion 2031-2040" +"Cumulative investment extrusion 2041-2050")*0.953	Dmnl	
Reduction in emissions primary aluminum	Cumulative investment primary/("Cumulative investment primary 2021-2030"+"Cumulative investment primary 2031-	Dmnl	

	2040" +"Cumulative investment primary 2041-2050")*0.95	
Reduction in emissions refining	Cumulative investment refining/("Cumulative investment refining 2021-2030"+"Cumulative investment refining 2031-2040"+"Cumulative investment refining 2041-2050")*0.937	Dmnl
Reduction in emissions remelting	Cumulative investment remelting/("Cumulative investment remelting 2021-2030" +"Cumulative investment remelting 2031-2040" +"Cumulative investment remelting 2041-2050")*0.935	Dmnl
Reduction in emissions sheet	Cumulative investment sheet/("Cumulative investment sheet 2021-2030"+"Cumulative investment sheet 2031-2040" +"Cumulative investment sheet 2041-2050")*0.953	Dmnl
Renovated floor space (non-residential Bldgs)	Average renovation rate in the EU (non-residential Bldgs)"*(Yearly floor space stock difference/Averge lifespan of renovated buildings)	Square meters/year
Renovated floor space (residential Bldgs)	"Averge renovation rate in the EU (residential Bldgs)"*(Yearly floor space stock difference /Averge lifespan of renovated buildings)	Square meters/year
Required import fraction for low-carbon Al	"Availability of low-carbon aluminum RP outside Europe for import"*"Required low-carbon Al by customers" *0	Dmnl
Required low-carbon AL by customers (fast increase)	[(1990,0)-(2090,1)],(1990,0),(2020,0),(2023,0.3125),(2026,0.5),(2029,0.5975),(2032,0.685),(2035,0.75),(2038,0.8075),(2041,0.86),(2044,0.9	Dmnl

	125),(2047,0.9525),(2050,1),(2090,1))	
"Required low-carbon AL by customers (slow increase)"	[(1990,0)-(2090,1)],(1990,0),(2020,0),(2023,0.0475),(2026,0.0875),(2029,0.14),(2032,0.1925),(2035,0.25),(2038,0.315),(2041,0.4025),(2044,0.5),(2047,0.6875),(2050,1),(2090,1))	Dmnl
Required low-carbon Al by customers (steady increase)	INTEG(Required low-carbon Al rate,0)	Dmnl
Required low-carbon Al by customers	IF THEN ELSE("Customers' behavior on requesting low-carbon Al"=1, "Required low-carbon Al by customers (steady increase)" , IF THEN ELSE("Customers' behavior on requesting low-carbon Al"=2, "Required low-carbon AL by customers (slow increase)" (Time) , "Required low-carbon AL by customers (fast increase)"(Time)))	Dmnl
Required low-carbon Al rate	Required low-carbon Al by customers"*Total demand of Rolled Al	Tonnes/year
Resource adequacy	EU passenger car stock per capita/Carrying capacity	Dmnl
Resource adequacy (Bldg & Const)	EU Building floor space stock per capita/"Carrying capacity (Bldg & Const)"	Dmnl
Resource adequacy (Packaging)	"EU stock per capita (square meter of Al packages)"/"Carying capacity (Packaging)"	Dmnl
Rolled AL inventory	INTEG((Yearly rolled AL production)-(Rolled needed for product), 60041)	Tonnes
Rolled AL inventory (Bldg & Const Ind.)	INTEG("Yearly Rolled AL usage (Bldg and const Ind)"-"yearly Post-consumer scrap production (Construction Ind.)", "Yearly Rolled AL usage (Bldg and const Ind)")	Tonnes
Rolled AL inventory (Other Inds.)	INTEG("Yearly Rolled AL usage (Other Ind)"-"yearly Post-consumer scrap production (Other Ind.)",	Tonnes

	"Yearly Rolled AL usage (Other Ind)")	
Rolled AL inventory (Packaging Ind.)	INTEG("Yearly Rolled AL usage (Packaging Ind)"-"yearly Post-consumer scrap production (Packaging Ind.)", "Yearly Rolled AL usage (Packaging Ind)")	Tonnes
Rolled AL inventory in Auto Ind.	INTEG("Yearly Rolled AL usage (Auto Ind)"-"yearly Post-consumer scrap production (Automotive Ind.)", "Yearly Rolled AL usage (Auto Ind)")	Tonnes
Rolled needed for product	MAX(Rolled AL inventory/TIME STEP,0)	Tonnes/year
Scrap fraction in Rolled AL production	0.15	Dmnl
Substitution trend	IF THEN ELSE(Decision on the substitution trend=1, "Substitution trend (no substitution)" , IF THEN ELSE(Decision on the substitution trend=2, "Substitution trend (slow increase)" (Time), "Substitution trend (fast increase)"(Time)))	Dmnl
Substitution trend (fast increase)	[(1990,0)-(2090,1)],(1990,0),(2020,0),(2023,0.3125),(2026,0.5),(2029,0.5975),(2032,0.685),(2035,0.75),(2038,0.8075),(2041,0.86),(2044,0.9125),(2047,0.9525),(2050,1),(2090,1))	Dmnl
"Substitution trend (slow increase)"	[(1990,0)-(2090,1)],(1990,0),(2020,0),(2023,0.0475),(2026,0.0875),(2029,0.14),(2032,0.1925),(2035,0.25),(2038,0.315),(2041,0.4025),(2044,0.5),(2047,0.6875),(2050,1),(2090,1))	Dmnl
"Tax percentage for importing carbon-intensive aluminum"	0.01	Dmnl
Total annual production capacity (Alumina)	$1.1*10^7$	Tonnes/year
Total annual production capacity (Primary Al)	$5.5*10^6$	Tonnes/year

"Total annual production capacity (Rolled Al)"	$2.1*10^7$	Tonnes/year
Total capital cost	Total capital investment in aluminum RP supply chain*Interest rate	USD/year
Total capital investment in aluminum RP supply chain	Investment extrusion+Investment primary aluminum+Investment refining+Investment remelting +Investment sheet	MEUR/year
Total cost (Rolled AL)	"Total energy costs (Rolled AL)"+"Total inventory holding costs (Rolled AL)" +"Total labor costs (Rolled AL)"+"Total material cost (Rolled AL)" +"Total transportation costs (Rolled AL)"+Total capital cost	USD/year
Total demand of Rolled Al	(("Demand for Rolled AL in Const Ind."+"Demand for Rolled AL in Packaging Ind." +Demand for Rolled AL in Auto industry +"Demand for Rolled AL in other Inds."))*Impact of substitution materials	Tonnes/year
Total inventory holding costs (Rolled AL	"Inventory holding cost (Rolled Al)"*IF THEN ELSE((Yearly rolled AL production -"Annual forecasted demand of Rolled Al (Market)")>0, (Yearly rolled AL production-"Annual forecasted demand of Rolled Al (Market)"), 0)	USD/year
Total labor costs (Rolled AL)	Labor cost*Yearly rolled AL production	USD/year
Total material cost (Rolled AL)	"Cost of imported primay Al (rolled Al)"+"Cost of other primary Al (rolled Al)" +"Cost of Post-consumer scrap (rolled Al)"+"Cost of Pre-consumer scrap (rolled Al)"	USD/year

Total transportation costs (Rolled AL)	Yearly rolled AL production*Transportation cost	USD/year	
Transportation cost	70	USD/tonnes	Freightos Data (n.a.)
yearly Pre-consumer scrap production (Bldg & Const Ind.)	("FRACTION PRE-CONSUMER SCRAP (Bldg & Const Ind.)"/(1-"FRACTION PRE-CONSUMER SCRAP (Bldg & Const Ind.)"))*"Yearly Rolled AL usage (Bldg and const Ind)"	Tonnes/year	
yearly Pre-consumer scrap production (Other Inds.)	("FRACTION PRE-CONSUMER SCRAP (Other Ind.)"/(1-"FRACTION PRE-CONSUMER SCRAP (Other Ind.)"))*"Yearly Rolled AL usage (Other Ind)"	Tonnes/year	
yearly Pre-consumer scrap production (Packaging Ind.)	("FRACTION PRE-CONSUMER SCRAP (Packaging Ind.)"/(1-"FRACTION PRE-CONSUMER SCRAP (Packaging Ind.)"))*"Yearly Rolled AL usage (Packaging Ind)"	Tonnes/year	
Yearly Al package stock difference	INTEG(newly built Al packages-Demolished Al packages, 9.02857e+09	Square meters	Statista (2020)
Yearly alumina production	MIN("Total annual production capacity (Alumina)",Bauxite needed for alumina/BAUXITE)	Tonnes/year	
Yearly Bauxite production	ALUMINUM ORE*MIN(Annual forecasted demand of Bauxite,BAUXITE MINING CAPACITY)	Tonnes/year	
Yearly car stock difference	INTEG(New cars-Discarded cars, 1.63628e+08)	cars	Statista (2020)
Yearly clean Internal scrap from Rolled AL production	MIN(Internal to Ingot, ("Annual forecasted demand of Rolled Al (Market)"*INTERNAL SCRAP ROLLED AL))	Tonnes/year	
Yearly floor space stock difference	INTEG(newly built floor space-Demolished floor space, 1.94823e+10)	Square meters	Statista (2020)
Yearly GWP	Yearly GWP extrusion+Yearly GWP primary+Yearly GWP primary import+Yearly GWP refining+Yearly GWP	Tonnes CO_2/year	

	remelting+Yearly GWP rolling		
Yearly GWP extrusion	GWP extrusion production*Yearly rolled AL production*(1-Reduction in emissions extrusion)	Tonnes CO_2/year	
Yearly GWP primary	(1-Reduction in emissions primary aluminum)*GWP primary aluminum produced in Europe*Yearly Primary AL production	Tonnes CO_2/year	
Yearly GWP primary import	GWP primary aluminum used in Europe*(yearly Primary AL import*(1-"Required import fraction for low-carbon Al"))	Tonnes CO_2/year	
Yearly GWP refining	GWP refining production*(1-Reduction in emissions refining)*"yearly Ingot AL production rate from Post-consumer scrap"	Tonnes CO_2/year	
Yearly GWP remelting	GWP remelting production*(yearly Internal scrap during Rolled AL production +"yearly Ingot AL production rate from Pre-consumer scrap")*(1-Reduction in emissions remelting)	Tonnes CO_2/year	
yearly increase rate of AL in car	0.00290345+STEP(0.000363552 , 2019)	Tonnes/car/year	Ducker Frontier (2019)
Yearly Ingot AL production	MIN(Primary needed for Ingot/PRIMARY AL,MIN(Annual forecasted demand of Ingot AL,INGOT AL PRODUCTION CAPACITY))	Tonnes/year	
yearly Ingot AL production rate from Post-consumer scrap	Post to ingot*"POST-CONSUMER SCRAP"	Tonnes/year	
yearly Ingot AL production rate from Pre-consumer scrap	Pre to ingot*"PRE-CONSUMER SCRAP"	Tonnes/year	
yearly Internal scrap during Rolled AL production	Scrap fraction in Rolled AL production*Yearly rolled AL production	Tonnes/year	
Yearly Low-carbon Rolled Al production	"Fraction of low-carbon aluminum RP (SC level)"*Total demand of Rolled Al	Tonnes/year	

"yearly Post-consumer scrap production (Automotive Ind.)"	"Rolled AL inventory in Auto Ind."/"Average lifespan of aluminum (Automotive Ind.)"	Tonnes/year	
"yearly Post-consumer scrap production (Construction Ind.)"	"Rolled AL inventory (Bldg & Const Ind.)"/"Average lifespan of aluminum (Construction Ind.)"	Tonnes/year	
"yearly Post-consumer scrap production (Other Ind.)"	"Rolled AL inventory (Other Inds.)"/"Average lifespan of aluminum (Other Ind.)"	Tonnes/year	
"yearly Post-consumer scrap production (Packaging Ind.)"	"Rolled AL inventory (Packaging Ind.)"/"Average lifespan of aluminum (Packaging Ind.)"	Tonnes/year	
"yearly Pre-consumer scrap production (Auto Ind.)"	("FRACTION PRE-CONSUMER SCRAP (Auto Ind.)"/(1-"FRACTION PRE-CONSUMER SCRAP (Auto Ind.)"))*"Yearly Rolled AL usage (Auto Ind)"	Tonnes/year	
yearly Primary AL import	Fraction of Primary Al import*Annual forecasted demand of primary AL	Tonnes/year	
Yearly Primary AL production	MIN(Alumina needed for primary/ALUMINA,(MIN(Annual forecasted demand of primary AL ,"Total annual production capacity (Primary Al)")))	Tonnes/year	
"yearly renovation rate (non-residential Bldgs)"	0.0001+STEP(0.00055, 2020)+STEP(-0.00065, 2050)	Dmnl	BPIE (2015)
"Yearly Rolled Al demand (Other Ind.)"	INTEG(Demand growth rate (Other Ind.),0)	Tonnes/year	
Yearly rolled AL production	MIN(Ingot needed for rolled/INGOT AL,MIN("Annual forecasted demand of Rolled Al (Market)" ,"Total annual production capacity (Rolled Al)"))	Tonnes/year	
"Yearly Rolled AL usage (Auto Ind)"	Rolled needed for product*(Demand for Rolled AL)	Tonnes/year	
"Yearly Rolled AL usage (Bldg and const Ind)"	Rolled needed for product*("Demand for Rolled AL in Const Ind."/Total demand of Rolled Al)	Tonnes/year	
"Yearly Rolled AL usage (Other Ind)"	Rolled needed for product*("Demand for	Tonnes/year	

	Rolled AL in other Inds."/Total demand of Rolled Al)	
"Yearly Rolled AL usage (Packaging Ind)"	Rolled needed for product*("Demand for Rolled AL in Packaging Ind."/Total demand of Rolled Al)	Tonnes/year