**Policy Pathways for Accelerating Electric Vehicle Adoption in Nigeria: A System Dynamics Approach**

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## Model Source code and instructions

### Instructions

1. **Building the model**

The paper and this supplementary material provides the full model description. The source code below allows replicating the exact formulations. The model is built in the Vensim PLE simulation environment (<http://vensim.com>), but the source code can be developed in any other environment. The provided equations are self-explanatory, but users can download supportive documentation from <https://github.com/abamichael/SD-Model-Nigeria> to find explanation.

1. **Model Source Code**

"INITIAL NO. OF CHARGING STATIONS" = 10

Units: Stations

Available Charging stations =

INTEG( Charging stations deployed

- Charging stations scrappage ,

"INITIAL NO. OF CHARGING STATIONS" )

Units: Stations

"Available Funds (Bioenergy)" =

INTEG( "Revenues (Bioenergy)"

- "Expenditures (Bioenergy)"

- "New generation capacity investment (Bioenergy)" ,

0)

Units: Dollars

"Available Funds (hydro)" =

INTEG( "Revenues (Hydro)"

- "Expenditures (hydro)"

- "New generation capacity investment (Hydro)" ,

0)

Units: Dollars

"Available Funds (NG CCGT)" =

INTEG( "Revenues (NG CCGT)"

- "Expenditures (NG CCGT)"

- "New generation capacity investment (NG CCGT)" ,

0)

Units: Dollars

"Available Funds (Solar)" =

INTEG( "Revenues (Solar)"

- "Expenditures (Solar)"

- "New generation capacity investment (Solar)" ,

0)

Units: Dollars

INITIAL REFUEL STATIONS = 6000

Units: Stations

Available refuel stations =

INTEG( refuel stations deployed

- Refuel stations scrappage ,

INITIAL REFUEL STATIONS )

Units: Stations

INITIAL BIOENERGY CAPACITY = 10

Units: MW

"Bio-energy capacity" =

INTEG( Bioenergy developing capacity

- Bioenergy retiring capacity ,

INITIAL BIOENERGY CAPACITY )

Units: MW

"1 Yr" = 1

Units: Year

COEFFICIENT OF POPULATION = 0.000117219

Units: Dmnl/People\*GWh

INITIAL POPULATION = 1.60953e+008

Units: People

Population =

INTEG( Births

+ Net Migration

- Deaths ,

INITIAL POPULATION )

Units: People

INTERCEPT = 6427.91

Units: GWh/Year

Other sectors =

COEFFICIENT OF POPULATION

\* Population

/ "1 Yr"

+ INTERCEPT

Units: GWh/Year

AVKT = 13621

Units: km/(Year\*Car)

EV FUEL ECONOMY = 0.2

Units: (kW\*h)/km

"Reference EV R&D Investment" = 5e+010

Units: USD

"Cumulative EV R&D Investment" =

INTEG( "EV R&D Investments" ,

"Reference EV R&D Investment" )

Units: USD

"EV R&D Learning rate" = 0.15

Units: Dmnl

"Strength of EV R&D Learning rate" =

- LOG ( "EV R&D Learning rate" ,

2)

Units: Dmnl

"EV R&D Factor" =

( "Cumulative EV R&D Investment"

/ "Reference EV R&D Investment" )

^ - "Strength of EV R&D Learning rate"

Units: Dmnl

Effective EV FE =

EV FUEL ECONOMY

\* "EV R&D Factor"

Units: (kW\*h)/km

INITIAL EV STOCK = 0

Units: Car

EV Stocks =

INTEG( EV New Sales

- EV Discards ,

INITIAL EV STOCK )

Units: Car

EV Electricity demand =

AVKT

\* Effective EV FE

\* EV Stocks

Units: (kW\*h)/Year

kWh to GWh converter = 1e-006

Units: GWh/(kW\*h)

Transport consumption =

EV Electricity demand

\* kWh to GWh converter

Units: GWh/Year

Sectoral Electricity demand =

Other sectors

+ Transport consumption

Units: GWh/Year

"Capacity factor (Bioenergy)" = 0.6

Units: Dmnl

hours per year = 8760

Units: h/Year

"Average Plant (Bioenergy) factor availability" = 0.8

Units: Dmnl

Bioenergy generation =

"Bio-energy capacity"

\* "Capacity factor (Bioenergy)"

\* hours per year

\* "Average Plant (Bioenergy) factor availability"

Units: (MW\*h)/Year

"Capacity factor (Hydro)" = 0.65

Units: Dmnl

INITIAL HYDRO CAPACITY = 2080

Units: MW

Hydropower capacity =

INTEG( Developing capacity

- Retiring capacity ,

INITIAL HYDRO CAPACITY )

Units: MW

"Average availability factor (Hydro)" = 0.9

Units: Dmnl

Hydropower generation =

"Capacity factor (Hydro)"

\* hours per year

\* Hydropower capacity

\* "Average availability factor (Hydro)"

Units: (MW\*h)/Year

"Capacity factor (NG CCGT)" = 0.8

Units: Dmnl

INITIAL NG CCGT CAPACITY = 6140

Units: MW

NG CCGT capacity =

INTEG( Developing NG CCGT capacity

- Retiring NG CCGT capacity ,

INITIAL NG CCGT CAPACITY )

Units: MW

"Average Availability factor (NG CCGT)" = 0.45

Units: Dmnl

NG CCGT Generation =

"Capacity factor (NG CCGT)"

\* hours per year

\* NG CCGT capacity

\* "Average Availability factor (NG CCGT)"

Units: (MW\*h)/Year

"Capacity factor (Solar)" = 0.19

Units: Dmnl

INITIAL SOLAR PV CAPACITY = 1

Units: MW

SOLAR PV capacity =

INTEG( Developing solar PV capacity

- Retiring Solar PV capacity ,

INITIAL SOLAR PV CAPACITY )

Units: MW

"Average Plant Availability Factor (Solar)" = 0.45

Units: Dmnl

Solar PV Generation =

"Capacity factor (Solar)"

\* hours per year

\* SOLAR PV capacity

\* "Average Plant Availability Factor (Solar)"

Units: (MW\*h)/Year

Total Electricity Generation =

Bioenergy generation

+ Hydropower generation

+ NG CCGT Generation

+ Solar PV Generation

Units: (MW\*h)/Year

GWh to MW converter = 0.001

Units: GWh/(MW\*h)

Load Factor = 0.6

Units: Dmnl

Generation cap deficit =

( Sectoral Electricity demand

- ( Total Electricity Generation

\* GWh to MW converter ) )

/ Load Factor

Units: GWh/Year

Power capacity deficit =

MAX ( 0,

Generation cap deficit

\* ( 1

/ GWh to MW converter )

\* ( 1

/ hours per year ) )

Units: MW

"Hist Mix (Bioenergy)" =

WITH LOOKUP( Time ,

([(2000,0)-(2023,0.0014)],(2000,0),(2001,0),(2002,0),(2003,0),(

2004,0),(2005,0),(2006,0),(2007,0),(2008,0),(2009,0),(2010,0.0012),(2011,0.0011

),(2012,0.001),(2013,0.0009),(2014,0.0009),(2015,0.0008),(2016,0.0008),(2017

,0.0008),(2018,0.0008),(2019,0.0008),(2020,0.0007),(2021,0.0014),(2022,0.0014

),(2023,0.0014),(2050,0) )

)

Units: Dmnl

CAPEX BIOENERGY = 2900

Units: USD/kW

DISCOUNT RATE = 0.11

Units: 1/Year

BIOENERGY PLANT LIFE = 20

Units: Year

Bioenergy CRF =

( DISCOUNT RATE

\* ( 1

+ DISCOUNT RATE

\* "1 Yr" )

^ ( BIOENERGY PLANT LIFE

/ "1 Yr" ) )

/ ( ( ( 1

+ DISCOUNT RATE

\* "1 Yr" )

^ ( BIOENERGY PLANT LIFE

/ "1 Yr" ) )

- 1)

Units: 1/Year

BIOENERGY FOM = 53.5

Units: USD/kW/Year

BIOENERGY CAPACITY FACTOR = 0.6

Units: Dmnl

BIOENERGY SPECIFIC FUEL = 0.004

Units: USD/Mbtu

BIOENERGY HEAT RATE =

1.5

/ 1000

Units: Mbtu/(h\*kW)

BIOENERGY VOM = 0.001

Units: USD/(h\*kW)

LCOE Bioenergy =

( ( ( CAPEX BIOENERGY

\* Bioenergy CRF )

+ BIOENERGY FOM )

/ ( hours per year

\* BIOENERGY CAPACITY FACTOR ) )

+ ( BIOENERGY SPECIFIC FUEL

\* BIOENERGY HEAT RATE )

+ BIOENERGY VOM

Units: USD/(h\*kW)

((Capex[Plant\_type]\*CRF[Plant\_type]+FOM[Plant\_type])/(8760\*Capaci

ty\_\_Factor[Plant\_type])) +

(Specific\_\_fuel[Plant\_type]\*Heat\_\_rate[Plant\_type])+VOM[Plant\_typ

e]

Initial Solar PV Capex = 1500

Units: USD/kW

SOLAR PV DECLINE RATE = 0.031

Units: Dmnl

INITIAL TIME = 2010

Units: Year

The initial time for the simulation.

SOLAR PV CAPEX =

Initial Solar PV Capex

\* ( 1

- SOLAR PV DECLINE RATE )

^ ( Time

- INITIAL TIME )

Units: USD/kW

SOLAR PV LIFE = 25

Units: Year

Solar CRF =

( DISCOUNT RATE

\* ( 1

+ DISCOUNT RATE

\* "1 Yr" )

^ ( SOLAR PV LIFE

/ "1 Yr" ) )

/ ( ( ( 1

+ DISCOUNT RATE

\* "1 Yr" )

^ ( SOLAR PV LIFE

/ "1 Yr" ) )

- 1)

Units: Dmnl/Year

SOLAR FOM = 30

Units: USD/(Year\*kW)

SOLAR CAPACITY FACTOR = 0.19

Units: Dmnl

SOLAR SPECIFIC FUEL = 0

Units: USD/Mbtu

SOLAR HEAT RATE = 0

Units: Mbtu/(h\*kW)

SOLAR VOM = 0.0001

Units: USD/(h\*kW)

LCOE Solar =

( ( SOLAR PV CAPEX

\* Solar CRF

+ SOLAR FOM )

/ ( hours per year

\* SOLAR CAPACITY FACTOR ) )

+ ( SOLAR SPECIFIC FUEL

\* SOLAR HEAT RATE )

+ SOLAR VOM

Units: USD/(h\*kW)

((Capex[Plant\_type]\*CRF[Plant\_type]+FOM[Plant\_type])/(8760\*Capaci

ty\_\_Factor[Plant\_type])) +

(Specific\_\_fuel[Plant\_type]\*Heat\_\_rate[Plant\_type])+VOM[Plant\_typ

e]

Capex = 1800

Units: USD/kW

HYDROPOWER LIFETIME = 40

Units: Year

Hydro CRF =

( DISCOUNT RATE

\* ( 1

+ DISCOUNT RATE

\* "1 Yr" )

^ ( HYDROPOWER LIFETIME

/ "1 Yr" ) )

/ ( ( ( 1

+ DISCOUNT RATE

\* "1 Yr" )

^ ( HYDROPOWER LIFETIME

/ "1 Yr" ) )

- 1)

Units: Dmnl/Year

FOM = 13.77

Units: USD/kW/Year

CAPACITY FACTOR = 0.65

Units: Dmnl

SPECIFIC FUEL = 0

Units: USD/Mbtu

HEAT RATE =

0

/ 1000

Units: Mbtu/(h\*kW)

VOM = 0.001

Units: USD/(h\*kW)

LCOE Hydro =

( ( Capex

\* Hydro CRF

+ FOM )

/ ( hours per year

\* CAPACITY FACTOR ) )

+ ( SPECIFIC FUEL

\* HEAT RATE )

+ VOM

Units: USD/(h\*kW)

((Capex[Plant\_type]\*CRF[Plant\_type]+FOM[Plant\_type])/(8760\*Capaci

ty\_\_Factor[Plant\_type])) +

(Specific\_\_fuel[Plant\_type]\*Heat\_\_rate[Plant\_type])+VOM[Plant\_typ

e]

NG CCGT Capex = 1000

Units: USD/kW

NG CCGT LIFE = 40

Units: Year

NG CCGT CRF =

( DISCOUNT RATE

\* ( 1

+ DISCOUNT RATE

\* "1 Yr" )

^ ( NG CCGT LIFE

/ "1 Yr" ) )

/ ( ( ( 1

+ DISCOUNT RATE

\* "1 Yr" )

^ ( NG CCGT LIFE

/ "1 Yr" ) )

- 1)

Units: Dmnl/Year

NG CCGT FOM = 15.5

Units: USD/kW/Year

NG CCGT CAPACITY FACTOR = 0.8

Units: Dmnl

NG CCGT SPECIFIC FUEL = 3.3

Units: USD/Mbtu

NG CCGT HEAT RATE =

11039

\* 1e-006

Units: Mbtu/(h\*kW)

NG CCGT VOM = 0.006

Units: USD/(h\*kW)

LCOE NG CCGT =

( ( ( NG CCGT Capex

\* NG CCGT CRF )

+ NG CCGT FOM )

/ ( hours per year

\* NG CCGT CAPACITY FACTOR ) )

+ ( NG CCGT SPECIFIC FUEL

\* NG CCGT HEAT RATE )

+ NG CCGT VOM

Units: USD/(h\*kW)

((Capex[Plant\_type]\*CRF[Plant\_type]+FOM[Plant\_type])/(8760\*Capaci

ty\_\_Factor[Plant\_type])) +

(Specific\_\_fuel[Plant\_type]\*Heat\_\_rate[Plant\_type])+VOM[Plant\_typ

e]

"Relative Benefit (Bioenergy)" =

MAX ( LCOE Bioenergy ,

LCOE Solar )

- LCOE Bioenergy

+ MIN ( LCOE Hydro ,

LCOE NG CCGT )

Units: USD/(h\*kW)

ARRAYMAX(LCOE[\*])-LCOE[Plant\_type]+ARRAYMIN(LCOE[\*])

"Relative Benefit (Solar)" =

MAX ( LCOE Bioenergy ,

LCOE Solar )

- LCOE Solar

+ MIN ( LCOE Hydro ,

LCOE NG CCGT )

Units: USD/(h\*kW)

ARRAYMAX(LCOE[\*])-LCOE[Plant\_type]+ARRAYMIN(LCOE[\*])

"Relative Benefit (NG CCGT)" =

MAX ( LCOE Bioenergy ,

LCOE Solar )

- LCOE NG CCGT

+ MIN ( LCOE Hydro ,

LCOE NG CCGT )

Units: USD/(h\*kW)

ARRAYMAX(LCOE[\*])-LCOE[Plant\_type]+ARRAYMIN(LCOE[\*])

"Relative Benefit (Hydro)" =

MAX ( LCOE Bioenergy ,

LCOE Solar )

- LCOE Hydro

+ MIN ( LCOE Hydro ,

LCOE NG CCGT )

Units: USD/(h\*kW)

ARRAYMAX(LCOE[\*])-LCOE[Plant\_type]+ARRAYMIN(LCOE[\*])

Emissions weight = 0.1

Units: Dmnl [0,1,0.1]

"Emission factor (Bioenergy)" = 0.23

Units: kgCO2/(h\*kW)

"Emission factor (Hydro)" = 0.01

Units: kgCO2/(h\*kW)

"Emission factor (NG CCGT)" = 0.55

Units: kgCO2/(h\*kW)

"Emission factor (Solar)" = 0.07

Units: kgCO2/(h\*kW)

"Overall Relative benefits (Bioenergy)" =

MAX ( ( "Relative Benefit (Bioenergy)"

/ ( "Relative Benefit (Solar)"

+ "Relative Benefit (NG CCGT)"

+ "Relative Benefit (Hydro)"

+ "Relative Benefit (Bioenergy)" ) )

- Emissions weight

\* ( "Emission factor (Bioenergy)"

/ ( "Emission factor (Bioenergy)"

+ "Emission factor (Hydro)"

+ "Emission factor (NG CCGT)"

+ "Emission factor (Solar)" ) ) ,

0)

Units: Dmnl

MAX(Relative\_Benefit[Plant\_type]/ARRAYSUM(Relative\_Benefit[\*]) -

elect\_mix\_\_Emissions\_weight\*(Emission\_factors[Plant\_type]/ARRAYSU

M(Emission\_factors[\*])),0)

"Overall Relative benefits (Hydro)" =

MAX ( ( "Relative Benefit (Hydro)"

/ ( "Relative Benefit (Solar)"

+ "Relative Benefit (NG CCGT)"

+ "Relative Benefit (Hydro)"

+ "Relative Benefit (Bioenergy)" ) )

- Emissions weight

\* ( "Emission factor (Hydro)"

/ ( "Emission factor (Bioenergy)"

+ "Emission factor (Hydro)"

+ "Emission factor (NG CCGT)"

+ "Emission factor (Solar)" ) ) ,

0)

Units: Dmnl

"Overall Relative benefits (NG CCGT)" =

MAX ( ( "Relative Benefit (NG CCGT)"

/ ( "Relative Benefit (Solar)"

+ "Relative Benefit (NG CCGT)"

+ "Relative Benefit (Hydro)"

+ "Relative Benefit (Bioenergy)" ) )

- Emissions weight

\* ( "Emission factor (NG CCGT)"

/ ( "Emission factor (Bioenergy)"

+ "Emission factor (Hydro)"

+ "Emission factor (NG CCGT)"

+ "Emission factor (Solar)" ) ) ,

0)

Units: Dmnl

"Overall Relative benefits (Solar)" =

MAX ( ( "Relative Benefit (Solar)"

/ ( "Relative Benefit (Solar)"

+ "Relative Benefit (NG CCGT)"

+ "Relative Benefit (Hydro)"

+ "Relative Benefit (Bioenergy)" ) )

- Emissions weight

\* ( "Emission factor (Solar)"

/ ( "Emission factor (Bioenergy)"

+ "Emission factor (Hydro)"

+ "Emission factor (NG CCGT)"

+ "Emission factor (Solar)" ) ) ,

0)

Units: Dmnl

Total benefits =

"Overall Relative benefits (Bioenergy)"

+ "Overall Relative benefits (Hydro)"

+ "Overall Relative benefits (NG CCGT)"

+ "Overall Relative benefits (Solar)"

Units: Dmnl

"Percentage of mix (Bioenergy)" =

IF THEN ELSE ( Time

< 2023,

"Hist Mix (Bioenergy)" ,

IF THEN ELSE ( Total benefits

> 0,

"Overall Relative benefits (Bioenergy)"

/ Total benefits ,

0) )

Units: Dmnl

"Unit cost of New investment (Bioenergy)" = 2.9e+006

Units: USD/MW

"Financial Resources Req for New Investment (Bioenergy)" =

( ( Power capacity deficit

\* "Percentage of mix (Bioenergy)"

\* "Unit cost of New investment (Bioenergy)" )

/ "Capacity factor (Bioenergy)" )

Units: USD

"Financial sufficiency (Bioenergy)" =

MIN ( "Available Funds (Bioenergy)"

/ "1 Yr" ,

"Financial Resources Req for New Investment (Bioenergy)"

/ "1 Yr" )

Units: Dollars/Year

"Realized Generation capacity (Bioenergy)" =

MAX ( "Financial sufficiency (Bioenergy)"

/ "Unit cost of New investment (Bioenergy)" ,

0)

Units: MW/Year

Bioenergy plant Construction time = 2

Units: Year

Bioenergy developing capacity =

"Realized Generation capacity (Bioenergy)"

/ Bioenergy plant Construction time

Units: MW/Year

Bioenergy retiring capacity =

DELAY FIXED ( Bioenergy developing capacity ,BIOENERGY PLANT LIFE ,

INITIAL BIOENERGY CAPACITY

/ BIOENERGY PLANT LIFE )

Units: \*\*undefined\*\*

INITIAL CHARGER TO EV RATIO = 1.38

Units: Stations/Car

Charger to EV ratio =

INTEG( Change in EV Charger ratio ,

INITIAL CHARGER TO EV RATIO )

Units: Stations/Car

Charging stations under construction =

INTEG( CHARGING STATIONS IN PLANNING

- Charging stations deployed ,

0)

Units: Stations

INITIAL CRUDE OIL RESERVES = 37000

Units: MBBL

Crude oil reserves =

INTEG( - Oil production ,

INITIAL CRUDE OIL RESERVES )

Units: MBBL

"Reference Battery R&D Investment" = 5e+010

Units: USD

"Cumulative Battery R&D investment" =

INTEG( "Battery R&D investment" ,

"Reference Battery R&D Investment" )

Units: USD

"Reference ICV R&D Investment" = 1e+009

Units: USD

"Cumulative ICV R&D Investment" =

INTEG( "ICV R&D Investments" ,

"Reference ICV R&D Investment" )

Units: USD

"Hist Mix (Hydro)" =

WITH LOOKUP( Time ,

([(2000,0.3215)-(2023,0.1959)],(2000,0.3215),(2001,0.3215),(2002

,0.3081),(2003,0.3081),(2004,0.3081),(2005,0.2877),(2006,0.2877),(2007,0.2715

),(2008,0.2503),(2009,0.2447),(2010,0.2444),(2011,0.242),(2012,0.218),(2013

,0.1983),(2014,0.1983),(2015,0.1692),(2016,0.1676),(2017,0.1675),(2018,0.1601

),(2019,0.1585),(2020,0.1594),(2021,0.1557),(2022,0.1553),(2023,0.1959),(2050

,0) )

)

Units: Dmnl

"Percentage of mix (Hydro)" =

IF THEN ELSE ( Time

< 2023,

"Hist Mix (Hydro)" ,

IF THEN ELSE ( Total benefits

> 0,

"Overall Relative benefits (Hydro)"

/ Total benefits ,

0) )

Units: Dmnl

MAX HYDROPOWER CAPACITY = 11000

Units: MW

Max possible new hydro capacity =

MAX ( 0,

MAX HYDROPOWER CAPACITY

- Hydropower capacity )

Units: MW

"Unit cost of New investment (Hydro)" = 1.8e+006

Units: USD/MW

"Financial Resources Req for New Investment (Hydro)" =

( ( MIN ( Power capacity deficit

\* "Percentage of mix (Hydro)" ,

Max possible new hydro capacity )

\* "Unit cost of New investment (Hydro)" )

/ "Capacity factor (Hydro)" )

Units: USD

"Financial sufficiency (Hydro)" =

MIN ( "Available Funds (hydro)"

/ "1 Yr" ,

"Financial Resources Req for New Investment (Hydro)"

/ "1 Yr" )

Units: Dollars/Year

"Realized Generation capacity (Hydro)" =

MAX ( "Financial sufficiency (Hydro)"

/ "Unit cost of New investment (Hydro)" ,

0)

Units: MW/Year

Construction time = 5

Units: Year

Developing capacity =

DELAY FIXED ( "Realized Generation capacity (Hydro)" ,Construction time

,

"Realized Generation capacity (Hydro)" )

Units: MW/Year

"Hist Mix (NG)" =

WITH LOOKUP( Time ,

([(2000,0.64)-(2023,0.78)],(2000,0.64),(2001,0.64),(2002,0.65),

(2003,0.65),(2004,0.65),(2005,0.67),(2006,0.67),(2007,0.69),(2008,0.72),(2009

,0.72),(2010,0.72),(2011,0.72),(2012,0.75),(2013,0.77),(2014,0.77),(2015,0.81

),(2016,0.81),(2017,0.81),(2018,0.82),(2019,0.82),(2020,0.82),(2021,0.82),(

2022,0.82),(2023,0.78),(2050,0) )

)

Units: Dmnl

"Percentage of mix (NG CCGT)" =

IF THEN ELSE ( Time

< 2023,

"Hist Mix (NG)" ,

IF THEN ELSE ( Total benefits

> 0,

"Overall Relative benefits (NG CCGT)"

/ Total benefits ,

0) )

Units: Dmnl

"Unit cost of New investment (NG CCGT)" = 1e+006

Units: USD/MW

"Financial Resources Req for New Investment (NG CCGT)" =

( ( Power capacity deficit

\* "Percentage of mix (NG CCGT)"

\* "Unit cost of New investment (NG CCGT)" )

/ "Capacity factor (NG CCGT)" )

Units: USD

"Financial sufficiency (NG CCGT)" =

MIN ( "Available Funds (NG CCGT)"

/ "1 Yr" ,

"Financial Resources Req for New Investment (NG CCGT)"

/ "1 Yr" )

Units: Dollars/Year

"Realized Generation capacity (NG CCGT)" =

MAX ( "Financial sufficiency (NG CCGT)"

/ "Unit cost of New investment (NG CCGT)" ,

0)

Units: MW/Year

NG CCGT Construction time = 3

Units: Year

Developing NG CCGT capacity =

DELAY FIXED ( "Realized Generation capacity (NG CCGT)" ,NG CCGT Construction time

,

"Realized Generation capacity (NG CCGT)" )

Units: MW/Year

"Hist Mix (Solar)" =

WITH LOOKUP( Time ,

([(2000,0)-(2023,0.0076)],(2000,0),(2001,0),(2002,0),(2003,0),(

2004,0),(2005,0),(2006,0),(2007,0),(2008,0),(2009,0),(2010,1e-007),(2011,1e-007

),(2012,1e-007),(2013,1e-007),(2014,1e-007),(2015,0.0008),(2016,0.0008),(2017

,0.0016),(2018,0.0015),(2019,0.003),(2020,0.0037),(2021,0.0051),(2022,0.0072

),(2023,0.0076),(2050,0) )

)

Units: Dmnl

"Percentage of mix (Solar)" =

IF THEN ELSE ( Time

< 2023,

"Hist Mix (Solar)" ,

IF THEN ELSE ( Total benefits

> 0,

"Overall Relative benefits (Solar)"

/ Total benefits ,

0) )

Units: Dmnl

kW to MW = 1000

Units: (h\*kW)/(MW\*h)

"Unit cost of New investment (Solar)" =

SOLAR PV CAPEX

\* kW to MW

Units: USD/MW

"Financial Resources Req for New Investment (Solar)" =

( ( Power capacity deficit

\* "Percentage of mix (Solar)"

\* "Unit cost of New investment (Solar)" )

/ "Capacity factor (Solar)" )

Units: USD

"Financial sufficiency (Solar)" =

MIN ( "Available Funds (Solar)"

/ "1 Yr" ,

"Financial Resources Req for New Investment (Solar)"

/ "1 Yr" )

Units: Dollars/Year

"Realized Generation capacity (Solar)" =

MAX ( "Financial sufficiency (Solar)"

/ "Unit cost of New investment (Solar)" ,

0)

Units: MW/Year

SOLAR PV Construction time = 1

Units: Year

Developing solar PV capacity =

DELAY FIXED ( "Realized Generation capacity (Solar)" ,SOLAR PV Construction time

,

"Realized Generation capacity (Solar)" )

Units: MW/Year

EV emissions =

INTEG( "EV emissions flow-in"

- EV Emissions outflow ,

0)

Units: kgCO2

INITIAL NETWORK EFFECT = 0

Units: Dmnl

EV Network effect =

INTEG( Network effect gain

- Network effect loss ,

INITIAL NETWORK EFFECT )

Units: Dmnl

INITIAL GROSS DOMESTIC PRODUCT = 3.6699e+011

Units: Dollars

Gross Domestic Product =

INTEG( Change in GDP ,

INITIAL GROSS DOMESTIC PRODUCT )

Units: Dollars

INITIAL HDI = 0.488

Units: Dmnl

"Human Development Index (HDI)" =

INTEG( Change in HDI ,

INITIAL HDI )

Units: Dmnl

ICV emissions =

INTEG( "ICV emissions flow-in"

- ICV Emissions outflow ,

0)

Units: kgCO2

Reference ICV Experience = 1e+008

Units: Car

ICV Experience =

INTEG( Annual Experience increase ,

Reference ICV Experience )

Units: Car

ICV INITIAL NETWORK EFFECT = 1

Units: Dmnl

ICV Network effect =

INTEG( ICV Network effect gain

- ICV Network effect loss ,

ICV INITIAL NETWORK EFFECT )

Units: Dmnl

INITIAL ICV STOCK = 2.4e+006

Units: Car

ICV Stocks =

INTEG( ICV New Sales

- ICV Discards ,

INITIAL ICV STOCK )

Units: Car

Refuel stations under construction =

INTEG( Refuel stations in planning

- refuel stations deployed ,

0)

Units: Stations

Retiring capacity =

DELAY FIXED ( Developing capacity ,HYDROPOWER LIFETIME ,

INITIAL HYDRO CAPACITY

/ HYDROPOWER LIFETIME )

Units: MW/Year

Retiring NG CCGT capacity =

DELAY FIXED ( Developing NG CCGT capacity ,NG CCGT LIFE ,

INITIAL NG CCGT CAPACITY

/ NG CCGT LIFE )

Units: MW/Year

Retiring Solar PV capacity =

DELAY FIXED ( Developing solar PV capacity ,SOLAR PV LIFE ,

INITIAL SOLAR PV CAPACITY

/ SOLAR PV LIFE )

Units: MW/Year

INITIAL VEHICLE STOCK = 2.4e+006

Units: Car

total vehicle market =

INTEG( Sales

- Discards ,

INITIAL VEHICLE STOCK )

Units: Car

"1 Person" = 1

Units: People/USD

MAX AUTO density = 0.1

Units: Car/People

Current Auto density =

total vehicle market

/ Population

Units: Car/People

Initial Auto Density =

INITIAL VEHICLE STOCK

/ INITIAL POPULATION

Units: Car/People

Normalized Auto density gap =

( MAX AUTO density

- Current Auto density )

/ ( MAX AUTO density

- Initial Auto Density )

Units: Dmnl

growth rate adjustment multiplier =

WITH LOOKUP( Normalized Auto density gap ,

([(0,0.1)-(1,1.5)],(0,0.1),(0.5,0.9),(1,1.5) )

)

Units: Dmnl

MARKET GROWTH RATE = 0.112

Units: 1/Year

Adjusted Growth rate =

growth rate adjustment multiplier

\* MARKET GROWTH RATE

Units: 1/Year

"Annual EV Battery R&D Investment" = 2e+009

Units: USD/Year

"Annual EV R & D Investments" = 1e+009

Units: USD/Year

Sales =

Adjusted Growth rate

\* total vehicle market

Units: Car/Year

ICV Coefficient of affordability = -1

Units: Dmnl

Based cost LR = 0.2

Units: Dmnl

Strength of base cost LR =

- LOG ( Based cost LR ,

2)

Units: Dmnl

Base cost Experience factor =

( ICV Experience

/ Reference ICV Experience )

^ - Strength of base cost LR

Units: Dmnl

INITIAL BASE COST = 15000

Units: USD

Base cost cost update =

Base cost Experience factor

\* INITIAL BASE COST

Units: USD

IC engine cost = 3000

Units: USD

IC Engine cost learning rate = 0.15

Units: Dmnl

strength of learning rate =

- LOG ( IC Engine cost learning rate ,

2)

Units: Dmnl

ICV Experience factor =

( ICV Experience

/ Reference ICV Experience )

^ - strength of learning rate

Units: Dmnl

IC Engine cost Update =

IC engine cost

\* ICV Experience factor

Units: USD

ICV Cost =

Base cost cost update

+ IC Engine cost Update

Units: USD

Profit Markup = 0.1

Units: Dmnl

VAT = 0.075

Units: Dmnl

VEHICLE PURCHASE TAX = 0.35

Units: Dmnl

POLICY START DATE = 2025

Units: Year

POLICY DURATION = 15

Units: Year

ICV MSRP =

ICV Cost

\* ( 1

+ Profit Markup )

\* ( 1

+ VAT )

\* ( 1

+ VEHICLE PURCHASE TAX

\* PULSE ( POLICY START DATE ,

POLICY DURATION ) )

Units: USD

GDP per capita =

Gross Domestic Product

/ Population

Units: Dollars/People

GDP =

GDP per capita

\* "1 Person"

Units: Dmnl

"LN(GDP)" =

LN ( GDP )

Units: Dmnl

ICV Relative Affordability Utility =

( ICV MSRP

/ 1000)

/ "LN(GDP)"

Units: Dmnl

Reference Affordability = 1

Units: Dmnl

Effect of Affordability =

ICV Coefficient of affordability

\* ( ICV Relative Affordability Utility

/ Reference Affordability )

Units: Dmnl

ICV Cultural Index coefficient = 0.057894

Units: Dmnl

National Cultural Index = 0.597

Units: Dmnl

Effect of culture on ICV adoption =

ICV Cultural Index coefficient

\* National Cultural Index

Units: Dmnl

"Sensitivity of ICV O&M cost" = -0.1898

Units: Dmnl/USD\*km

ICV Maintenance cost = 0.077

Units: USD/km

ICV FUEL ECONOMY = 0.083

Units: L/km

"ICV R&D Learning rate" = 0.2

Units: Dmnl

"Strength of ICV R&D Learning rate" =

- LOG ( "ICV R&D Learning rate" ,

2)

Units: Dmnl

"ICV R&D Factor" =

( "Cumulative ICV R&D Investment"

/ "Reference ICV R&D Investment" )

^ - "Strength of ICV R&D Learning rate"

Units: Dmnl

Effective ICV FE =

ICV FUEL ECONOMY

\* "ICV R&D Factor"

Units: L/km

Fuel Prices =

WITH LOOKUP( Time ,

([(2000,22)-(2060,1239)],(2000,22),(2001,26),(2002,30),(2003,40

),(2004,55),(2005,60),(2006,65),(2007,70),(2008,65),(2009,65),(2010,65),(2011

,65),(2012,120),(2013,120),(2014,120),(2015,145),(2016,145),(2017,145.35),(

2018,145.35),(2019,145.35),(2020,167.27),(2021,165.77),(2022,206.19),(2023,

671.86),(2024,1184.83),(2025,1239),(2060,1239) )

)

Units: NGN/L

Fx exchange rate =

WITH LOOKUP( Time ,

([(105.34,105.34)-(2050,1500.68)],(2000,105.34),(2001,114.99),(

2002,122.32),(2003,132.03),(2004,133.21),(2005,131.75),(2006,128.41),(2007,

125.33),(2008,119.5),(2009,149.85),(2010,151.12),(2011,156.15),(2012,158.43

),(2013,159.42),(2014,166.1),(2015,198.22),(2016,260.1),(2017,305.6),(2018,

305.55),(2019,306),(2020,366.35),(2021,400.59),(2022,423.99),(2023,651.26),

(2024,1508),(2050,1500.68) )

)

Units: NGN/USD

Fuel Prices USD =

Fuel Prices

/ Fx exchange rate

Units: USD/L

"Effect of ICV O&M Cost" =

"Sensitivity of ICV O&M cost"

\* ( ICV Maintenance cost

+ Effective ICV FE

\* Fuel Prices USD )

Units: Dmnl

Sensitivity of ICV Range = 4.5385

Units: Dmnl

ICV Tank size = 35

Units: L

ICV effective range =

ICV Tank size

/ Effective ICV FE

Units: km

Desirable Range = 500

Units: km

ICV Relative Range Index =

ICV effective range

/ Desirable Range

Units: Dmnl

effect of ICV Range =

Sensitivity of ICV Range

\* ICV Relative Range Index

Units: Dmnl

ICV refueling station coverage coefficient = 0.47616

Units: Dmnl

Total stations =

Available Charging stations

+ Available refuel stations

Units: Stations

Refuel stations coverage =

Available refuel stations

/ Total stations

Units: Dmnl

Reference Charging station coverage = 0.2

Units: Dmnl

Effect of ICV Refuel station coverage =

ICV refueling station coverage coefficient

\* ( Refuel stations coverage

/ Reference Charging station coverage )

Units: Dmnl

ICV Utility =

EXP ( Effect of Affordability )

\* EXP ( Effect of culture on ICV adoption )

\* EXP ( "Effect of ICV O&M Cost" )

\* EXP ( effect of ICV Range )

\* EXP ( Effect of ICV Refuel station coverage )

Units: Dmnl

ICV Attractiveness =

ICV Network effect

\* ICV Utility

Units: Dmnl

EV Cultural Index Coefficient = 0.0001

Units: Dmnl

Effect of culture =

EV Cultural Index Coefficient

\* National Cultural Index

Units: Dmnl

Battery capacity = 37

Units: kW\*h

Battery cost learning rate = 0.1

Units: Dmnl

Strength of Battery cost Learning rate =

- LOG ( Battery cost learning rate ,

2)

Units: Dmnl

EV Battery cost factor =

( "Cumulative Battery R&D investment"

/ "Reference Battery R&D Investment" )

^ - Strength of Battery cost Learning rate

Units: Dmnl

Unit Battery cost = 1182.9

Units: USD/(kW\*h)

"Battery cost- update" =

MAX ( 70,

EV Battery cost factor

\* Unit Battery cost )

Units: USD/(kW\*h)

EV Cost =

Battery capacity

\* "Battery cost- update"

+ Base cost cost update

Units: USD

EV Subsidy = 0.15

Units: Dmnl

EV MSRP =

( EV Cost

\* ( 1

- EV Subsidy ) )

\* ( 1

+ Profit Markup )

\* ( 1

+ VAT )

Units: USD

EV Relative Affordability Utility =

( EV MSRP

/ 1000)

/ "LN(GDP)"

Units: Dmnl

Sensitivity of EV affordability = -1.9354

Units: Dmnl

Effect of EV Affordability =

( EV Relative Affordability Utility

/ Reference Affordability )

\* Sensitivity of EV affordability

Units: Dmnl

Charging station coverage =

Available Charging stations

/ Total stations

Units: Dmnl

SENSITIVITY OF EV CHARGING STATION COVERAGE = 0.6239

Units: Dmnl

Effect of EV charging station coverage =

( Charging station coverage

/ Reference Charging station coverage )

\* SENSITIVITY OF EV CHARGING STATION COVERAGE

Units: Dmnl

EV effective range =

Battery capacity

/ Effective EV FE

Units: km

EV Relative Range Index =

EV effective range

/ Desirable Range

Units: Dmnl

Sensitivity of EV Range = 6

Units: Dmnl

Effect of EV Range =

EV Relative Range Index

\* Sensitivity of EV Range

Units: Dmnl

EV Maintenance cost = 0.052

Units: USD/km

Average Generation cost =

( LCOE Bioenergy

+ LCOE Hydro

+ LCOE NG CCGT

+ LCOE Solar )

/ 4

Units: USD/(h\*kW)

Transmission and distribution costs = 10.4

Units: NGN/(h\*kW)

ATC and C Losses =

WITH LOOKUP( Time ,

([(0.38,0.38)-(2050,0.08)],(2000,0.38),(2001,0.39),(2002,0.38),

(2003,0.33),(2004,0.31),(2005,0.24),(2006,0.31),(2007,0.12),(2008,0.09),(2009

,0.06),(2010,0.17),(2011,0.1),(2012,0.09),(2013,0.15),(2014,0.16),(2050,0.1

) )

)

Units: Dmnl

Inflation rate =

WITH LOOKUP( Time ,

([(0,0)-(2050,0.3)],(2000,0.07),(2001,0.19),(2002,0.13),(2003,0.14

),(2004,0.15),(2005,0.18),(2006,0.08),(2007,0.05),(2008,0.12),(2009,0.13),(

2010,0.14),(2011,0.11),(2012,0.12),(2013,0.09),(2014,0.08),(2015,0.09),(2016

,0.16),(2017,0.17),(2018,0.12),(2019,0.11),(2020,0.13),(2021,0.17),(2022,0.19

),(2023,0.25),(2050,0.15) )

)

Units: Dmnl

ROI = 0.1

Units: Dmnl

Subsidy =

WITH LOOKUP( Time ,

([(18.98,18.98)-(2050,0)],(2010,18.98),(2011,14.83),(2012,13.35

),(2013,13.9),(2014,13.91),(2015,12.41),(2016,11.09),(2017,13.99),(2018,10.95

),(2019,17.7),(2020,28.26),(2021,34.13),(2022,38.73),(2023,70.54),(2024,0),

(2050,0) )

)

Units: NGN/(h\*kW)

Electricity tariff =

( ( Average Generation cost

\* Fx exchange rate )

+ Transmission and distribution costs )

\* ( 1

+ ATC and C Losses )

\* ( 1

+ Inflation rate )

\* ( 1

+ ROI )

- Subsidy

Units: NGN/(h\*kW)

((((SUM(Gen\_cost\*Fx\_rate[Tariff],Trans\_Distr\_Admin\_cost)\*(1+ATC\_a

nd\_C\_losses[Elect\_Tarriff])))\*(1+Inflation))\*(1+ROI))-Subsidy

Electricity tariff USD =

Electricity tariff

/ Fx exchange rate

Units: USD/(h\*kW)

"Sensitivity of O&M cost" = -0.07884

Units: Dmnl/USD\*(km)

"Effect of O&M Cost" =

( EV Maintenance cost

+ Effective EV FE

\* Electricity tariff USD )

\* "Sensitivity of O&M cost"

Units: Dmnl

EV Utility =

EXP ( Effect of culture )

\* EXP ( Effect of EV Affordability )

\* EXP ( Effect of EV charging station coverage )

\* EXP ( Effect of EV Range )

\* EXP ( "Effect of O&M Cost" )

Units: Dmnl

EV Attractiveness =

EV Network effect

\* EV Utility

Units: Dmnl

Total Attractiveness =

EV Attractiveness

+ ICV Attractiveness

Units: Dmnl

Share of ICV Sales =

ICV Attractiveness

/ Total Attractiveness

Units: Dmnl

ICV New Sales =

Sales

\* Share of ICV Sales

Units: Car/Year

Annual Experience increase =

ICV New Sales

Units: Car/Year

"Annual ICV R & D Investments" = 1e+007

Units: USD/Year

AVERAGE DAILY PRODUCTION =

WITH LOOKUP( Time ,

([(2.45,2.45)-(2050,2.5)],(2008,2.45),(2011,2.37),(2012,2.34),(

2013,2.19),(2014,2.05),(2015,2.2),(2016,1.9),(2017,1.97),(2018,2),(2019,2.1

),(2020,1.89),(2021,1.68),(2022,1.45),(2023,1.54),(2024,1.5),(2025,2),(2030

,2.5),(2050,2.5) )

)

Units: MBBL/Day

Bioenergy emissions =

Bioenergy generation

\* "Emission factor (Bioenergy)"

\* kW to MW

Units: kgCO2/Year

"Elect. emissions (NG CCGT)" =

"Emission factor (NG CCGT)"

\* kW to MW

\* NG CCGT Generation

Units: kgCO2/Year

Hydropower Emissions =

"Emission factor (Hydro)"

\* Hydropower generation

\* kW to MW

Units: kgCO2/Year

Solar PV Emissions =

"Emission factor (Solar)"

\* kW to MW

\* Solar PV Generation

Units: kgCO2/Year

Electricity Generation emissions =

Bioenergy emissions

+ "Elect. emissions (NG CCGT)"

+ Hydropower Emissions

+ Solar PV Emissions

Units: kgCO2/Year

MWh to KWh = 0.001

Units: (MW\*h)/(kW\*h)

AVERAGE ELECTRICITY SUPPLY EMISSIONS =

Electricity Generation emissions

/ ( Total Electricity Generation

\* ( 1

/ MWh to KWh ) )

Units: kgCO2/(kW\*h)

Average electricity supply emissions per km =

AVERAGE ELECTRICITY SUPPLY EMISSIONS

\* Effective EV FE

Units: kgCO2/km

PETROL FUEL SUPPLY EMISSION FACTOR = 0.5519

Units: kgCO2/L

Average petrol fuel emissions per km =

PETROL FUEL SUPPLY EMISSION FACTOR

\* Effective ICV FE

Units: kgCO2/km

"Battery R&D investment" =

"Annual EV Battery R&D Investment"

Units: USD/Year

BBL to MBBL Converter = 1e+006

Units: BBL/MBBL

HISTORICAL BIRTH RATE =

WITH LOOKUP( Time ,

([(0.043147,0.043147)-(2050,0.026929)],(2000,0.043147),(2001,0.043084

),(2002,0.04302),(2003,0.042956),(2004,0.042753),(2005,0.042551),(2006,0.042348

),(2007,0.042146),(2008,0.041943),(2009,0.041658),(2010,0.041374),(2011,0.041089

),(2012,0.040805),(2013,0.04052),(2014,0.040036),(2015,0.039551),(2016,0.039067

),(2017,0.038582),(2018,0.038098),(2019,0.037684),(2020,0.037269),(2021,0.036855

),(2022,0.03644),(2023,0.036026),(2024,0.035683),(2025,0.035341),(2030,0.033666

),(2050,0.026929) )

)

Units: 1/Year

Births =

Population

\* HISTORICAL BIRTH RATE

Units: People/Year

"Capacity utilization (Bioenergy)" =

WITH LOOKUP( Time ,

([(0.31,0.31)-(2050,0.88)],(2000,0.31),(2001,0.27),(2002,0.36),

(2003,0.22),(2004,0.45),(2005,0.4),(2006,0.43),(2007,0.44),(2008,0.49),(2009

,0.46),(2010,0.48),(2024,0.48),(2050,0.88) )

)

Units: Dmnl

"Capacity utilization (Hydro)" =

WITH LOOKUP( Time ,

([(0.31,0.31)-(2050,0.88)],(2000,0.31),(2001,0.27),(2002,0.36),

(2003,0.22),(2004,0.45),(2005,0.4),(2006,0.43),(2007,0.44),(2008,0.49),(2009

,0.46),(2010,0.48),(2024,0.48),(2050,0.88) )

)

Units: Dmnl

"Capacity utilization (NG CCGT)" =

WITH LOOKUP( Time ,

([(0.31,0.31)-(2050,0.88)],(2000,0.31),(2001,0.27),(2002,0.36),

(2003,0.22),(2004,0.45),(2005,0.4),(2006,0.43),(2007,0.44),(2008,0.49),(2009

,0.46),(2010,0.48),(2024,0.48),(2050,0.88) )

)

Units: Dmnl

"Capacity utilization (Solar)" =

WITH LOOKUP( Time ,

([(0.31,0.31)-(2050,0.88)],(2000,0.31),(2001,0.27),(2002,0.36),

(2003,0.22),(2004,0.45),(2005,0.4),(2006,0.43),(2007,0.44),(2008,0.49),(2009

,0.46),(2010,0.48),(2024,0.48),(2050,0.88) )

)

Units: Dmnl

CHARGER TO EVE RATIO LIMIT = 0.04

Units: Stations/Car

TIME TO CHANGE CHARGER TO EV ARTIO = 30

Units: Year

Change in EV Charger ratio =

( CHARGER TO EVE RATIO LIMIT

- Charger to EV ratio )

/ TIME TO CHANGE CHARGER TO EV ARTIO

Units: Stations/(Year\*Car)

GDP GROWTH RATE =

WITH LOOKUP( Time ,

([(0.025,0.025)-(2050,0.1)],(2010,0.129366),(2011,0.119441),(2012

,0.121012),(2013,0.103951),(2014,-0.141343),(2015,-0.179255),(2016,-0.0714283

),(2017,0.122406),(2018,0.125144),(2019,-0.0891824),(2020,0.0199786),(2021,

0.0829559),(2022,-0.237864),(2024,0.025),(2025,0.03),(2050,0.03),(2075,0.03

) )

)

Units: 1/Year

Change in GDP =

( GDP GROWTH RATE

\* Gross Domestic Product )

Units: Dollars/Year

HDI LIMIT = 1

Units: Dmnl

TIME TO CHANGE HDI = 97

Units: Year

Change in HDI =

( HDI LIMIT

- "Human Development Index (HDI)" )

/ TIME TO CHANGE HDI

Units: Dmnl/Year

Optimal charger required =

Charger to EV ratio

\* EV Stocks

Units: Stations

Total Chargers =

Available Charging stations

+ Charging stations under construction

Units: Stations

Charging station deficit =

MAX ( 0,

Optimal charger required

- Total Chargers )

Units: Stations

CHARGING STATION LIFESPAN = 20

Units: Year

Time to Deploy Charging station = 1

Units: Year

Charging stations deployed =

ZIDZ ( Charging stations under construction ,

Time to Deploy Charging station )

Units: Stations/Year

GOVT CHARGING STATION INVEST =

2000

\* PULSE ( 2025,

5)

Units: Stations

CHARGING STATIONS IN PLANNING APPROVAL RATE = 1

Units: Year

CHARGING STATIONS IN PLANNING =

( Charging station deficit

+ GOVT CHARGING STATION INVEST )

/ CHARGING STATIONS IN PLANNING APPROVAL RATE

Units: Stations/Year

Charging stations scrappage =

ZIDZ ( Available Charging stations ,

CHARGING STATION LIFESPAN )

Units: Stations/Year

DAYS OF THE YEAR = 365

Units: Days/Year

"HIST. DEATH RATE" =

WITH LOOKUP( Time ,

([(0.017842,0.017842)-(2050,0.008195)],(2000,0.017842),(2001,0.01766

),(2002,0.017479),(2003,0.017298),(2004,0.016863),(2005,0.016428),(2006,0.015993

),(2007,0.015558),(2008,0.015123),(2009,0.0148),(2010,0.014478),(2011,0.014155

),(2012,0.013833),(2013,0.01351),(2014,0.013201),(2015,0.012892),(2016,0.012583

),(2017,0.012274),(2018,0.011965),(2019,0.011771),(2020,0.011577),(2021,0.011382

),(2022,0.011188),(2023,0.010994),(2024,0.010833),(2025,0.010672),(2030,0.009923

),(2050,0.008195) )

)

Units: 1/Year

Deaths =

"HIST. DEATH RATE"

\* Population

Units: People/Year

DIRECT CONTACT EFFECT = 0.25

Units: Dmnl/Year

EV LIFETIME = 14.6401

Units: Year

EV Discards =

EV Stocks

/ EV LIFETIME

Units: Car/Year

ICV LIFETIME = 20

Units: Year

ICV Discards =

ICV Stocks

/ ICV LIFETIME

Units: Car/Year

Total Vehicle Discards =

EV Discards

+ ICV Discards

Units: Car/Year

Discards =

Total Vehicle Discards

Units: Car/Year

REFERENCE SOCIAL EXPOSURE = 0.05

Units: 1/Year

epsilon =

1

/ REFERENCE SOCIAL EXPOSURE

Units: Year

EV Market Share =

EV Stocks

/ total vehicle market

Units: Dmnl

INDIRECT CONTACT EFFECT = 0.15

Units: Dmnl/Year

MARKETING EFFECTIVENESS = 1.5e-011

Units: Dmnl/USD

MARKETING SPENDING = 1.5e+008

Units: Dollars/Year

EV MARKETING DURATION = 15

Units: Year

MARKETING EFFECT =

IF THEN ELSE ( Time

>= POLICY START DATE ,

MARKETING EFFECTIVENESS

\* MARKETING SPENDING

\* PULSE ( POLICY START DATE ,

EV MARKETING DURATION ) ,

MARKETING EFFECTIVENESS

\* MARKETING SPENDING

\* PULSE ( POLICY START DATE ,

EV MARKETING DURATION ) )

Units: Dmnl/Year

Total network effect =

DIRECT CONTACT EFFECT

\* EV Market Share

+ INDIRECT CONTACT EFFECT

\* EV Market Share

+ MARKETING EFFECT

Units: Dmnl/Year

Effect of social exposure on forgetfulness =

EXP ( -4

\* epsilon

\* ( Total network effect

- REFERENCE SOCIAL EXPOSURE ) )

/ ( 1

+ EXP ( -4

\* epsilon

\* ( Total network effect

- REFERENCE SOCIAL EXPOSURE ) ) )

Units: Dmnl

"Elect-BBL converter" = 0.000588441

Units: BBL/(kW\*h)

EMBODIED EMISSIONS = 0.016

Units: kgCO2/km

kgCO2 to TCO2 converter = 1000

Units: kgCO2/TCO2

Total Transport emissions =

( EV emissions

+ ICV emissions )

/ kgCO2 to TCO2 converter

Units: TCO2

Emissions per car =

Total Transport emissions

/ total vehicle market

Units: TCO2/Car

Emissions per KWh =

Electricity Generation emissions

/ Total Electricity Generation

Units: MW\*h/kgCO2

EV TAIL PIPE EMISSION = 0

Units: kgCO2/km

"EV emissions flow-in" =

( Average electricity supply emissions per km

+ EMBODIED EMISSIONS

+ EV TAIL PIPE EMISSION )

\* EV Stocks

\* AVKT

Units: kgCO2/Year

EV Emissions outflow =

EV emissions

/ "1 Yr"

Units: kgCO2/Year

Share of EV sales =

EV Attractiveness

/ Total Attractiveness

Units: Dmnl

EV New Sales =

Sales

\* Share of EV sales

Units: Car/Year

"EV R&D Investments" =

"Annual EV R & D Investments"

\* PULSE ( 2025,

20)

Units: USD/Year

"Expenditures (Bioenergy)" =

"Bio-energy capacity"

\* kW to MW

\* hours per year

\* LCOE Bioenergy

\* "Capacity utilization (Bioenergy)"

Units: USD/Year

"Expenditures (hydro)" =

Hydropower capacity

\* kW to MW

\* hours per year

\* LCOE Hydro

\* "Capacity utilization (Hydro)"

Units: USD/Year

"Expenditures (NG CCGT)" =

NG CCGT capacity

\* kW to MW

\* hours per year

\* LCOE NG CCGT

\* "Capacity utilization (NG CCGT)"

Units: USD/Year

"Expenditures (Solar)" =

SOLAR PV capacity

\* kW to MW

\* hours per year

\* LCOE Solar

\* "Capacity utilization (Solar)"

Units: USD/Year

EXPORT DEMAND =

2

\* 365

Units: MBBL/Year

FINAL TIME = 2075

Units: Year

The final time for the simulation.

FORGETTING RATE = 0.00424

Units: 1/Year [0,?,1]

Petrol Fuel Demand =

AVKT

\* Effective ICV FE

\* ICV Stocks

Units: L/Year

"Petrol Fuel-BBL Converter" =

1

/ 159

Units: BBL/L

Total fuel demand =

( "Elect-BBL converter"

\* EV Electricity demand )

+ ( Petrol Fuel Demand

\* "Petrol Fuel-BBL Converter" )

Units: BBL/Year

Fuel Demand per car =

ZIDZ ( Total fuel demand ,

total vehicle market )

Units: BBL/(Year\*Car)

HIST NET MIGRATION =

WITH LOOKUP( Time ,

([(-0.000203,-0.000203)-(2050,-0.000157)],(2000,-0.000203),(2001

,-0.000222),(2002,-0.000241),(2003,-0.00026),(2004,-0.000289),(2005,-0.000318

),(2006,-0.000346),(2007,-0.000375),(2008,-0.000404),(2009,-0.000394),(2010

,-0.000384),(2011,-0.000373),(2012,-0.000363),(2013,-0.000353),(2014,-0.000344

),(2015,-0.000336),(2016,-0.000327),(2017,-0.000319),(2018,-0.00031),(2019,

-0.000303),(2020,-0.000295),(2021,-0.000288),(2022,-0.00028),(2023,-0.000273

),(2024,-0.000267),(2025,-0.000261),(2030,-0.000235),(2050,-0.0001566) )

)

Units: 1/Year

ICV DIRECT CONTACT EFFECT = 0.25

Units: Dmnl/Year

ICV REFERENCE SOCIAL EXPOSURE = 0.24

Units: 1/Year

ICV epsilon =

1

/ ICV REFERENCE SOCIAL EXPOSURE

Units: Year

ICV Market share =

ICV Stocks

/ total vehicle market

Units: Dmnl

ICV INDIRECT CONTACT EFFECT = 0.05

Units: Dmnl/Year

ICV MARKETING EFFECTIVENESS = 4.29e-005

Units: Dmnl/Year

ICV Total network effect =

ICV DIRECT CONTACT EFFECT

\* ICV Market share

+ ICV INDIRECT CONTACT EFFECT

\* ICV Market share

+ ICV MARKETING EFFECTIVENESS

Units: Dmnl/Year

ICV Effect of social exposure on forgetfulness =

EXP ( -4

\* ICV epsilon

\* ( ICV Total network effect

- ICV REFERENCE SOCIAL EXPOSURE ) )

/ ( 1

+ EXP ( -4

\* ICV epsilon

\* ( ICV Total network effect

- ICV REFERENCE SOCIAL EXPOSURE ) ) )

Units: Dmnl

ICV EMBODIED EMISSIONS = 0.016

Units: kgCO2/km

ICV TAIL PIPE EMISSION = 0.012

Units: kgCO2/km

"ICV emissions flow-in" =

( Average petrol fuel emissions per km

+ ICV EMBODIED EMISSIONS

+ ICV TAIL PIPE EMISSION )

\* ICV Stocks

\* AVKT

Units: kgCO2/Year

ICV Emissions outflow =

ICV emissions

/ "1 Yr"

Units: kgCO2/Year

ICV FORGETTING RATE = 0.2

Units: 1/Year [0,?,1]

ICV Network effect gain =

ICV Total network effect

\* ( 1

- ICV Network effect )

Units: Dmnl/Year

ICV Network effect loss =

ICV Effect of social exposure on forgetfulness

\* ICV FORGETTING RATE

\* ICV Network effect

Units: Dmnl/Year

"ICV R&D Investments" =

"Annual ICV R & D Investments"

\* PULSE ( 2025,

20)

Units: USD/Year

ICV REFUELING STATIONS IN PLANNING APPROVAL RATE = 5.12

Units: Year

IDEAL REFUEL STATIONS TO EV RATIO = 0.000819

Units: Stations/Car

Net Migration =

HIST NET MIGRATION

\* Population

Units: People/Year

Network effect gain =

Total network effect

\* ( 1

- EV Network effect )

Units: Dmnl/Year

Network effect loss =

Effect of social exposure on forgetfulness

\* FORGETTING RATE

\* EV Network effect

Units: Dmnl/Year

"New generation capacity investment (Bioenergy)" =

"Financial sufficiency (Bioenergy)"

Units: Dollars/Year

"New generation capacity investment (Hydro)" =

"Financial sufficiency (Hydro)"

Units: Dollars/Year

"New generation capacity investment (NG CCGT)" =

"Financial sufficiency (NG CCGT)"

Units: Dollars/Year

"New generation capacity investment (Solar)" =

"Financial sufficiency (Solar)"

Units: Dollars/Year

Oil production =

AVERAGE DAILY PRODUCTION

\* DAYS OF THE YEAR

Units: MBBL/Year

Passenger transport demand =

Petrol Fuel Demand

\* "Petrol Fuel-BBL Converter"

Units: BBL/Year

Oil export =

MIN ( EXPORT DEMAND ,

Oil production

- ( Passenger transport demand

/ BBL to MBBL Converter ) )

Units: MBBL/Year

optimal refuel stations =

ICV Stocks

\* IDEAL REFUEL STATIONS TO EV RATIO

Units: Stations

REFUEL STATION COMMISSIONING TIME = 1

Units: Year

Total Refuel stations =

Available refuel stations

+ Refuel stations under construction

Units: Stations

Refuel station deficit =

MAX ( 0,

optimal refuel stations

- Total Refuel stations )

Units: Stations

REFUEL STATION LIFESPAN = 25

Units: Year

refuel stations deployed =

ZIDZ ( Refuel stations under construction ,

REFUEL STATION COMMISSIONING TIME )

Units: Stations/Year

Refuel stations in planning =

Refuel station deficit

/ ICV REFUELING STATIONS IN PLANNING APPROVAL RATE

Units: Stations/Year

Refuel stations scrappage =

ZIDZ ( Available refuel stations ,

REFUEL STATION LIFESPAN )

Units: Stations/Year

"Tariff USD/MWh" =

Electricity tariff USD

\* kW to MW

Units: USD/(MW\*h)

"Revenues (Bioenergy)" =

"Capacity utilization (Bioenergy)"

\* hours per year

\* "Bio-energy capacity"

\* "Tariff USD/MWh"

Units: USD/Year

"Revenues (Hydro)" =

"Capacity utilization (Hydro)"

\* hours per year

\* Hydropower capacity

\* "Tariff USD/MWh"

Units: USD/Year

"Revenues (NG CCGT)" =

"Capacity utilization (NG CCGT)"

\* hours per year

\* NG CCGT capacity

\* "Tariff USD/MWh"

Units: USD/Year

"Revenues (Solar)" =

"Capacity utilization (Solar)"

\* hours per year

\* SOLAR PV capacity

\* "Tariff USD/MWh"

Units: USD/Year

TIME STEP = 0.125

Units: Year [0,?]

The time step for the simulation.

SAVEPER =

TIME STEP

Units: Year [0,?]

The frequency with which output is stored.

Total Generation capacity =

"Bio-energy capacity"

+ NG CCGT capacity

+ Hydropower capacity

+ SOLAR PV capacity

Units: MW