

$Batteries\_collected\_for\_2nd\_use[Electric\_vehicles](t) =$   
 $Batteries\_collected\_for\_2nd\_use[Electric\_vehicles](t - dt) +$   
 $(storing\_for\_second\_use[Electric\_vehicles] -$   
 $Outflow\_for\_remanufacturing[Electric\_vehicles] -$   
 $Outflow\_for\_direct\_use[Electric\_vehicles]) * dt \{NON-NEGATIVE\}$

INIT Batteries\_collected\_for\_2nd\_use[Electric\_vehicles] = 0

UNITS: battery

INFLOWS:

$storing\_for\_second\_use[Electric\_vehicles] =$   
 $batteries\_packs\_waiting * high\_quality\_batteries\_rate \{UNIFLOW\}$

UNITS: battery/Year

OUTFLOWS:

$Outflow\_for\_remanufacturing[Electric\_vehicles] =$   
 $Batteries\_collected\_for\_2nd\_use * second\_use\_battery\_rate\_with\_uncertainty$   
 $\{UNIFLOW\}$

UNITS: battery/Year

$Outflow\_for\_direct\_use[Electric\_vehicles] =$   
 $Batteries\_collected\_for\_2nd\_use * second\_use\_battery\_rate\_with\_uncertainty$   
 $\{UNIFLOW\}$

UNITS: battery/Year

$batteries\_packs\_waiting[Electric\_vehicles](t) =$   
 $batteries\_packs\_waiting[Electric\_vehicles](t - dt) +$   
 $(EV\_batt\_leaving\_the\_road[Electric\_vehicles] -$   
 $storing\_for\_recycling[Electric\_vehicles] - storing\_for\_second\_use[Electric\_vehicles]) * dt \{NON-NEGATIVE\}$

INIT batteries\_packs\_waiting[Electric\_vehicles] = 1

UNITS: battery

INFLOWS:

$EV\_batt\_leaving\_the\_road[Electric\_vehicles] =$   
 $Outflow\_EOL\_cars * batteries\_per\_car \{UNIFLOW\}$

UNITS: battery/Year

OUTFLOWS:

$storing\_for\_recycling[Electric\_vehicles] =$   
 $(batteries\_packs\_waiting * low\_quality\_batteries\_rate) \{UNIFLOW\}$

UNITS: battery/Year

storing\_for\_second\_use[Electric\_vehicles] =  
batteries\_packs\_waiting\*high\_quality\_batteries\_rate {UNIFLOW}

UNITS: battery/Year

Direct\_strategy\_for\_2nd\_use[Electric\_vehicles](t) =  
Direct\_strategy\_for\_2nd\_use[Electric\_vehicles](t - dt) +  
(Outflow\_for\_direct\_use[Electric\_vehicles] - Transfer\_DS[Electric\_vehicles]) \* dt  
{NON-NEGATIVE}

INIT Direct\_strategy\_for\_2nd\_use[Electric\_vehicles] = 0

UNITS: battery

INFLOWS:

Outflow\_for\_direct\_use[Electric\_vehicles] =  
Batteries\_collected\_for\_2nd\_use\*second\_use\_battery\_rate\_with\_uncertainty  
{UNIFLOW}

UNITS: battery/Year

OUTFLOWS:

Transfer\_DS[Electric\_vehicles] = DELAYN(Outflow\_for\_direct\_use;  
battery\_second\_lifetime; 10; 0) {UNIFLOW}

UNITS: battery/Year

EOL\_cars(t) = EOL\_cars(t - dt) + (Outflow\_EOL\_cars) \* dt {NON-NEGATIVE}

INIT EOL\_cars = 1

UNITS: cars

INFLOWS:

Outflow\_EOL\_cars[Electric\_vehicles] = DELAYN(Adoption\_flow; Car\_life\_1;  
8.5; 0) {UNIFLOW}

UNITS: cars/Year

EV\_Batteries\_on\_the\_Road[Electric\_vehicles](t) =  
EV\_Batteries\_on\_the\_Road[Electric\_vehicles](t - dt) +  
(EV\_batt\_entering\_the\_road[Electric\_vehicles] -  
EV\_batt\_leaving\_the\_road[Electric\_vehicles]) \* dt {NON-NEGATIVE}

INIT EV\_Batteries\_on\_the\_Road[Electric\_vehicles] = 0

UNITS: battery

INFLOWS:

EV\_batt\_entering\_the\_road[Electric\_vehicles] = Adoption\_flow\*batteries\_per\_car  
{UNIFLOW}

UNITS: battery/Year

OUTFLOWS:

EV\_batt\_leaving\_the\_road[Electric\_vehicles] =  
Outflow\_EOL\_cars\*batteries\_per\_car {UNIFLOW}

UNITS: battery/Year

EVs[Electric\_vehicles](t) = EVs[Electric\_vehicles](t - dt) +  
(Adoption\_flow[Electric\_vehicles] - Outflow\_EOL\_cars[Electric\_vehicles]) \* dt  
{NON-NEGATIVE}

INIT EVs[Electric\_vehicles] = initial\_Adopters

UNITS: cars

INFLOWS:

Adoption\_flow[Electric\_vehicles] =  
Adoption\_by\_innovation+Adoption\_by\_imitation {UNIFLOW}

UNITS: cars/Year

OUTFLOWS:

Outflow\_EOL\_cars[Electric\_vehicles] = DELAYN(Adoption\_flow; Car\_life\_1;  
8.5; 0) {UNIFLOW}

UNITS: cars/Year

Indirect\_strategy\_for\_2nd\_use[Electric\_vehicles](t) =  
Indirect\_strategy\_for\_2nd\_use[Electric\_vehicles](t - dt) +  
(Outflow\_2nd\_use[Electric\_vehicles] - Transfer\_IS[Electric\_vehicles]) \* dt {NON-  
NEGATIVE}

INIT Indirect\_strategy\_for\_2nd\_use[Electric\_vehicles] = 1

UNITS: battery

INFLOWS:

Outflow\_2nd\_use[Electric\_vehicles] = Remanufactured/Delay\_remanufacturing  
{UNIFLOW}

UNITS: battery/Year

OUTFLOWS:

Transfer\_IS[Electric\_vehicles] = DELAYN(Outflow\_2nd\_use;  
battery\_second\_lifetime; 8; 0) {UNIFLOW}

UNITS: battery/Year

$Potential\_adopters[Electric\_vehicles](t) = Potential\_adopters[Electric\_vehicles](t - dt) + (Repurchase[Electric\_vehicles] + Growth[Electric\_vehicles] - Adoption\_flow[Electric\_vehicles]) * dt \{NON-NEGATIVE\}$

INIT  $Potential\_adopters[Electric\_vehicles] = initial\_PM - initial\_Adopters$

UNITS: cars

INFLOWS:

$Repurchase[Electric\_vehicles] = Repurchase\_rate * Outflow\_EOL\_cars$   
{UNIFLOW}

UNITS: cars/Year

$Growth[Electric\_vehicles] = Growth\_potential\_market \{UNIFLOW\}$

UNITS: cars/Year

OUTFLOWS:

$Adoption\_flow[Electric\_vehicles] =$   
 $Adoption\_by\_innovation + Adoption\_by\_imitation \{UNIFLOW\}$

UNITS: cars/Year

$Potential\_market[Electric\_vehicles](t) = Potential\_market[Electric\_vehicles](t - dt) + (Growth\_potential\_market[Electric\_vehicles]) * dt \{NON-NEGATIVE\}$

INIT  $Potential\_market[Electric\_vehicles] = initial\_PM$

UNITS: cars

INFLOWS:

$Growth\_potential\_market[Electric\_vehicles] = Potential\_market * Fractional\_rate$   
{UNIFLOW}

UNITS: cars/Year

$Real\_Charge[Electric\_vehicles](t) = Real\_Charge[Electric\_vehicles](t - dt) + (total\_charge\_per\_year[Electric\_vehicles] - charge\_loss\_per\_year[Electric\_vehicles]) * dt \{NON-NEGATIVE\}$

INIT  $Real\_Charge[Electric\_vehicles] = 0$

UNITS: kWh

INFLOWS:

$total\_charge\_per\_year[Electric\_vehicles] =$   
 $(Outflow\_for\_direct\_use + Outflow\_2nd\_use) * variation\_kWh \{UNIFLOW\}$

UNITS: kWh/Year

OUTFLOWS:

charge\_loss\_per\_year[Electric\_vehicles] =  
(Transfer\_DS+Transfer\_IS)\*variation\_kWh\*charge\_loss\_rate {UNIFLOW}

UNITS: kWh/Year

recycling\_stock[Electric\_vehicles](t) = recycling\_stock[Electric\_vehicles](t - dt) +  
(storing\_for\_recycling[Electric\_vehicles] + Transfer\_DS[Electric\_vehicles] +  
Transfer\_IS[Electric\_vehicles] - exporting\_recycled\_materials[Electric\_vehicles]) \* dt  
{NON-NEGATIVE}

INIT recycling\_stock[Electric\_vehicles] = 1

UNITS: battery

INFLOWS:

storing\_for\_recycling[Electric\_vehicles] =  
(batteries\_packs\_waiting\*low\_quality\_batteries\_rate) {UNIFLOW}

UNITS: battery/Year

Transfer\_DS[Electric\_vehicles] = DELAYN(Outflow\_for\_direct\_use;  
battery\_second\_lifetime; 8; 0) {UNIFLOW}

UNITS: battery/Year

Transfer\_IS[Electric\_vehicles] = DELAYN(Outflow\_2nd\_use;  
battery\_second\_lifetime; 8; 0) {UNIFLOW}

UNITS: battery/Year

OUTFLOWS:

exporting\_recycled\_materials[Electric\_vehicles] =  
recycling\_stock\*Recycling\_rate\_with\_uncertainty {UNIFLOW}

UNITS: battery/Year

Remanufactured[Electric\_vehicles](t) = Remanufactured[Electric\_vehicles](t - dt) +  
(Outflow\_for\_remanufacturing[Electric\_vehicles] -  
Outflow\_2nd\_use[Electric\_vehicles]) \* dt {NON-NEGATIVE}

INIT Remanufactured[Electric\_vehicles] = 0

UNITS: battery

INFLOWS:

Outflow\_for\_remanufacturing[Electric\_vehicles] =  
Batteries\_collected\_for\_2nd\_use\*second\_use\_battery\_rate\_with\_uncertainty  
{UNIFLOW}

UNITS: battery/Year

OUTFLOWS:

Outflow\_2nd\_use[Electric\_vehicles] = Remanufactured/Delay\_remanufacturing  
{UNIFLOW}

UNITS: battery/Year

"A.\_Imitation" = Adopters\_wind\*PA\_wind\*q\_wind/"P.\_market\_wind"

UNITS: GWh/Years

"A.\_Innovation" = PA\_wind\*p\_wind

UNITS: GWh/Years

Adoption\_by\_imitation[Electric\_vehicles] =  
q\*(EVs/Potential\_market)\*Potential\_adopters

UNITS: car/year

Adoption\_by\_innovation = Potential\_adopters\*p

UNITS: car/years

batteries\_per\_car = 1

UNITS: battery/car

battery\_second\_lifetime = 8.5

UNITS: Years

battery\_weight = 0,454

UNITS: Ton/battery

charge\_loss\_rate = 0,1

UNITS: Per Year

Converter\_1 = SUM(storing\_for\_second\_use)

UNITS: battery/Year

Converter\_kWh\_for\_GWh = 1000000

UNITS: kWh/GWh

Delay\_remanufacturing = 0,5

UNITS: Years

Final\_Ratio\_of\_Recycling\_Batteries = IF TIME > 2024 THEN  
sum\_Ratio\_Recycled\_Batteries/9 ELSE 0

UNITS: Dimensionless

Fractional\_rate = 0,05

UNITS: 1/year

GWh\_on\_the\_Road = sum\_kWh\_on\_the\_Road/Converter\_kWh\_for\_GWh

UNITS: GWh

high\_quality\_batteries\_rate = 1-low\_quality\_batteries\_rate

UNITS: 1/year

historical\_data = GRAPH(TIME)

(2011,00, 637), (2012,00, 689), (2013,00, 2318), (2014,00, 6695), (2015,00, 11446),  
(2016,00, 12355), (2017,00, 16426), (2018,00, 18282), (2019,00, 38806), (2020,00,  
107913), (2021,00, 190420), (2022,00, 266875), (2023,00, 231046)

UNITS: car

initial\_Adopters[Electric\_vehicles] = 637

UNITS: cars

kWh\_On\_the\_Road[Electric\_vehicles] = EV\_Batteries\_on\_the\_Road\*variation\_kWh

UNITS: kWh

low\_quality\_batteries\_rate = 0,5

UNITS: 1/year

Ratio\_of\_Recycled\_Batteries[Electric\_vehicles] =  
exporting\_recycled\_materials/(Adoption\_flow+0,01)

UNITS: Dimensionless

Recycling\_rate = GRAPH(TIME)

(2011,00, 0,01), (2012,00, 0,01021), (2013,00, 0,01046), (2014,00, 0,01078), (2015,00,  
0,01118), (2016,00, 0,01169), (2017,00, 0,01232), (2018,00, 0,01312), (2019,00,  
0,01413), (2020,00, 0,01538), (2021,00, 0,01695), (2022,00, 0,01888), (2023,00,  
0,02125), (2024,00, 0,0241), (2025,00, 0,02749), (2026,00, 0,03144), (2027,00,  
0,03595), (2028,00, 0,04097), (2029,00, 0,0464), (2030,00, 0,0521), (2031,00, 0,0579),  
(2032,00, 0,0636), (2033,00, 0,06903), (2034,00, 0,07405), (2035,00, 0,07856),  
(2036,00, 0,08251), (2037,00, 0,0859), (2038,00, 0,08875), (2039,00, 0,09112),  
(2040,00, 0,09305), (2041,00, 0,09462), (2042,00, 0,09587), (2043,00, 0,09688),

(2044,00, 0,09768), (2045,00, 0,09831), (2046,00, 0,09882), (2047,00, 0,09922),  
(2048,00, 0,09954), (2049,00, 0,09979), (2050,00, 0,1)

UNITS: 1/year

Recycling\_rate\_with\_uncertainty = Recycling\_rate\*Uncertainty\_for\_recycling\_rate

UNITS: 1/year

Recyled\_by\_weight[Electric\_vehicles] = exporting\_recycled\_materials\*battery\_weight

UNITS: Tons/Years

Repurchase\_rate = 0,01

UNITS: Dimensionless

second\_use\_battery\_rate = GRAPH(TIME)

(2011,00, 0,01), (2012,00, 0,01021), (2013,00, 0,01046), (2014,00, 0,01078), (2015,00,  
0,01118), (2016,00, 0,01169), (2017,00, 0,01232), (2018,00, 0,01312), (2019,00,  
0,01413), (2020,00, 0,01538), (2021,00, 0,01695), (2022,00, 0,01888), (2023,00,  
0,02125), (2024,00, 0,0241), (2025,00, 0,02749), (2026,00, 0,03144), (2027,00,  
0,03595), (2028,00, 0,04097), (2029,00, 0,0464), (2030,00, 0,0521), (2031,00, 0,0579),  
(2032,00, 0,0636), (2033,00, 0,06903), (2034,00, 0,07405), (2035,00, 0,07856),  
(2036,00, 0,08251), (2037,00, 0,0859), (2038,00, 0,08875), (2039,00, 0,09112),  
(2040,00, 0,09305), (2041,00, 0,09462), (2042,00, 0,09587), (2043,00, 0,09688),  
(2044,00, 0,09768), (2045,00, 0,09831), (2046,00, 0,09882), (2047,00, 0,09922),  
(2048,00, 0,09954), (2049,00, 0,09979), (2050,00, 0,1)

UNITS: 1/year

second\_use\_battery\_rate\_with\_uncertainty =  
second\_use\_battery\_rate\*Uncertainty\_for\_second\_use\_battery\_rate

UNITS: 1/year

sum\_2nd\_use\_Batt = SUM(Batteries\_collected\_for\_2nd\_use[\*])

UNITS: battery

sum\_adopters = SUM(EVs)

UNITS: car

sum\_adoption = SUM(Adoption\_flow)

UNITS: car/year

sum\_battery\_input = SUM(EV\_batt\_leaving\_the\_road[\*])

UNITS: battery/Year

sum\_Battery\_Packs = SUM(batteries\_packs\_waiting[\*])

UNITS: battery

$\text{sum\_Battery\_Packs\_by\_weight} = \text{battery\_weight} * \text{sum\_EOL\_Cars} * \text{batteries\_per\_car}$

UNITS: Tons

$\text{sum\_EOL\_Cars} = \text{SUM}(\text{EOL\_cars}[*])$

UNITS: car

$\text{sum\_GWh\_capacity\_battery} = \text{Total\_real\_charge} / \text{Converter\_kWh\_for\_GWh}$

UNITS: GWh

$\text{sum\_historical} = \text{SUM}(\text{historical\_data})$

$\text{sum\_initial\_PM} = \text{SUM}(\text{initial\_PM}[*])$

UNITS: cars

$\text{sum\_kWh\_on\_the\_Road} = \text{SUM}(\text{kWh\_On\_the\_Road}[*])$

UNITS: kWh

$\text{sum\_outflow\_EOL\_cars} = \text{SUM}(\text{Outflow\_EOL\_cars}[*])$

UNITS: car/years

$\text{sum\_PM} = \text{SUM}(\text{Potential\_market}[*])$

UNITS: cars

$\text{sum\_Potential\_Market} = 28300000$

UNITS: cars

$\text{sum\_Ratio\_Recycled\_Batteries} = \text{SUM}(\text{Ratio\_of\_Recycled\_Batteries}[*])$

UNITS: 1/year

$\text{sum\_recycling} = \text{SUM}(\text{Recycled\_by\_weight}[*])$

UNITS: Tons/Years

$\text{sum\_recycle\_stock} = \text{SUM}(\text{recycling\_stock}[*])$

UNITS: battery

$\text{sum\_repurchase} = \text{SUM}(\text{Repurchase}[*])$

$\text{sum\_second\_use} = \text{SUM}(\text{Outflow\_2nd\_use}[*]) + \text{SUM}(\text{Outflow\_for\_direct\_use}[*])$

UNITS: battery/Year

$\text{Total\_real\_charge} = \text{SUM}(\text{Real\_Charge})$

UNITS: kWh

Uncertainty\_for\_recycling\_rate = 1

UNITS: Dimensionless

Uncertainty\_for\_second\_use\_battery\_rate = 1

UNITS: Dimensionless