1 The sd0WF12 model

annual CO2 emissions avoided = net specific CO2 emissions avoided * total energy generated by wind capacity / 1000 ;[tCO2 / YEAR]

annual CO2 emissions avoided cte = tCO2 avoided per GWh if constant mix * total energy generated by wind capacity / 1000 ;[tCO2 / YEAR]

annual CO2 emissions avoided WF12 = WITH LOOKUP (Time, ([(2001, 0) - (2100, 6 e+009)], (2001, 3.27 e+007), (2002, 4.39 e+007), (2003, 5.78 e+007), (2004, 7.53 e+007), (2005, 9.71 e+007), (2006, 1.244 e+008), (2007, 1.585 e+008), (2008, 1.99 e+008), (2009, 2.48 e+008), (2010, 3.07 e+008), (2011, 4.23 e+008), (2012, 5.18 e+008), (2013, 6.28 e+008), (2014, 7.53 e+008), (2015, 8.98 e+008), (2016, 1.057 e+009), (2017, 1.231 e+009), (2018, 1.424 e+009), (2019, 1.635 e+009), (2020, 1.856 e+009), (2020, 1.856 e+009), (2040, 4.8 e+009))) ;[tCO2 / YEAR]

annual total cost wind capacity = total cost capacity installed * (interest rate + operational and maintenance cost rate) + writeoff costs capacity installed ;[€]

capacity cost of new decommissioned capacity = DELAY FIXED (total cost new capacity installed, lifetime wind capacity, 0) ;[€ / YEAR]

capacity cost of old decommissioned capacity = IF THEN ELSE(Time < INITIAL TIME + lifetime wind capacity, (initial cost 2001 * cost surplus rate historic capacity + study and construction costs + initial siting costs) * initial capacity * 1000 / lifetime wind capacity, 0) ;[€ / YEAR]

capacity factor = WITH LOOKUP (Time, ([(2000, 0.2) - (2050, 0.4)], (2001, 0.25), (2010, 0.25), (2011, 0.28), (2034, 0.28), (2035, 0.3), (2050, 0.3))) ;[dmnl]

CO2 emissions coal = electricity generation coal * specific CO2 emissions coal * 1000 ;[tCO2]

CO2 emissions gas = electricity generation gas * specific CO2 emissions gas * 1000 ;[tCO2]

CO2 emissions hydro = electricity generation hydro * specific CO2 emissions hydro * 1000 ;[tCO2]

CO2 emissions nuclear = electricity generation nuclear * specific CO2 emissions nuclear * 1000 ;[tCO2]

CO2 emissions oil = electricity generation oil * specific CO2 emissions oil * 1000 ;[tCO2]

CO2 emissions other renewables = electricity generation other renewables * specific CO2 emissions other renewables * 1000 ;[tCO2]

CO2 emissions wind = specific CO2 emissions wind * total energy generated by wind capacity / 1000 ;[tCO2]

"cost new capacity (t)" = "cost new capacity (t - 1)" * (cumulative historical number / "cumulative historical number t - 1")∧ (- experience curve parameter) ;[€ / kW]

"cost new capacity (t + 1)" = INTEG ("cost new capacity (t)" - "cost new capacity (t - 1)",

879) ;[€ / kW]

"cost new capacity (t - 1)" = "cost new capacity (t + 1)" ;[€ / kW]

cost surplus rate historic capacity = 1 ;[dmnl]

"cost wind turbine electricity generated € / MWh" = annual total cost wind capacity / total energy generated by wind capacity ;[€ / MWh]

"cost wind turbine electricity generated €ct / kWh" = "cost wind turbine electricity generated € / MWh" * 100 / 1000 ;[€ct / kWh]

cumulative CO2 emissions avoided = INTEG (annual CO2 emissions avoided, 0) ;[tCO2]

cumulative CO2 emissions avoided cte = INTEG (annual CO2 emissions avoided cte, 0) ;[tCO2]

cumulative CO2 emissions avoided WF12 = INTEG (annual CO2 emissions avoided WF12, 0) ;[tCO2]

cumulative decommissioned capacity of installed wind turbines = INTEG (decommissioning capacity of installed wind turbines, 0) ;[MW]

cumulative decommissioned number of installed wind turbines = INTEG (decommissioning number of installed wind turbines, 0) ;[wind turbines]

cumulative historical number = cumulative decommissioned number of installed wind turbines + total number of installed wind turbines ;[wind turbines]

"cumulative historical number t - 1" = DELAY FIXED(cumulative historical number, 1, 56000) ;[wind turbines]

decommissioning capacity new = DELAY FIXED (new capacity of wind turbines, lifetime wind capacity, 0) ;[MW / YEAR]

decommissioning capacity of installed wind turbines = IF THEN ELSE(Time<2023, 0, decommissioning capacity new + decommissioning capacity old) ;[MW / YEAR]

decommissioning capacity old = IF THEN ELSE(Time < INITIAL TIME + lifetime wind capacity, initial capacity / lifetime wind capacity, 0) ;[MW / YEAR]

decommissioning number new = DELAY FIXED(new number of wind turbines, lifetime wind capacity, 0) ;[wind turbines / YEAR]

decommissioning number of installed wind turbines = IF THEN ELSE(Time<2023, 0, decommissioning number new + decommissioning number old) ;[wind turbines / YEAR]

decommissioning number old = IF THEN ELSE(Time < INITIAL TIME + lifetime wind capacity, initial number / lifetime wind capacity, 0) ;[wind turbines / YEAR]

electricity generation coal = WITH LOOKUP (Time, ([(2000, 0) - (2020, 10000)], (1997, 5337), (2010, 7467), (2020, 9763))) ;[TWh]

electricity generation gas = WITH LOOKUP (Time, ([(0, 0) - (2100, 8000)], (1997, 2159), (2010, 4698), (2020, 7745))) ;[TWh]

electricity generation hydro = WITH LOOKUP (Time, ([(0, 0) - (2100, 4000)], (1997, 2566), (2010, 3341), (2020, 3904))) ;[TWh]

electricity generation nuclear = WITH LOOKUP (Time, ([(2000, 0) - (2020, 4000)], (1997, 2393), (2010, 2647), (2020, 2369))) ;[TWh]

electricity generation oil = WITH LOOKUP (Time, ([(0, 0) - (2100, 2000)], (1997, 1282), (2010, 1442), (2020, 1498))) ;[TWh]

electricity generation other renewables = WITH LOOKUP (Time, ([(0, 0) - (2100, 800)], (1997, 211), (2010, 395), (2020, 603))) ;[TWh]

energy generated by new decommissioned capacity = DELAY FIXED(energy generation new capacity, lifetime wind capacity, 0) ;[MWh / YEAR]

energy generated by old decommissioned capacity = IF THEN ELSE(Time < INITIAL TIME + lifetime wind capacity, energy gererated by initial capacity / lifetime wind capacity, 0) ;[MWh / YEAR]

energy generation decommissioned capacity = IF THEN ELSE(Time<2023, 0, energy generated by new decommissioned capacity + energy generated by old decommissioned capacity) ;[MWh / YEAR]

energy generation new capacity = capacity factor * hours per year * new capacity of wind turbines ;[MWh / YEAR]

energy gererated by initial capacity = 5.4531 e+007 ;[MWh]

experience curve parameter = - LOG(progress ratio, 2) ;[dmnl]

FINAL TIME = 2050 ;[YEAR]

hours per year = 8760 ;[hours / YEAR]

initial capacity = 24900 ;[MW]

initial cost 2001 = 879 ;[€ / (YEAR * kW)]

initial number = 56000 ;[wind turbines]

initial siting costs = 0 ;[€ / kW]

INITIAL TIME = 2001 ;[YEAR]

installation jobs per MW = 5 ;[manyear / MW]

interest rate = 0.1 ;[dmnl]

jobyear per MW lookup = WITH LOOKUP (Time, ([(1998, 0) - (2020, 40)], (1998, 22), (2005, 14.7), (2010, 12.2), (2015, 10.9), (2020, 9.8))) ;[manyear]

lifetime wind capacity = 20 ;[YEAR]

manufacturing jobs per MW = 17 ;[manyear / MW]

net specific CO2 emissions avoided = specific CO2 emissions world generation mix - specific CO2 emissions wind ;[tCO2 / GWh]

new capacity growth = percentage growth new capacity of wind turbines * new wind turbines capacity capacity ;[MW / YEAR]

new capacity of wind turbines = new wind turbines capacity capacity ;[MW]

new number of wind turbines = new capacity of wind turbines / wind turbine size ;[wind turbines / YEAR]

new wind turbines capacity capacity = INTEG (new capacity growth, 8500) ;[MW / YEAR]

operational and maintenance cost rate = 0.03 ;[dmnl]

percentage growth new capacity of wind turbines = WITH LOOKUP (Tim e+2, ([(2000, 0) - (2100, 1)], (2000, 0.25), (2002, 0.25), (2007, 0.25), (2008, 0.2), (2012, 0.2), (2013, 0.15), (2015, 0.15), (2016, 0.1), (2019, 0.1), (2020, 0.04364), (2021, 0), (2052, 0))) ;[dmnl]

progress ratio = WITH LOOKUP (Time, ([(2000, 0.7) - (2050, 1.1)], (2001, 0.85), (2010, 0.85), (2011, 0.9), (2025, 0.9), (2026, 1), (2050, 1))) ;[dmnl]

sales = "cost new capacity (t)" * 1000 * new capacity of wind turbines ;[€]

SAVEPER = 1 ;[YEAR]

share wind = total energy generated by wind capacity / 1 e+006 / world electricity supply ;[dmnl]

siting costs = initial siting costs ;[€ / kW]

specific CO2 emissions coal = 800 ;[tCO2 / GWh]

specific CO2 emissions gas = 400 ;[tCO2 / GWh]

specific CO2 emissions hydro = 8 ;[tCO2 / GWh]

specific CO2 emissions nuclear = 7 ;[tCO2 / GWh]

specific CO2 emissions oil = 726 ;[tCO2 / GWh]

specific CO2 emissions other renewables = 100 ;[tCO2 / GWh]

specific CO2 emissions wind = 9 ;[tCO2 / GWh]

specific CO2 emissions world generation mix = total CO2 emissions / world electricity supply / 1000 ;[tCO2 / GWh]

study and construction costs = 0 ;[€ / kW]

tCO2 avoided per GWh if constant mix = 600 ;[tCO2 / GWh]

TIME STEP = 1 ;[YEAR]

total capacity of installed wind turbines = INTEG (+ new capacity of wind turbines - decommissioning capacity of installed wind turbines, initial capacity) ;[MW]

total CO2 emissions = CO2 emissions coal + CO2 emissions hydro + CO2 emissions gas + CO2 emissions nuclear + CO2 emissions oil + CO2 emissions other renewables + CO2 emissions wind ;[tCO2]

total cost capacity installed = INTEG (+ total cost new capacity installed - total cost decommissioned capacity, (initial cost 2001 * cost surplus rate historic capacity + study and construction costs + initial siting costs) * initial capacity * 1000) ;[€]

total cost decommissioned capacity = capacity cost of new decommissioned capacity + capacity cost of old decommissioned capacity ;[€]

total cost new capacity installed = ("cost new capacity (t)" + study and construction costs + siting costs) * new capacity of wind turbines * 1000 ;[€]

"total energy generated by capacity (EWEA's WF12)" = capacity factor * total capacity of installed wind turbines * 8760 ;[MWh]

total energy generated by wind capacity = INTEG (- energy generation decommissioned capacity + energy generation new capacity, energy gererated by initial capacity) ;[MWh]

total jobs per MW = (installation jobs per MW + manufacturing jobs per MW) * new capacity of wind turbines ;[manyear]

total jobs per MW corrected = jobyear per MW lookup * new capacity of wind turbines ;[manyear]

total jobs per sales = 22 * sales / 1 e+006 ;[manyear]

total jobs per sales corrected = sales * jobyear per MW lookup / 1 e+006 ;[manyear]

total jobs per total costs new capacity installed = 22 * total cost new capacity installed / 1 e+006 ;[manyear]

total jobs per total costs new capacity installed corrected = jobyear per MW lookup * total cost new capacity installed / 1 e+006 ;[manyear]

total jobs WF12 = WITH LOOKUP (Time, ([(2000, 0) - (2020, 2 e+006)], (2001, 114000), (2005, 244000), (2010, 546600), (2015, 1.0682 e+006), (2020, 1.47 e+006))) ;[manyear]

total number of installed wind turbines = INTEG (+ new number of wind turbines - decommissioning number of installed wind turbines, initial number) ;[wind turbines]

wind turbine size = WITH LOOKUP (Time + 1, ([(2000, 0) - (2050, 3)], (2000, 1), (2003, 1), (2004, 1.2), (2006, 1.2), (2007, 1.3), (2008, 1.3), (2009, 1.4), (2011, 1.4), (2012, 1.5), (2030, 1.5), (2031, 2), (2052, 2))) ;[MW / wind turbines]

world electricity supply = electricity generation coal + electricity generation gas + electricity generation hydro + electricity generation nuclear + electricity generation oil + electricity generation other renewables + total energy generated by wind capacity / 1 e+006 ;[TWh]

writeoff costs capacity installed = total cost capacity installed / lifetime wind capacity ;[€]

2 The sd1WF12 model

annual CO2 emissions avoided = net specific CO2 emissions avoided * total energy generated by wind capacity / 1000 ;[tCO2 / YEAR]

annual CO2 emissions avoided cte = tCO2 avoided per GWh if constant mix * total energy generated by wind capacity / 1000 ;[tCO2 / YEAR]

annual CO2 emissions avoided WF12 = WITH LOOKUP (Time, ([(2001, 0) - (2100, 6 e+009)], (2001, 3.27 e+007), (2002, 4.39 e+007), (2003, 5.78 e+007), (2004, 7.53 e+007), (2005, 9.71 e+007), (2006, 1.244 e+008), (2007, 1.585 e+008), (2008, 1.99 e+008), (2009, 2.48 e+008), (2010, 3.07 e+008), (2011, 4.23 e+008), (2012, 5.18 e+008), (2013, 6.28 e+008), (2014, 7.53 e+008), (2015, 8.98 e+008), (2016, 1.057 e+009), (2017, 1.231 e+009), (2018, 1.424 e+009), (2019, 1.635 e+009), (2020, 1.856 e+009), (2020, 1.856 e+009), (2040, 4.8 e+009))) ;[tCO2 / YEAR]

annual total cost wind capacity = total cost capacity installed * (interest rate + operational and maintenance cost rate) + writeoff costs capacity installed ;[€]

AVERAGE WIND TURBINE SIZE = WITH LOOKUP (cumulative historical number, ([(0, 0) - (4 e+006, 4)], (50000, 1), (86192.7, 1.2), (137274, 1.3), (187900, 1.4), (300000, 1.5), (611621, 1.68421), (990826, 1.78947), (1.44343 e+006, 1.91228), (1.98232 e+006, 2), (2.89908 e+006, 2.08772), (3.76758 e+006, 2.15789), (3.97554 e+006, 2.19298))) ;[dmnl]

AVERAGE WINDYNESS FACTOR = AVERAGE WINDYNESS FACTOR LOOKUP(GAP INITIAL MAXIMUM POTENTIAL) ;[dmnl]

AVERAGE WINDYNESS FACTOR LOOKUP([(- 2, - 0.4) - (10, 10)], (0, 1.1), (0.5, 1), (1, 0.9), (2, 0.8), (3, 0.7)) ;[dmnl]

capacity cost of new decommissioned capacity = DELAY FIXED (total cost new capacity installed, lifetime wind capacity, 0) ;[€ / YEAR]

capacity cost of old decommissioned capacity = IF THEN ELSE(Time < INITIAL TIME + lifetime wind capacity, (initial cost 2001 * cost surplus rate historic capacity + study and construction costs + initial siting costs) * initial capacity * 1000 / lifetime wind capacity, 0) ;[€ / YEAR]

CAPACITY FACTOR IMPROVEMENT LOOKUP([(0, 0) - (2 e+009, 1)], (56000, 0.25), (258338, 0.28), (2.28231 e+006, 0.3), (2 e+009, 0.32)) ;[dmnl]

CO2 emissions coal = electricity generation coal * specific CO2 emissions coal * 1000 ;[tCO2]

CO2 emissions gas = electricity generation gas * specific CO2 emissions gas * 1000 ;[tCO2]

CO2 emissions hydro = electricity generation hydro * specific CO2 emissions hydro * 1000 ;[tCO2]

CO2 emissions nuclear = electricity generation nuclear * specific CO2 emissions nuclear * 1000 ;[tCO2]

CO2 emissions oil = electricity generation oil * specific CO2 emissions oil * 1000 ;[tCO2]

CO2 emissions other renewables = electricity generation other renewables * specific CO2 emissions other renewables * 1000 ;[tCO2]

CO2 emissions wind = specific CO2 emissions wind * total energy generated by wind capacity / 1000 ;[tCO2]

"cost new capacity (t)" = "cost new capacity (t - 1)" * (cumulative historical number / "cumulative historical number t - 1")∧ (- experience curve parameter) ;[€ / kW / YEAR]

"cost new capacity (t + 1)" = INTEG ("cost new capacity (t)" - "cost new capacity (t - 1)", initial cost 2001) ;[€ / kW]

"cost new capacity (t - 1)" = "cost new capacity (t + 1)" ;[€ / kW / YEAR]

cost surplus rate historic capacity = 1 ;[dmnl]

"cost wind turbine electricity generated € / MWh" = annual total cost wind capacity / total energy generated by wind capacity ;[€ / MWh]

"cost wind turbine electricity generated €ct / kWh" = "cost wind turbine electricity generated € / MWh" * 100 / 1000 ;[€ct / kWh]

cumulative CO2 emissions avoided = INTEG (annual CO2 emissions avoided, 0) ;[tCO2]

cumulative CO2 emissions avoided cte = INTEG (annual CO2 emissions avoided cte, 0) ;[tCO2]

cumulative CO2 emissions avoided WF12 = INTEG (annual CO2 emissions avoided WF12, 0) ;[tCO2]

cumulative decommissioned capacity of installed wind turbines = INTEG (decommissioning capacity of installed wind turbines, 0) ;[MW]

cumulative decommissioned number of installed wind turbines = INTEG (decommissioning number of installed wind turbines, 0) ;[wind turbines]

cumulative historical number = cumulative decommissioned number of installed wind turbines + total number of installed wind turbines ;[wind turbines]

"cumulative historical number t - 1" = DELAY FIXED(cumulative historical number, 1, 56000) ;[wind turbines]

CUMULATIVELY IMPROVED CAPACITY FACTOR = CAPACITY FACTOR IMPROVEMENT LOOKUP(cumulative historical number) ;[dmnl]

decommissioning capacity new = DELAY FIXED (new capacity of wind turbines, lifetime wind capacity, 0) ;[MW / YEAR]

decommissioning capacity of installed wind turbines = decommissioning capacity new + decommissioning capacity old ;[MW / YEAR]

decommissioning capacity old = IF THEN ELSE(Time < INITIAL TIME + lifetime wind ca-

pacity, initial capacity / lifetime wind capacity, 0) ;[MW / YEAR]

decommissioning number new = DELAY FIXED(new number of wind turbines, lifetime wind capacity, 0) ;[wind turbines / YEAR]

decommissioning number of installed wind turbines = decommissioning number new + decommissioning number old ;[wind turbines / YEAR]

decommissioning number old = IF THEN ELSE(Time < INITIAL TIME + lifetime wind capacity, initial number / lifetime wind capacity, 0) ;[wind turbines / YEAR]

electricity generation coal = WITH LOOKUP (Time, ([(2000, 0) - (2020, 10000)], (1997, 5337), (2010, 7467), (2020, 9763))) ;[TWh]

electricity generation gas = WITH LOOKUP (Time, ([(0, 0) - (2100, 8000)], (1997, 2159), (2010, 4698), (2020, 7745))) ;[TWh]

electricity generation hydro = WITH LOOKUP (Time, ([(0, 0) - (2100, 4000)], (1997, 2566), (2010, 3341), (2020, 3904))) ;[TWh]

electricity generation nuclear = WITH LOOKUP (Time, ([(2000, 0) - (2020, 4000)], (1997, 2393), (2010, 2647), (2020, 2369))) ;[TWh]

electricity generation oil = WITH LOOKUP (Time, ([(0, 0) - (2100, 2000)], (1997, 1282), (2010, 1442), (2020, 1498))) ;[TWh]

electricity generation other renewables = WITH LOOKUP (Time, ([(0, 0) - (2100, 800)], (1997, 211), (2010, 395), (2020, 603))) ;[TWh]

energy generated by new decommissioned capacity = DELAY FIXED(energy generation new capacity, lifetime wind capacity, 0) ;[MWh / YEAR]

energy generated by old decommissioned capacity = IF THEN ELSE(Time < INITIAL TIME + lifetime wind capacity, energy gererated by initial capacity / lifetime wind capacity, 0) ;[MWh / YEAR]

energy generation decommissioned capacity = energy generated by new decommissioned capacity + energy generated by old decommissioned capacity ;[MWh / YEAR]

energy generation new capacity = ON SITE CAPACITY FACTOR * hours per year * new capacity of wind turbines ;[MWh / YEAR]

energy gererated by initial capacity = 5.4531 e+007 ;[MWh]

experience curve parameter = - LOG(progress ratio, 2) ;[dmnl]

FINAL TIME = 2050 ;[YEAR]

GAP INITIAL MAXIMUM POTENTIAL = total number of installed wind turbines / INITIAL MAXIMUM POTENTIAL ;[dmnl]

GAP MAXIMUM POTENTIAL = total number of installed wind turbines / MAXIMUM POTENTIAL ;[dmnl]

hours per year = 8760 ;[hours / YEAR]

initial capacity = 24900 ;[MW]

initial cost 2001 = 879 ;[€ / (YEAR * kW)]

INITIAL MAXIMUM POTENTIAL = 907313 ;[wind turbines]

initial number = 56000 ;[wind turbines]

initial siting costs = 0 ;[€ / kW]

INITIAL TIME = 2001 ;[YEAR]

installation jobs per MW = 5 ;[manyear / MW]

interest rate = 0.1 ;[dmnl]

jobyear per MW lookup = WITH LOOKUP (Time, ([(1998, 0) - (2020, 40)], (1998, 22), (2005, 14.7), (2010, 12.2), (2015, 10.9), (2020, 9.8))) ;[manyear]

lifetime wind capacity = 20 ;[YEAR]

manufacturing jobs per MW = 17 ;[manyear / MW]

MAXIMUM POTENTIAL = DELAY FIXED(initial cost 2001 / "cost new capacity (t + 1)" * INITIAL MAXIMUM POTENTIAL, 10, INITIAL MAXIMUM POTENTIAL) ;[wind turbines]

net specific CO2 emissions avoided = specific CO2 emissions world generation mix - specific CO2 emissions wind ;[tCO2 / GWh]

new capacity growth = percentage growth new capacity of wind turbines * new wind turbines capacity capacity ;[MW / YEAR]

new capacity of wind turbines = new wind turbines capacity capacity ;[MW / YEAR]

new number of wind turbines = new capacity of wind turbines / AVERAGE WIND TURBINE SIZE ;[wind turbines / YEAR]

new wind turbines capacity capacity = INTEG (new capacity growth, 8500) ;[MW / YEAR]

new wind turbines capacity capacity WF12 = WITH LOOKUP (Time, ([(2000, 0) - (2150, 200000)], (2001, 6800), (2002, 8500), (2003, 10625), (2004, 13281), (2005, 16602), (2006, 20752), (2007, 25940), (2008, 31128), (2009, 37354), (2010, 44824), (2011, 53789), (2012, 64547), (2013, 74229), (2014, 85363), (2015, 98168), (2016, 107985), (2017, 118783), (2018, 130661), (2019, 143727), (2020, 150000), (2150, 150000))) ;[MW / YEAR]

ON SITE CAPACITY FACTOR = AVERAGE WINDYNESS FACTOR * CUMULATIVELY IMPROVED CAPACITY FACTOR ;[dmnl]

operational and maintenance cost rate = 0.03 ;[dmnl]

percentage growth new capacity of wind turbines = WITH LOOKUP (GAP MAXIMUM POTENTIAL, ([(0, - 0.06) - (2, 1)], (0.06, 0.25), (0.15, 0.2), (0.3, 0.15), (0.5, 0.09), (0.75, 0), (1, 0), (2, 0))) ;[dmnl]

progress ratio = 0.9 ;[dmnl]

sales = "cost new capacity (t)" * 1000 * new capacity of wind turbines ;[€]

SAVEPER = 1 ;[YEAR]

share wind = total energy generated by wind capacity / 1 e+006 / world electricity supply ;[dmnl]

siting costs = initial siting costs ;[€ / kW]

specific CO2 emissions coal = 800 ;[tCO2 / GWh]

specific CO2 emissions gas = 400 ;[tCO2 / GWh]

specific CO2 emissions hydro = 8 ;[tCO2 / GWh]

specific CO2 emissions nuclear = 7 ;[tCO2 / GWh]

specific CO2 emissions oil = 726 ;[tCO2 / GWh]

specific CO2 emissions other renewables = 100 ;[tCO2 / GWh]

specific CO2 emissions wind = 9 ;[tCO2 / GWh]

specific CO2 emissions world generation mix = total CO2 emissions / world electricity supply / 1000 ;[tCO2 / GWh]

study and construction costs = 0 ;[€ / kW]

tCO2 avoided per GWh if constant mix = 600 ;[tCO2 / GWh]

TIME STEP = 1 ;[YEAR]

tot cap WF12 = WITH LOOKUP (Time, ([(2000, 0) - (2150, 4 e+006)], (2001, 24900), (2002, 33400), (2003, 44025), (2004, 57306), (2005, 73908), (2006, 94660), (2007, 120600), (2008, 151728), (2009, 189081), (2010, 233905), (2011, 287694), (2012, 352241), (2013, 426470), (2014, 511833), (2015, 610001), (2016, 717986), (2017, 836769), (2018, 967430), (2019, 1.11116 e+006), (2020, 1.26116 e+006), (2021, 1.41116 e+006), (2022, 1.56116 e+006), (2023, 1.71116 e+006), (2024, 1.84788 e+006), (2025, 1.98127 e+006), (2026, 2.11052 e+006), (2027, 2.23458 e+006), (2028, 2.35346 e+006), (2029, 2.4661 e+006), (2030, 2.57128 e+006), (2031, 2.66749 e+006), (2032, 2.75294 e+006), (2033, 2.82871 e+006), (2034, 2.89335 e+006), (2035, 2.94518 e+006), (2036, 2.9872 e+006), (2037, 3.01841 e+006), (2038, 3.03775 e+006), (2039, 3.04403 e+006), (2150, 3.04403 e+006))) ;[MW]

total capacity of installed wind turbines = INTEG (+ new capacity of wind turbines - decommissioning capacity of installed wind turbines, initial capacity) ;[MW]

total CO2 emissions = CO2 emissions coal + CO2 emissions hydro + CO2 emissions gas + CO2 emissions nuclear + CO2 emissions oil + CO2 emissions other renewables + CO2 emissions wind ;[tCO2]

total cost capacity installed = INTEG (+ total cost new capacity installed - total cost decommissioned capacity, (initial cost 2001 * cost surplus rate historic capacity + study and construction costs + initial siting costs) * initial capacity * 1000) ;[€]

total cost decommissioned capacity = capacity cost of new decommissioned capacity + capacity cost of old decommissioned capacity ;[€]

total cost new capacity installed = ("cost new capacity (t)" + study and construction costs + siting costs) * new capacity of wind turbines * 1000 ;[€]

total energy generated by wind capacity = INTEG (+ energy generation new capacity - energy generation decommissioned capacity, energy gererated by initial capacity) ;[MWh]

total jobs per MW = (installation jobs per MW + manufacturing jobs per MW) * new capacity of wind turbines ;[manyear]

total jobs per MW corrected = jobyear per MW lookup * new capacity of wind turbines ;[manyear]

total jobs per sales = 22 * sales / 1 e+006 ;[manyear]

total jobs per sales corrected = sales * jobyear per MW lookup / 1 e+006 ;[manyear]

total jobs per total costs new capacity installed = 22 * total cost new capacity installed / 1 e+006 ;[manyear]

total jobs per total costs new capacity installed corrected = jobyear per MW lookup * total cost new capacity installed / 1 e+006 ;[manyear]

total jobs WF12 = WITH LOOKUP (Time, ([(2000, 0) - (2020, 2 e+006)], (2001, 114000), (2005, 244000), (2010, 546600), (2015, 1.0682 e+006), (2020, 1.47 e+006))) ;[manyear]

total number of installed wind turbines = INTEG (+ new number of wind turbines - decommissioning number of installed wind turbines, initial number) ;[wind turbines]

world electricity supply = electricity generation coal + electricity generation gas + electricity generation hydro + electricity generation nuclear + electricity generation oil + electricity generation other renewables + total energy generated by wind capacity / 1 e+006 ;[TWh]

writeoff costs capacity installed = total cost capacity installed / lifetime wind capacity ;[€ / YEAR]

3 The sd2WF12 model

additional siting costs = WITH LOOKUP (gap maximum potential, ([(0, 0) - (10, 4000)], (0, 0), (0.7, 150), (1.4, 700), (2, 1400), (3, 2800))) ;[€ / kW] Assumption subject to sensitivity analysis.

additional study and construction costs = 0 ;[€ / kW]

annual CO2 emissions avoided = net specific CO2 emissions avoided * total energy generated by wind capacity / 1000 ;[tCO2] / 1000 to switch from MWh to GWh

annual CO2 emissions avoided cte = tCO2 avoided per GWh if constant mix * total energy generated by wind capacity / 1000 ;[tCO2]

annual CO2 emissions avoided WF12 = WITH LOOKUP (Time, ([(2001, 0) - (2100, 6 e+009)], (2001, 3.27 e+007), (2002, 4.39 e+007), (2003, 5.78 e+007), (2004, 7.53 e+007), (2005, 9.71 e+007), (2006, 1.244 e+008), (2007, 1.585 e+008), (2008, 1.99 e+008), (2009, 2.48 e+008), (2010, 3.07 e+008), (2011, 4.23 e+008), (2012, 5.18 e+008), (2013, 6.28 e+008), (2014, 7.53 e+008), (2015, 8.98 e+008), (2016, 1.057 e+009), (2017, 1.231 e+009), (2018, 1.424 e+009), (2019, 1.635 e+009), (2020, 1.856 e+009), (2020, 1.856 e+009), (2040, 4.8 e+009))) ;[tCO2]

annual total cost wind capacity = total cost capacity installed * (interest rate + operational and maintenance cost rate) + writeoff costs capacity installed ;[€]

average wind turbine size = WITH LOOKUP (cumulative historical number, ([(0, 0) - (4 e+006, 4)], (50000, 1), (86192.7, 1.2), (137274, 1.3), (187900, 1.4), (300000, 1.5), (611621, 1.68421), (990826, 1.78947), (1.44343 e+006, 1.91228), (1.98232 e+006, 2), (2.89908 e+006, 2.08772), (3.76758 e+006, 2.15789), (3.97554 e+006, 2.19298))) ;[MW / wind turbines]

average windyness factor = average windyness factor lookup(gap initial maximum potential) ;[dmnl]

average windyness factor lookup([(- 2, - 0.4) - (10, 10)], (0, 1.1), (0.5, 1), (1, 0.9), (2, 0.8), (3, 0.7)) ;[dmnl]

capacity cost of new decommissioned capacity = DELAY FIXED (total cost new capacity installed, lifetime wind capacity, 0) ;[€]

capacity cost of old decommissioned capacity = IF THEN ELSE(Time < INITIAL TIME + lifetime wind capacity, (initial cost 2001 * cost surplus rate historic capacity + additional study and construction costs + initial additional siting costs) * initial capacity * 1000 / lifetime wind capacity, 0) ;[€]

capacity factor improvement lookup([(0, 0) - (2 e+009, 1)], (56000, 0.25), (258338, 0.28), (2.28231 e+006, 0.3), (2 e+009, 0.35)) ;[1 / wind turbines]

CO2 emissions coal = electricity generation coal * specific CO2 emissions coal * 1000 ;[tCO2]

CO2 emissions gas = electricity generation gas * specific CO2 emissions gas * 1000 ;[tCO2]

CO2 emissions hydro = electricity generation hydro * specific CO2 emissions hydro * 1000 ;[tCO2]

CO2 emissions nuclear = electricity generation nuclear * specific CO2 emissions nuclear * 1000 ;[tCO2]

CO2 emissions oil = electricity generation oil * specific CO2 emissions oil * 1000 ;[tCO2]

CO2 emissions other renewables = electricity generation other renewables * specific CO2 emissions other renewables * 1000 ;[tCO2]

CO2 emissions wind = specific CO2 emissions wind * total energy generated by wind capacity / 1000 ;[tCO2] ;[/ 1000 to switch from MWh to GWh

"cost new capacity (t)" = "cost new capacity (t - 1)" * (cumulative historical number / "cu-

mulative historical number t - 1")∧ (- experience curve parameter) ;[€ / kW]

"cost new capacity (t + 1)" = INTEG ("cost new capacity (t)" - "cost new capacity (t - 1)", initial cost 2001) ;[€ / kW]

"cost new capacity (t - 1)" = "cost new capacity (t + 1)" ;[€ / kW]

cost surplus rate historic capacity = 1 ;[dmnl] This variable could increase the historic capacity cost above the 2001 cost. 1.2 would make it 20% more expensive.

"cost wind turbine electricity generated € / MWh" = annual total cost wind capacity / total energy generated by wind capacity ;[€ / MWh]

"cost wind turbine electricity generated €ct / kWh" = "cost wind turbine electricity generated € / MWh" * 100 / 1000 ;[€ct / kWh]

cumulative CO2 emissions avoided = INTEG (annual CO2 emissions avoided, 0) ;[tCO2]

cumulative CO2 emissions avoided cte = INTEG (annual CO2 emissions avoided cte, 0) ;[tCO2]

cumulative CO2 emissions avoided WF12 = INTEG (annual CO2 emissions avoided WF12, 0) ;[tCO2]

cumulative decommissioned capacity of installed wind turbines = INTEG (decommissioning capacity of installed wind turbines, 0) ;[MW]

cumulative decommissioned number of installed wind turbines = INTEG (decommissioning number of installed wind turbines, 0) ;[wind turbines]

cumulative historical number = cumulative decommissioned number of installed wind turbines + total number of installed wind turbines ;[wind turbines]

"cumulative historical number t - 1" = DELAY FIXED(cumulative historical number, 1, 56000) ;[wind turbines]

cumulatively improved capacity factor = capacity factor improvement lookup(cumulative historical number) ;[1 / wind turbines]

decommissioning capacity new = DELAY FIXED (new capacity of wind turbines, lifetime wind capacity, 0) ;[MW / year]

decommissioning capacity of installed wind turbines = decommissioning capacity new + decommissioning capacity old ;[MW / year]

decommissioning capacity old = IF THEN ELSE(Time < INITIAL TIME + lifetime wind capacity, initial capacity / lifetime wind capacity, 0) ;[MW / year]

decommissioning number new = DELAY FIXED(new number of wind turbines, lifetime wind capacity, 0) ;[wind turbines / year]

decommissioning number of installed wind turbines = decommissioning number new + decommissioning number old ;[wind turbines / year]

decommissioning number old = IF THEN ELSE(Time < INITIAL TIME + lifetime wind ca-

pacity, initial number / lifetime wind capacity, 0) ;[wind turbines / year]

drastic output reductions = IF THEN ELSE(expected profitability<0, 0.5, 1) ;[dmnl] A value of 0 means a 100% output reduction when profitability becomes negative, 0.5 means 50% and 1 means 0%.

electricity generation coal = WITH LOOKUP (Time, ([(2000, 0) - (2020, 10000)], (1997, 5337), (2010, 7467), (2020, 9763))) ;[TWh]

electricity generation gas = WITH LOOKUP (Time, ([(0, 0) - (2100, 8000)], (1997, 2159), (2010, 4698), (2020, 7745))) ;[TWh]

electricity generation hydro = WITH LOOKUP (Time, ([(0, 0) - (2100, 4000)], (1997, 2566), (2010, 3341), (2020, 3904))) ;[TWh]

electricity generation nuclear = WITH LOOKUP (Time, ([(2000, 0) - (2020, 4000)], (1997, 2393), (2010, 2647), (2020, 2369))) ;[TWh]

electricity generation oil = WITH LOOKUP (Time, ([(0, 0) - (2100, 2000)], (1997, 1282), (2010, 1442), (2020, 1498))) ;[TWh]

electricity generation other renewables = WITH LOOKUP (Time, ([(0, 0) - (2100, 800)], (1997, 211), (2010, 395), (2020, 603))) ;[TWh]

energy generated by new decommissioned capacity = DELAY FIXED(energy generation new capacity, lifetime wind capacity, 0) ;[MWh / (year * year)]

energy generated by old decommissioned capacity = IF THEN ELSE(Time < INITIAL TIME + lifetime wind capacity, energy gererated by initial capacity / lifetime wind capacity, 0) ;[MWh / (year * year)]

energy generation decommissioned capacity = energy generated by new decommissioned capacity + energy generated by old decommissioned capacity ;[MWh / (year * year)]

energy generation new capacity = on site capacity factor * hours per year * new capacity of wind turbines ;[MWh / (year * year)]

energy gererated by initial capacity = 5.4531 e+007 ;[MWh / year]

expected CO2 TEC price = WITH LOOKUP (share wind, ([(0, 0) - (10, 10)], (0, 10), (0.2, 10), (10, 10))) ;[€ / tCO2] 1 tCO2 costs €10. (However, there is no emission trading in the basecase.)

"expected cost NEW wind turbine electricity generated € / MWh" = marginal annual cost NEW wind capacity / marginal annual generation NEW wind capacity ;[€ / MWh]

"expected cost NEW wind turbine electricity generated €ct / kWh" = "expected cost NEW wind turbine electricity generated € / MWh" * 100 / 1000 ;[€ct / kWh]

"expected electricity generation price €ct / kWh" = 6 ;[€ct / kWh]

expected profitability = (("expected electricity generation price €ct / kWh" - "expected cost NEW wind turbine electricity generated €ct / kWh" * (1 - governmental wind turbine electricity aid rate)) * hours per year * on site capacity factor * lifetime wind capacity / 100 + net specific

CO2 emissions avoided * expected CO2 TEC price * switch CO2 trade and tax * hours per year * on site capacity factor * lifetime wind capacity / 1 e+006) / ("cost new capacity (t)") ;[dmnl] / 100 to go from €ct to € ; / 1000 to go from GW to kW. This function calculates roughly the expected profits before taxes divided by the expected capital costs of new wind turbines. Other formula's are possible and would influence the results.

experience curve parameter = - LOG(progress ratio, 2) ;[dmnl]

FINAL TIME = 2050 ;[year] The final time for the simulation.

gap initial maximum potential = total number of installed wind turbines / initial maximum potential ;[dmnl]

gap maximum potential = total number of installed wind turbines / maximum potential ;[dmnl]

governmental wind turbine electricity aid rate = IF THEN ELSE(Time<2010, 0.15, 0) ;[dmnl]

hours per year = 8760 ;[hours / year]

initial additional siting costs = 0 ;[€ / kW]

initial capacity = 24900 ;[MW]

initial cost 2001 = 879 ;[€ / kW]

initial maximum potential = 907313 ;[wind turbines] This is the value after which the growth percentage becomes 0 in the Wind Force 12 report. Therefore this value has been chosen as the initial maximum potential.

initial number = 56000 ;[wind turbines]

INITIAL TIME = 2001 ;[year] The initial time for the simulation.

installation jobs per MW = 5 ;[manyear / MW]

interest rate = 0.1 ;[dmnl] This is a 'world' interest rate.

jobyear per M€ lookup = WITH LOOKUP (Time, ([(1998, 0) - (2020, 40)], (1998, 22), (2005, 14.7), (2010, 12.2), (2015, 10.9), (2020, 9.8))) ;[manyear / M€]

jobyear per MW lookup = WITH LOOKUP (Time, ([(1998, 0) - (2020, 40)], (1998, 22), (2005, 14.7), (2010, 12.2), (2015, 10.9), (2020, 9.8))) ;[manyear / MW]

lifetime wind capacity = 20 ;[year]

manufacturing jobs per MW = 17 ;[manyear / MW]

marginal annual cost NEW wind capacity = ("cost new capacity (t)" + additional siting costs + additional study and construction costs) * 1000 * (interest rate + operational and maintenance cost rate + 1 / lifetime wind capacity) ;[€ / MW] x 1000 to go from kW to MW. 1 / lifetime wind capacity * ... represents the annual writeoff costs or capital instalment.

marginal annual generation NEW wind capacity = hours per year * on site capacity factor * marginal capacity ;[MWh / year]

marginal capacity = 1 ;[MW]

maximum potential = DELAY FIXED (initial cost 2001 / "cost new capacity (t + 1)" * initial maximum potential, 10, initial maximum potential) ;[wind turbines] The 10 - year delay has to do with the slow value - and legal changes.

net specific CO2 emissions avoided = specific CO2 emissions world generation mix - specific CO2 emissions wind ;[tCO2 / GWh]

new capacity growth = percentage growth new capacity of wind turbines * new wind turbines capacity capacity ;[MW / year / year]

new capacity of wind turbines = new wind turbines capacity capacity * drastic output reductions ;[MW / year]

new number of wind turbines = new capacity of wind turbines / average wind turbine size ;[wind turbines / year]

new wind turbines capacity capacity = INTEG (new capacity growth, 7225) ;[MW / year] With an initial value of 8500 in case of the Euler integration scheme, 7225 in case of the RK4 integration scheme.

new wind turbines capacity capacity WF12 = WITH LOOKUP (Time, ([(2000, 0) - (2150, 200000)], (2001, 6800), (2002, 8500), (2003, 10625), (2004, 13281), (2005, 16602), (2006, 20752), (2007, 25940), (2008, 31128), (2009, 37354), (2010, 44824), (2011, 53789), (2012, 64547), (2013, 74229), (2014, 85363), (2015, 98168), (2016, 107985), (2017, 118783), (2018, 130661), (2019, 143727), (2020, 150000), (2150, 150000))) ;[MW / year]

on site capacity factor = average windyness factor * cumulatively improved capacity factor ;[dmnl]

operational and maintenance cost rate = 0.03 ;[dmnl] 3% per year of installed capacity costs.

percentage growth new capacity of wind turbines = WITH LOOKUP (expected profitability, ([(- 1, 0) - (20, 1)], (- 1, 0), (0, 0), (0.25, 0.1), (0.5, 0.18), (1, 0.24), (2, 0.28), (4, 0.35), (8, 0.42), (16, 0.49))) ;[MW / year]

progress ratio = 0.9 ;[dmnl]

sales = "cost new capacity (t)" * 1000 * new capacity of wind turbines ;[€ / year]

SAVEPER = 1 ;[year] The frequency with which output is stored.

share wind = total energy generated by wind capacity / 1 e+006 / world electricity supply ;[dmnl]

specific CO2 emissions coal = 800 ;[tCO2 / GWh] 751 - 962 (WF12)

specific CO2 emissions gas = 400 ;[tCO2 / GWh] 400 (d'Haeseleer) - 428 (WF12)

specific CO2 emissions hydro = 8 ;[tCO2 / GWh] 8 - 15 (D'haeseleer, 1999)

specific CO2 emissions nuclear = 7 ;[tCO2 / GWh] 7 (D'haeseleer, 1999)

specific CO2 emissions oil = 726 ;[tCO2 / GWh] 726 (EWEA, 2002)

specific CO2 emissions other renewables = 100 ;[tCO2 / GWh] BIOMASS: 55 - 540 (D'haeseleer, 1999). Here, 'other renewables' stands for biomass.

specific CO2 emissions wind = 9 ;[tCO2 / GWh] 9 - 28 (D'haeseleer, 1999)

specific CO2 emissions world generation mix = total CO2 emissions / world electricity supply / 1000 ;[tCO2 / GWh]

switch CO2 trade and tax = 0 ;[dmnl] 0 or 1 switch to switch CO2 avoided remunerations on or off.

tCO2 avoided per GWh if constant mix = 600 ;[tCO2 / GWh]

TIME STEP = 1 ;[year] The time step for the simulation.

tot cap WF12 = WITH LOOKUP (Time, ([(2000, 0) - (2150, 4 e+006)], (2001, 24900), (2002, 33400), (2003, 44025), (2004, 57306), (2005, 73908), (2006, 94660), (2007, 120600), (2008, 151728), (2009, 189081), (2010, 233905), (2011, 287694), (2012, 352241), (2013, 426470), (2014, 511833), (2015, 610001), (2016, 717986), (2017, 836769), (2018, 967430), (2019, 1.11116 e+006), (2020, 1.26116 e+006), (2021, 1.41116 e+006), (2022, 1.56116 e+006), (2023, 1.71116 e+006), (2024, 1.84788 e+006), (2025, 1.98127 e+006), (2026, 2.11052 e+006), (2027, 2.23458 e+006), (2028, 2.35346 e+006), (2029, 2.4661 e+006), (2030, 2.57128 e+006), (2031, 2.66749 e+006), (2032, 2.75294 e+006), (2033, 2.82871 e+006), (2034, 2.89335 e+006), (2035, 2.94518 e+006), (2036, 2.9872 e+006), (2037, 3.01841 e+006), (2038, 3.03775 e+006), (2039, 3.04403 e+006), (2150, 3.04403 e+006))) ;[MW]

total capacity of installed wind turbines = INTEG (+ new capacity of wind turbines - decommissioning capacity of installed wind turbines, initial capacity) ;[MW]

total CO2 emissions = CO2 emissions coal + CO2 emissions hydro + CO2 emissions gas + CO2 emissions nuclear + CO2 emissions oil + CO2 emissions other renewables + CO2 emissions wind ;[tCO2]

total cost capacity installed = INTEG (+ total cost new capacity installed - total cost decommissioned capacity, (initial cost 2001 * cost surplus rate historic capacity + additional study and construction costs + initial additional siting costs) * initial capacity * 1000) ;[€]

total cost decommissioned capacity = capacity cost of new decommissioned capacity + capacity cost of old decommissioned capacity ;[€]

total cost new capacity installed = ("cost new capacity (t)" + additional study and construction costs + additional siting costs) * new capacity of wind turbines * 1000 ;[€] x 1000 to switch from kW to MW

total energy generated by wind capacity = INTEG (+ energy generation new capacity - energy generation decommissioned capacity, energy gererated by initial capacity) ;[MWh / year]

total jobs per MW = (installation jobs per MW + manufacturing jobs per MW) * new capacity of wind turbines ;[manyear / year]

total jobs per MW corrected = jobyear per MW lookup * new capacity of wind turbines ;[manyear / year]

total jobs per sales = 22 * sales / 1 e+006 ;[manyear / year]

total jobs per sales corrected = sales * jobyear per M€ lookup / 1 e+006 ;[manyear / year]

total jobs per total costs new capacity installed = 22 * total cost new capacity installed / 1 e+006 ;[manyear / year]

total jobs per total costs new capacity installed corrected = jobyear per M€ lookup * total cost new capacity installed / 1 e+006 ;[manyear / year]

total jobs WF12 = WITH LOOKUP (Time, ([(2000, 0) - (2020, 2 e+006)], (2001, 114000), (2005, 244000), (2010, 546600), (2015, 1.0682 e+006), (2020, 1.47 e+006))) ;[manyear / year] The jobs created as in the WF12 report.

total number of installed wind turbines = INTEG (+ new number of wind turbines - decommissioning number of installed wind turbines, initial number) ;[wind turbines]

world electricity supply = electricity generation coal + electricity generation gas + electricity generation hydro + electricity generation nuclear + electricity generation oil + electricity generation other renewables + total energy generated by wind capacity / 1 e+006 ;[TWh] 1 / 1000000 to transform wind energy from MWh to TWh

writeoff costs capacity installed = total cost capacity installed / lifetime wind capacity ;[€]