DICE2016inR

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Contents

An R-version of DICE2016 model, with step-by-step translation from GAMS

This is a *standalone* R-version of DICE2016 model, with (commented) original GAMS-code lines, folowed by R-interpretation. This R-version of the model reproduces identical results to the GAMS version (excluding some minor differences at the end of the model horizon, which are behind normaly reported analyses, based on the model, and can be ignored).

Model SETs and PARAMETERs

```
#set
t <- 1:100 #  Time periods (5 years per period)                  /1*100/
NT <- length(t) # Total number of periods for convenience

#PARAMETERS
#** Availability of fossil fuels
        fosslim <- 6000 # Maximum cumulative extraction fossil fuels (GtC)  /6000/
#**Time Step
        tstep  <- 5 #  Years per Period                                /5/
#** If optimal control
        ifopt  <- 0 #  Indicator where optimized is 1 and base is 0      /0/
#** Preferences
        elasmu <- 1.45 #  Elasticity of marginal utility of consumption     /1.45 /
        prstp <- 0.015 #   Initial rate of social time preference per year   /.015/
#** Population and technology
        gama  <- .300 #   Capital elasticity in production function         /.300 /
        pop0  <- 7403   # Initial world population 2015 (millions)          /7403 /
        popadj <- 0.134 #  Growth rate to calibrate to 2050 pop projection  /0.134/
        popasym <- 11500 # Asymptotic population (millions)                 /11500/
        dk  <- .100 #     Depreciation rate on capital (per year)           /.100 /
```

```r
        q0  <- 105.5 #     Initial world gross output 2015 (trill 2010 USD) /105.5/
        k0  <- 223 #     Initial capital value 2015 (trill 2010 USD)       /223  /
        a0  <- 5.115 #     Initial level of total factor productivity      /5.115/
        ga0  <- 0.076 #    Initial growth rate for TFP per 5 years         /0.076/
        dela  <- 0.005 #   Decline rate of TFP per 5 years                 /0.005/
#** Emissions parameters
        gsigma1  <- -0.0152 # Initial growth of sigma (per year)           /-0.0152/
        dsig  <- -0.001 #   Decline rate of decarbonization (per period)    /-0.001 /
        eland0 <- 2.6 #  Carbon emissions from land 2015 (GtCO2 per year)   / 2.6   /
        deland <- .115 # Decline rate of land emissions (per period)        / .115  /
        e0   <- 35.85 #    Industrial emissions 2015 (GtCO2 per year)       /35.85  /
        miu0  <- .03 #   Initial emissions control rate for base case 2015  /.03    /
#** Carbon cycle
#* Initial Conditions
        mat0 <- 851 #  Initial Concentration in atmosphere 2015 (GtC)       /851  /
        mu0  <- 460 #  Initial Concentration in upper strata 2015 (GtC)     /460  /
        ml0  <- 1740 #  Initial Concentration in lower strata 2015 (GtC)    /1740 /
        mateq <- 588 # mateq Equilibrium concentration atmosphere  (GtC)    /588  /
        mueq  <- 360 # mueq Equilibrium concentration in upper strata (GtC) /360  /
        mleq <- 1720 # mleq Equilibrium concentration in lower strata (GtC) /1720 /
#* Flow paramaters
        b12  <- .12 #    Carbon cycle transition matrix                     /.12  /
        b23  <- 0.007 #   Carbon cycle transition matrix                    /0.007/
#* These are for declaration and are defined later
        b11  <- NULL   # Carbon cycle transition matrix
        b21  <- NULL  # Carbon cycle transition matrix
        b22  <- NULL  # Carbon cycle transition matrix
        b32  <- NULL  # Carbon cycle transition matrix
        b33  <- NULL  # Carbon cycle transition matrix
        sig0  <- NULL  # Carbon intensity 2010 (kgCO2 per output 2005 USD 2010)
#** Climate model parameters
        t2xco2  <- 3.1 # Equilibrium temp impact (oC per doubling CO2)    / 3.1 /
        fex0  <- 0.5 #   2015 forcings of non-CO2 GHG (Wm-2)              / 0.5 /
        fex1  <- 1.0 #   2100 forcings of non-CO2 GHG (Wm-2)              / 1.0 /
        tocean0  <- .0068 # Initial lower stratum temp change (C from 1900) /.0068/
        tatm0  <- 0.85 #  Initial atmospheric temp change (C from 1900)    /0.85/
        c1  <- 0.1005 #     Climate equation coefficient for upper level  /0.1005/
        c3  <- 0.088 #     Transfer coefficient upper to lower stratum    /0.088/
        c4  <- 0.025 #     Transfer coefficient for lower level           /0.025/
        fco22x  <- 3.6813 # Forcings of equilibrium CO2 doubling (Wm-2)   /3.6813 /
#** Climate damage parameters
        a10  <- 0 #     Initial damage intercept                        /0   /
        a20  <- NULL #     Initial damage quadratic term
        a1  <- 0 #      Damage intercept                                /0   /
        a2  <- 0.00236 #      Damage quadratic term                    /0.00236/
        a3  <- 2.00 #      Damage exponent                             /2.00   /
#** Abatement cost
        expcost2 <- 2.6 # Exponent of control cost function            / 2.6  /
        pback  <- 550 #   Cost of backstop 2010$ per tCO2 2015          / 550  /
        gback  <- .025 #   Initial cost decline backstop cost per period / .025/
        limmiu  <- 1.2 #  Upper limit on control rate after 2150        / 1.2 /
        tnopol  <- 45 #  Period before which no emissions controls base  / 45   /
        cprice0  <- 2 # Initial base carbon price (2010$ per tCO2)      / 2    /
```

```
        gcprice  <- .02 # Growth rate of base carbon price per year     /.02  /

#** Scaling and inessential parameters
#* Note that these are unnecessary for the calculations
#* They ensure that MU of first period's consumption =1 and PV cons = PV utilty
        scale1  <- 0.0302455265681763 #    Multiplicative scaling coefficient           /0.030245526568
        scale2  <- -10993.704 #    Additive scaling coefficient       /-10993.704/;

#* Program control variables
#sets     tfirst(t), tlast(t), tearly(t), tlate(t);

# PARAMETERS
#          l(t)          Level of population and labor
#          al(t)         Level of total factor productivity
#          sigma(t)      CO2-equivalent-emissions output ratio
#          rr(t)         Average utility social discount rate
#          ga(t)         Growth rate of productivity from
#          forcoth(t)    Exogenous forcing for other greenhouse gases
#          gl(t)         Growth rate of labor
#          gcost1        Growth of cost factor
#          gsig(t)       Change in sigma (cumulative improvement of energy efficiency)
#          etree(t)      Emissions from deforestation
#          cumetree(t)   Cumulative from land
#          cost1(t)      Adjusted cost for backstop
#          lam           Climate model parameter
#          gfacpop(t)    Growth factor population
#          pbacktime(t)  Backstop price
#          optlrsav      Optimal long-run savings rate used for transversality
#          scc(t)        Social cost of carbon
#          cpricebase(t) Carbon price in base case
#          photel(t)     Carbon Price under no damages (Hotelling rent condition)
#          ppm(t)        Atmospheric concentrations parts per million
#          atfrac(t)     Atmospheric share since 1850
#          atfrac2010(t)     Atmospheric share since 2010 ;
```

Model Variables and Equations

```
## Declaration in R is not needed
# VARIABLES
#          MIU(t)           Emission control rate GHGs
#          FORC(t)          Increase in radiative forcing (watts per m2 from 1900)
#          TATM(t)          Increase temperature of atmosphere (degrees C from 1900)
#          TOCEAN(t)        Increase temperature of lower oceans (degrees C from 1900)
#          MAT(t)           Carbon concentration increase in atmosphere (GtC from 1750)
#          MU(t)            Carbon concentration increase in shallow oceans (GtC from 1750)
#          ML(t)            Carbon concentration increase in lower oceans (GtC from 1750)
#          E(t)             Total CO2 emissions (GtCO2 per year)
#          EIND(t)          Industrial emissions (GtCO2 per year)
#          C(t)             Consumption (trillions 2005 US dollars per year)
#          K(t)             Capital stock (trillions 2005 US dollars)
#          CPC(t)           Per capita consumption (thousands 2005 USD per year)
#          I(t)             Investment (trillions 2005 USD per year)
```

```
#         S(t)            Gross savings rate as fraction of gross world product
#         RI(t)           Real interest rate (per annum)
#         Y(t)            Gross world product net of abatement and damages (trillions 2005 USD per year
#         YGROSS(t)       Gross world product GROSS of abatement and damages (trillions 2005 USD per ye
#         YNET(t)         Output net of damages equation (trillions 2005 USD per year)
#         DAMAGES(t)      Damages (trillions 2005 USD per year)
#         DAMFRAC(t)      Damages as fraction of gross output
#         ABATECOST(t)    Cost of emissions reductions  (trillions 2005 USD per year)
#         MCABATE(t)      Marginal cost of abatement (2005$ per ton CO2)
#         CCA(t)          Cumulative industrial carbon emissions (GTC)
#         CCATOT(t)       Total carbon emissions (GtC)
#         PERIODU(t)      One period utility function
#         CPRICE(t)       Carbon price (2005$ per ton of CO2)
#         CEMUTOTPER(t)   Period utility
#         UTILITY         Welfare function;
#
# NONNEGATIVE VARIABLES  MIU, TATM, MAT, MU, ML, Y, YGROSS, C, K, I;
#
# EQUATIONS
# *Emissions and Damages
#         EEQ(t)           Emissions equation
#         EINDEQ(t)        Industrial emissions
#         CCACCA(t)        Cumulative industrial carbon emissions
#         CCATOTEQ(t)        Cumulative total carbon emissions
#         FORCE(t)         Radiative forcing equation
#         DAMFRACEQ(t)     Equation for damage fraction
#         DAMEQ(t)         Damage equation
#         ABATEEQ(t)       Cost of emissions reductions equation
#         MCABATEEQ(t)     Equation for MC abatement
#         CARBPRICEEQ(t)   Carbon price equation from abatement
#
# *Climate and carbon cycle
#         MMAT(t)          Atmospheric concentration equation
#         MMU(t)           Shallow ocean concentration
#         MML(t)           Lower ocean concentration
#         TATMEQ(t)        Temperature-climate equation for atmosphere
#         TOCEANEQ(t)      Temperature-climate equation for lower oceans
#
# *Economic variables
#         YGROSSEQ(t)      Output gross equation
#         YNETEQ(t)        Output net of damages equation
#         YY(t)            Output net equation
#         CC(t)            Consumption equation
#         CPCE(t)          Per capita consumption definition
#         SEQ(t)           Savings rate equation
#         KK(t)            Capital balance equation
#         RIEQ(t)          Interest rate equation
#
# * Utility
#         CEMUTOTPEREQ(t)  Period utility
#         PERIODUEQ(t)     Instantaneous utility function equation
#         UTIL             Objective function      ;
```

DICE equations as R-functions

All equations are converted to functions of other variables. Parameters are taken from the global environment, i.e. we do not parcing them to functions expliciely. Variables are denoted with uppercase letters, exogenous parameters - lowercase (excluding Labor). If time **t** is specifies, the functions return a scalar for the time. Otherwise, the output will the the whole vector. For recursive variables the previous vector should be also specified if only one value is expected.

The model has two control variables (their values are result of the following optimisation routine): **S** - savings rate, which manages intertemporal equilibrium between generations **MIU** - emissions control rate, manages level of controlled emissions.

The objective

The objective is formulated as an R function of two control variables (MIU and S), which are now parameters in the function optimization problem. The solution of the model is then a finding a maxima of the function subject to parameters *MIU* and *S*. The base-run of DICE modes can be formulated reqursively without additional constrains on variables (like TATM or fosslim). Hotteling and low-carbon scenarios require additional constrain functions, which are discussed later.

Solving the model

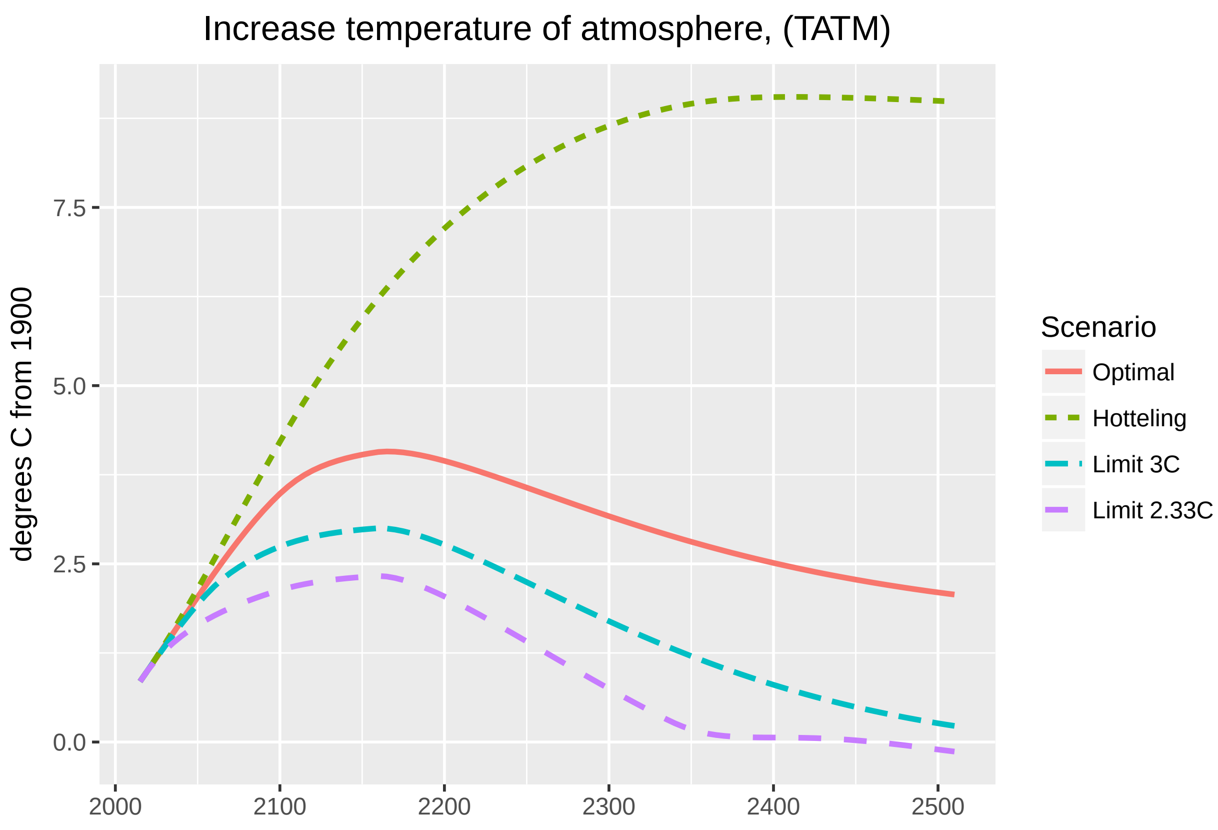
If no other constrains imposed on any other than control DICE variables, the problem can be solved with a non-linear solver.

Estimating Social Costs of Carbon (SCC)

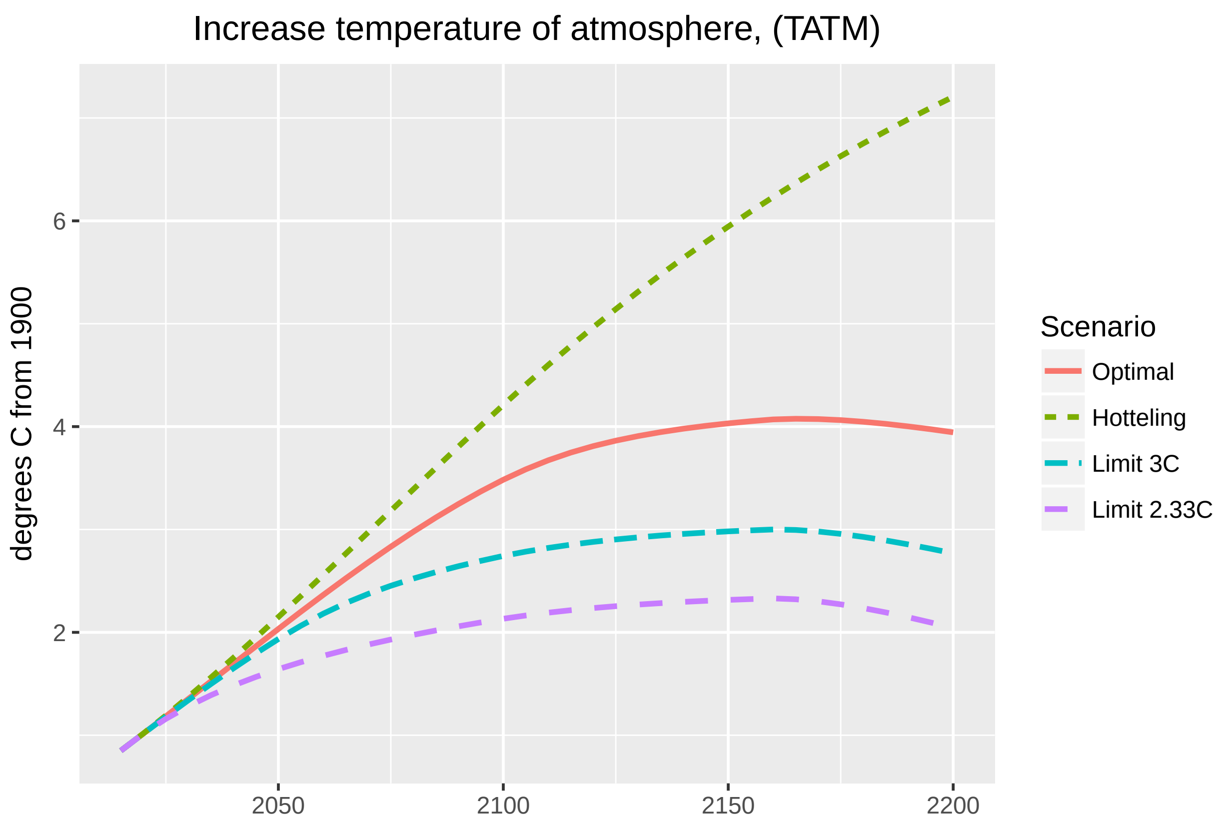
Solving with limits on temperature (*TATM*) and fossil fuels (*fosslim*)

Quick comparative plots

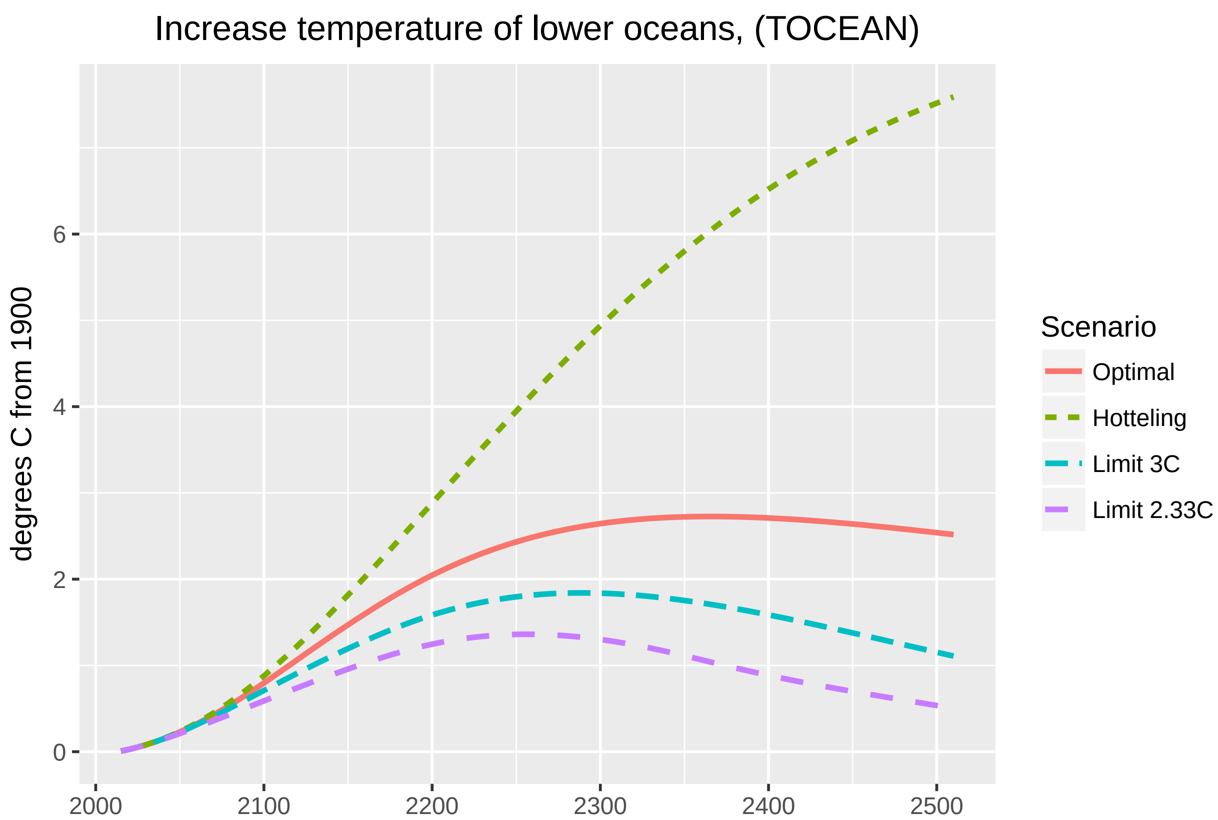
```
# Store scenarios' results in list-object
scn <- list("Optimal" = bb,
            "Hotteling" = hot,
            "Limit 3C" = t3dc,
            "Limit 2.33C" = t233dc)

ggdice(scen = scn, y = "TATM")
```



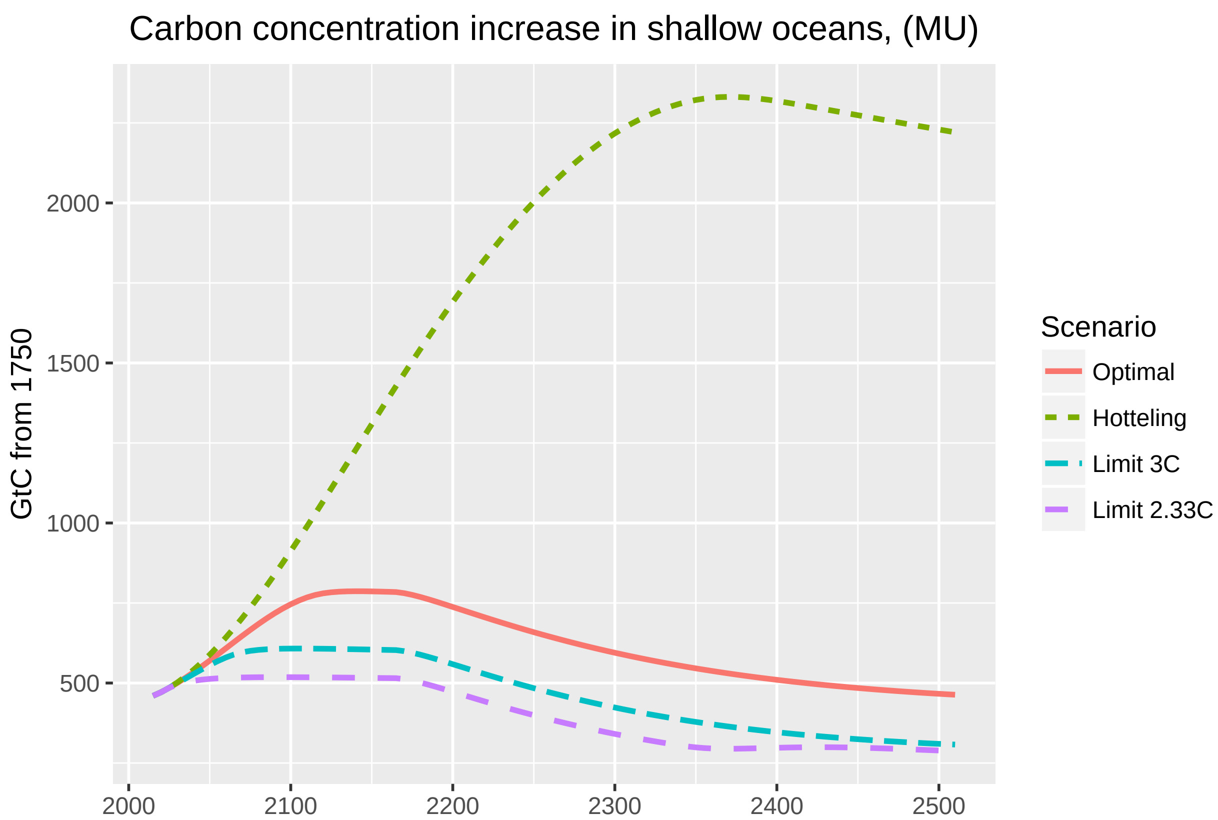

```
ggdice(scen = scn, y = "TATM", select_t = seq(2015, 2200, by = 5))
```



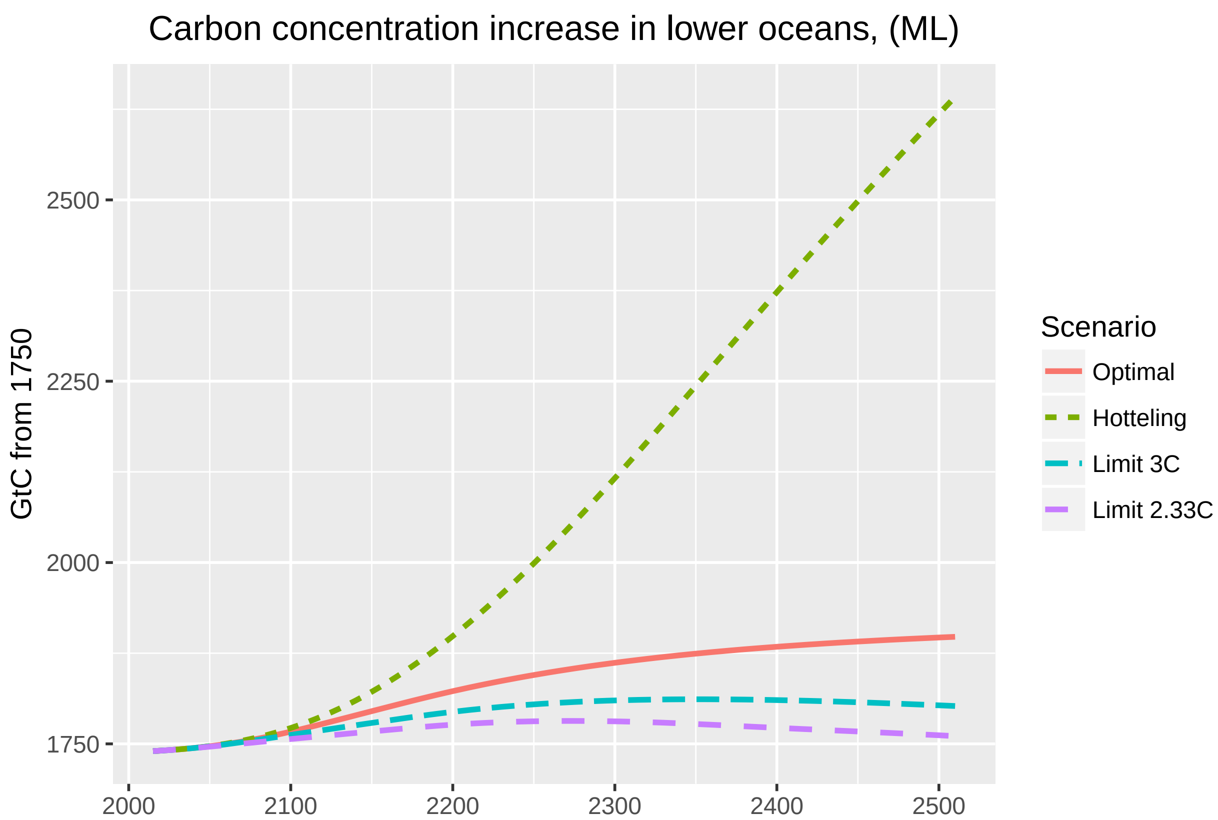

```r
ggdice(scen = scn, y = "TOCEAN")
```



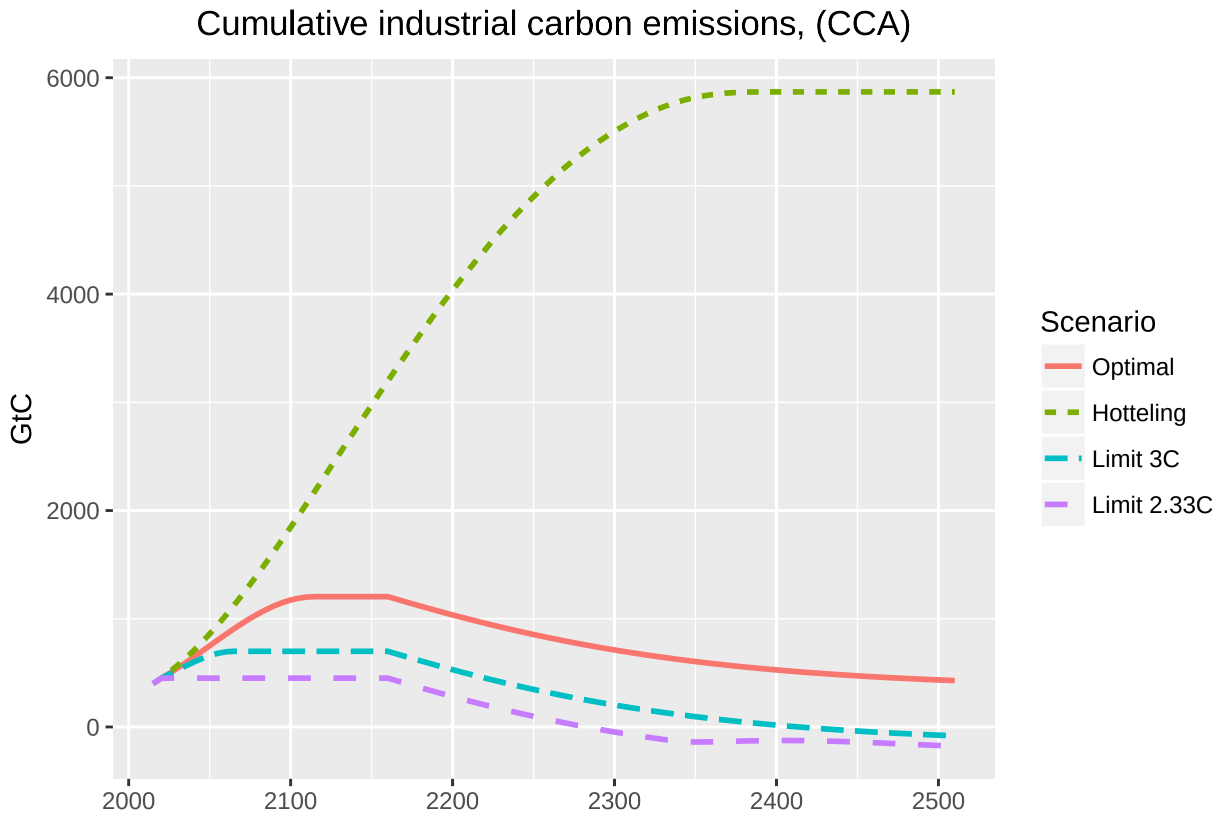

```
ggdice(scen = scn, y = "MU")
```



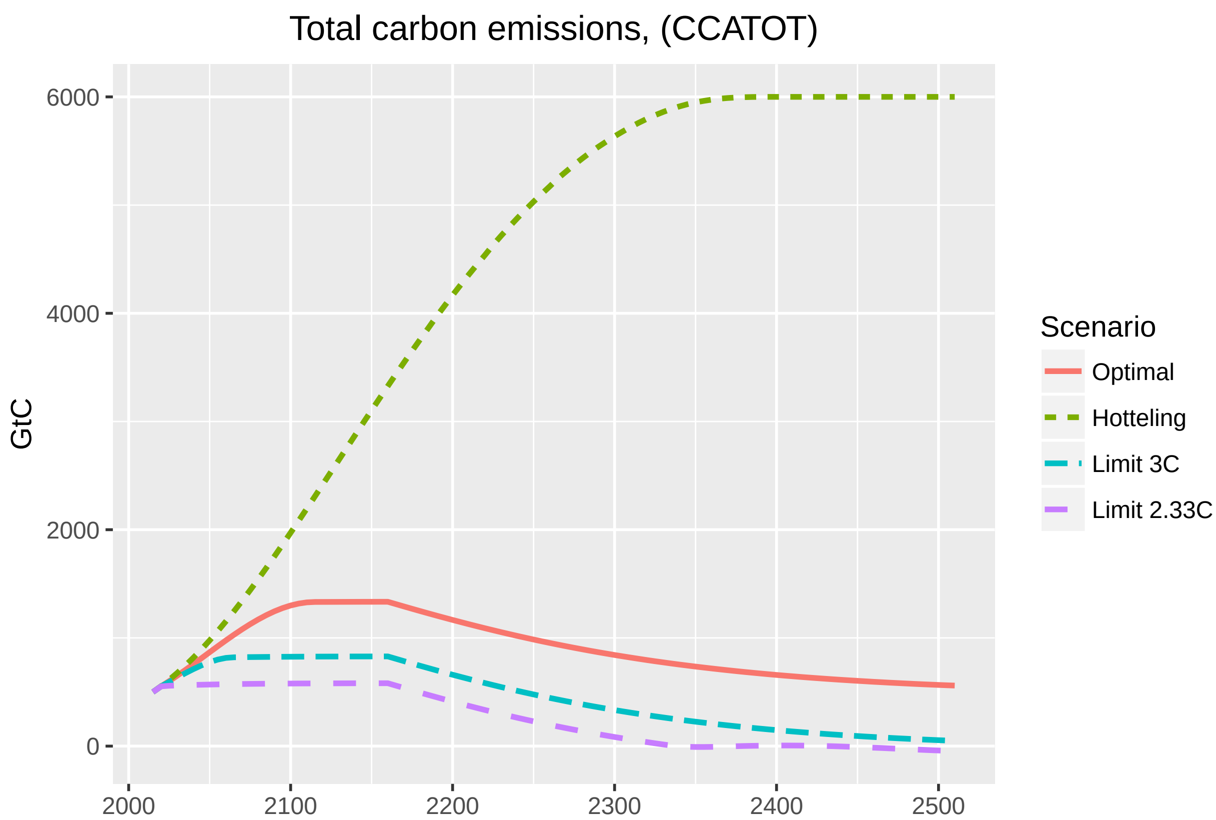

```r
ggdice(scen = scn, y = "ML")
```



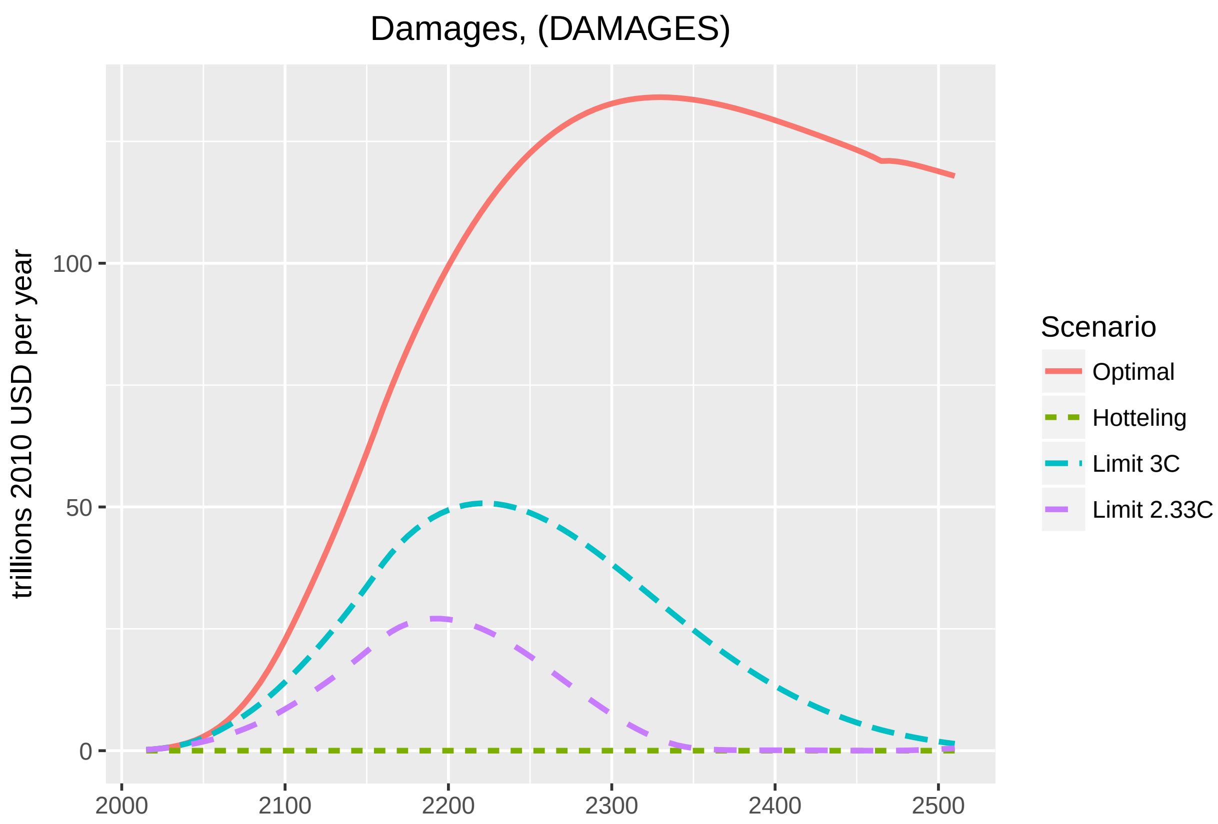

```
ggdice(scen = scn, y = "CCA")
```



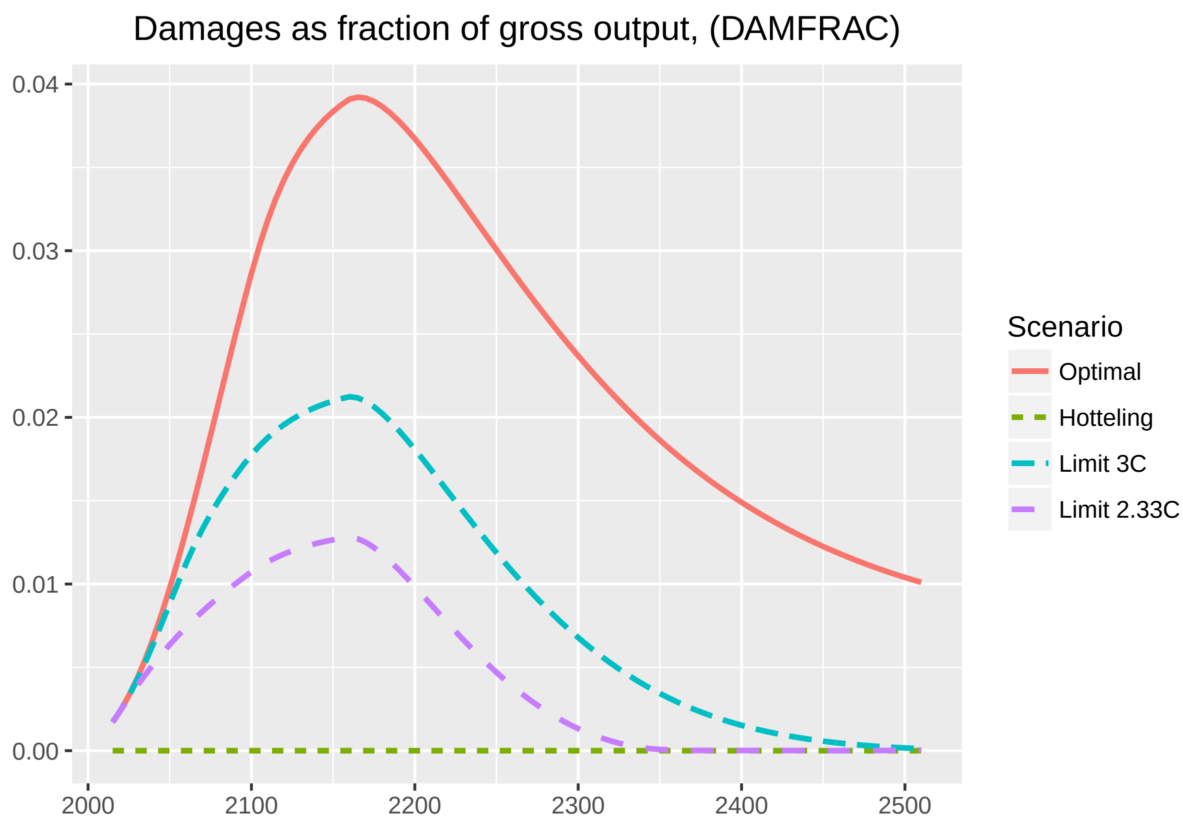

```r
ggdice(scen = scn, y = "CCATOT")
```



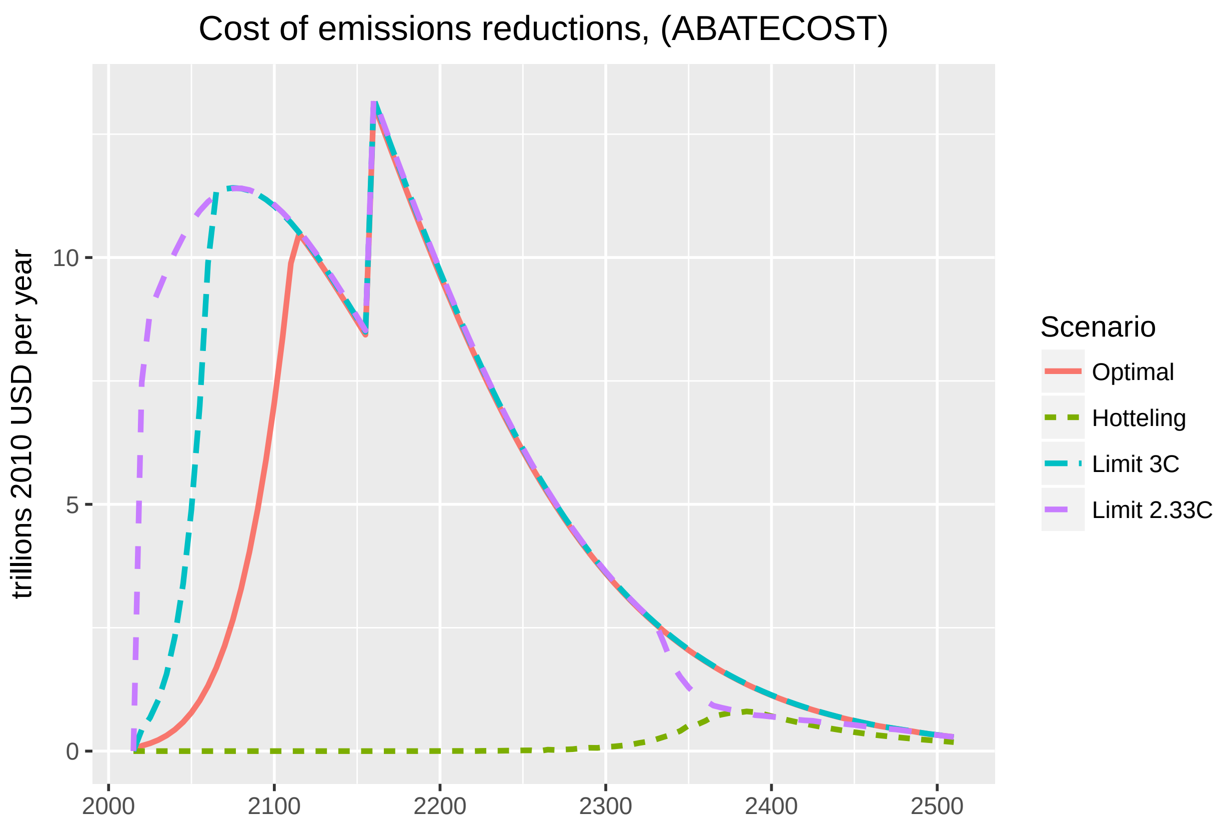

```
ggdice(scen = scn, y = "DAMAGES")
```



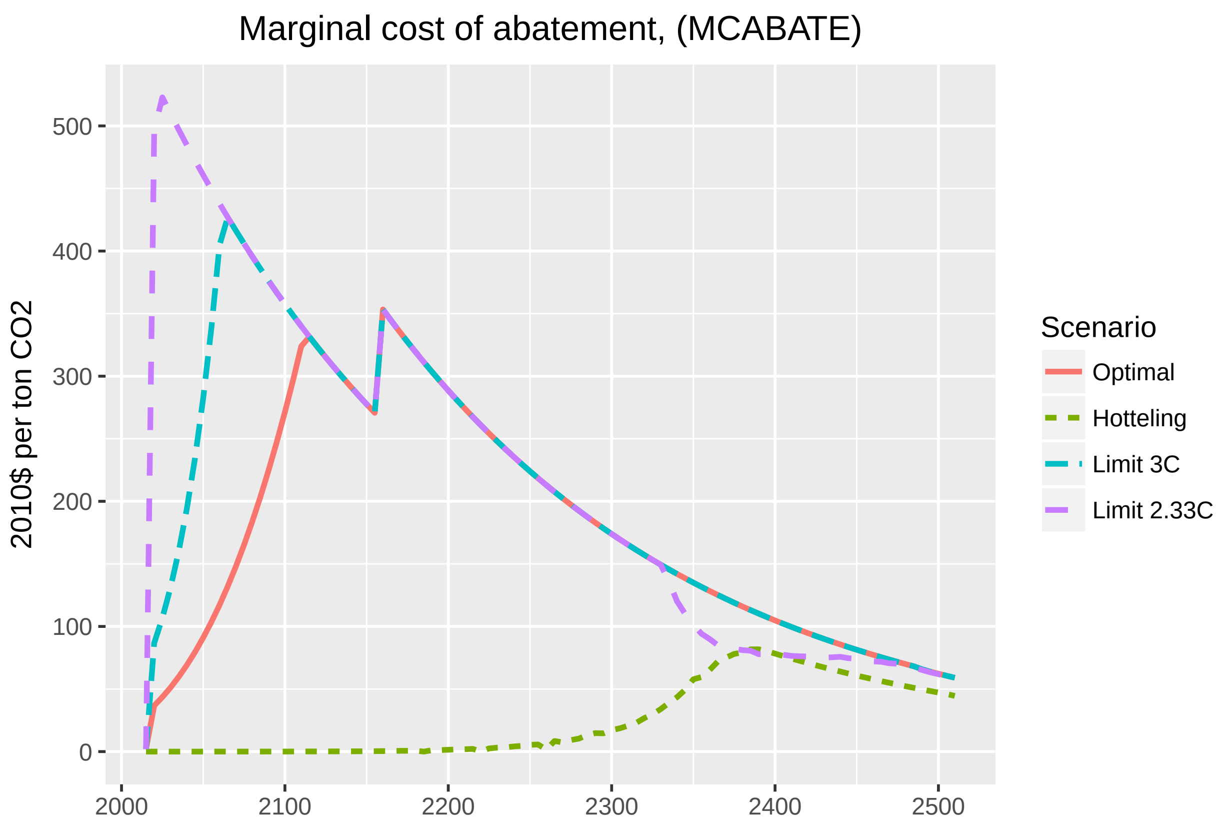

```r
ggdice(scen = scn, y = "DAMFRAC")
```



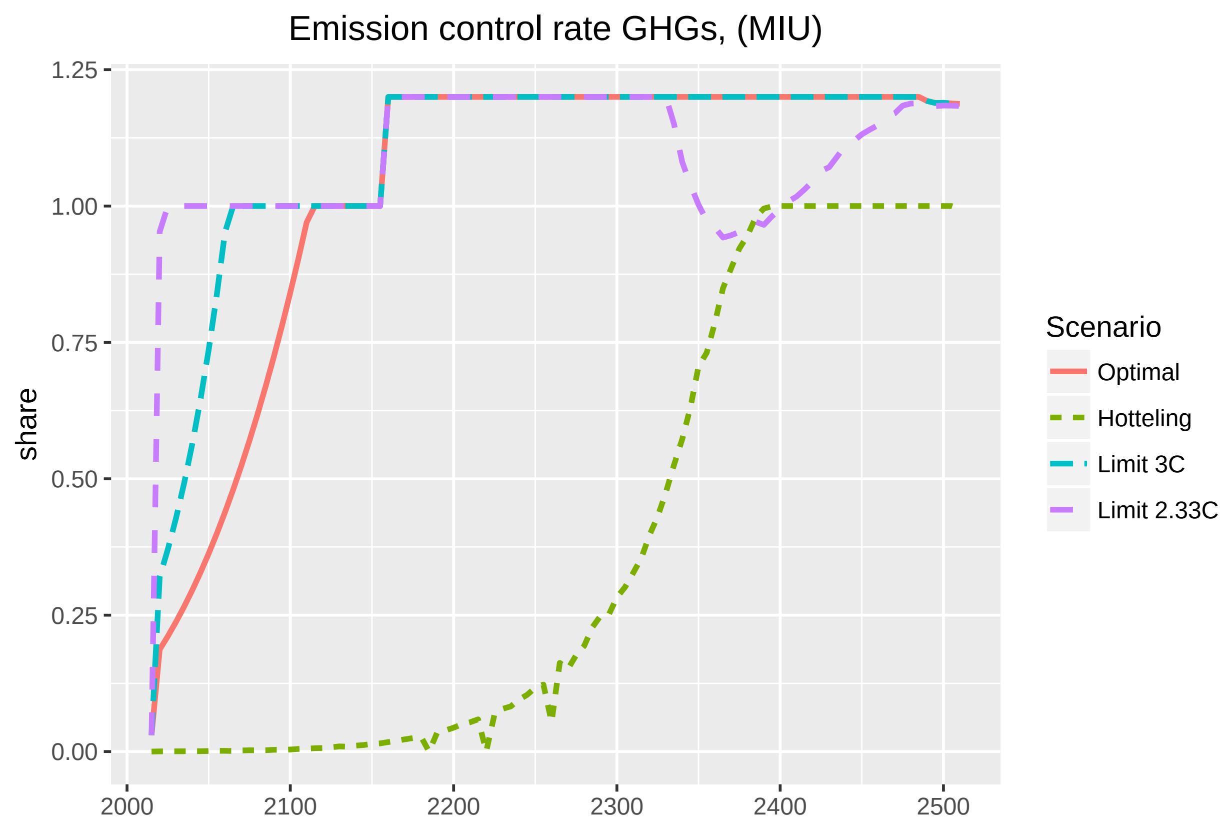

```
ggdice(scen = scn, y = "ABATECOST")
```



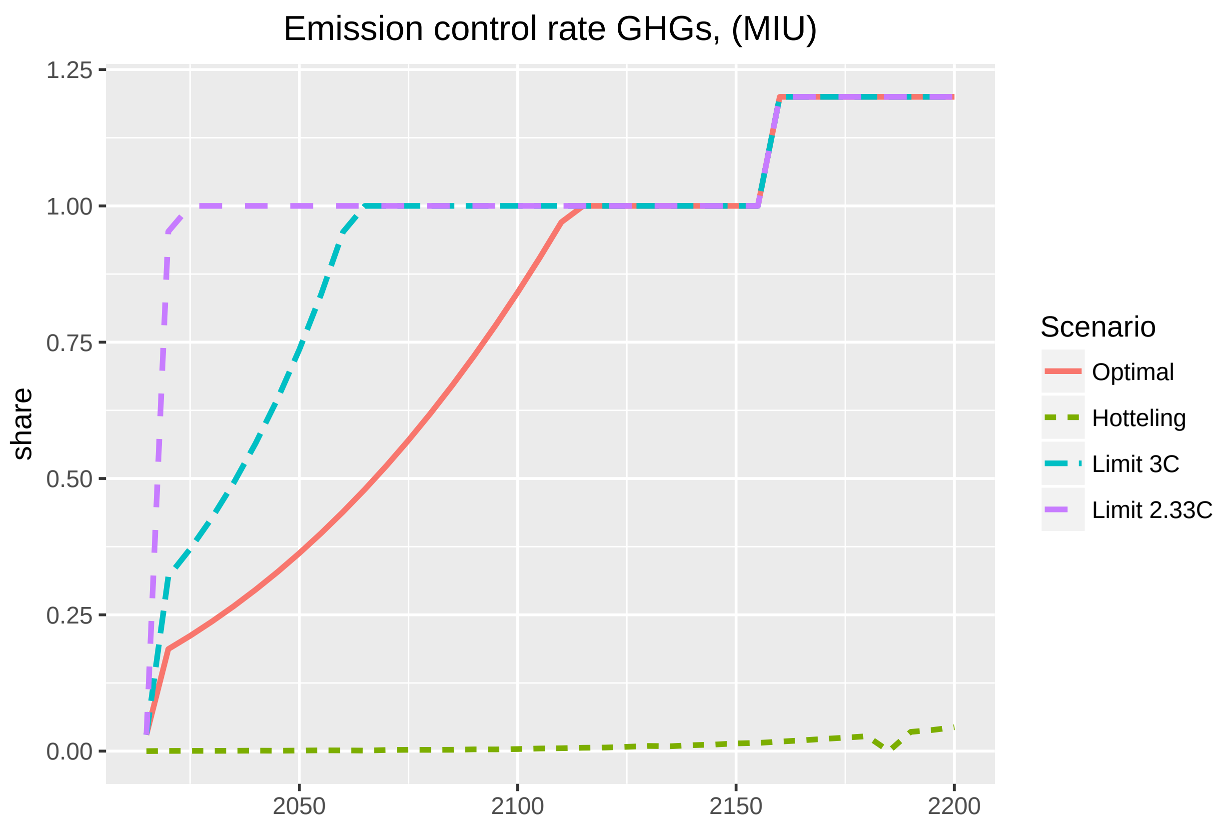

```r
ggdice(scen = scn, y = "MCABATE")
```



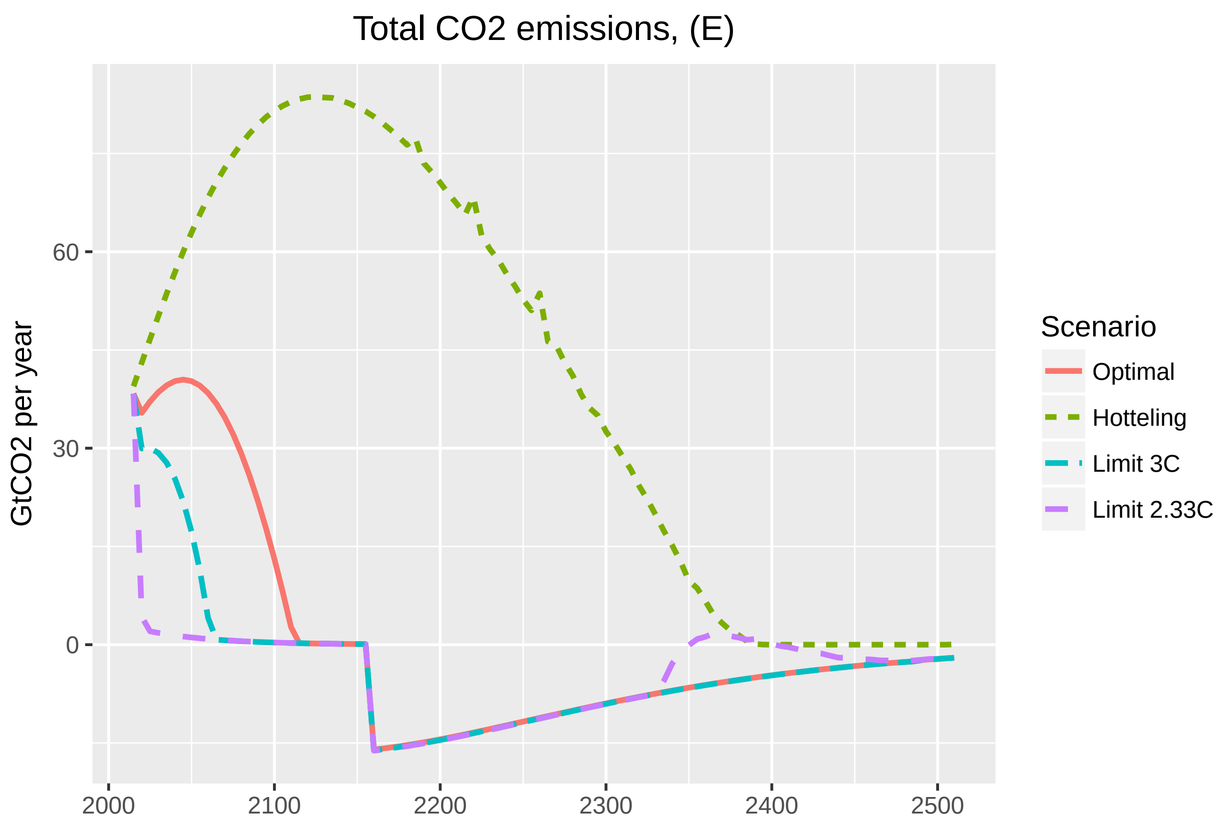

```r
ggdice(scen = scn, y = "MIU", select_t = seq(2015, 2600, by = 5))
```



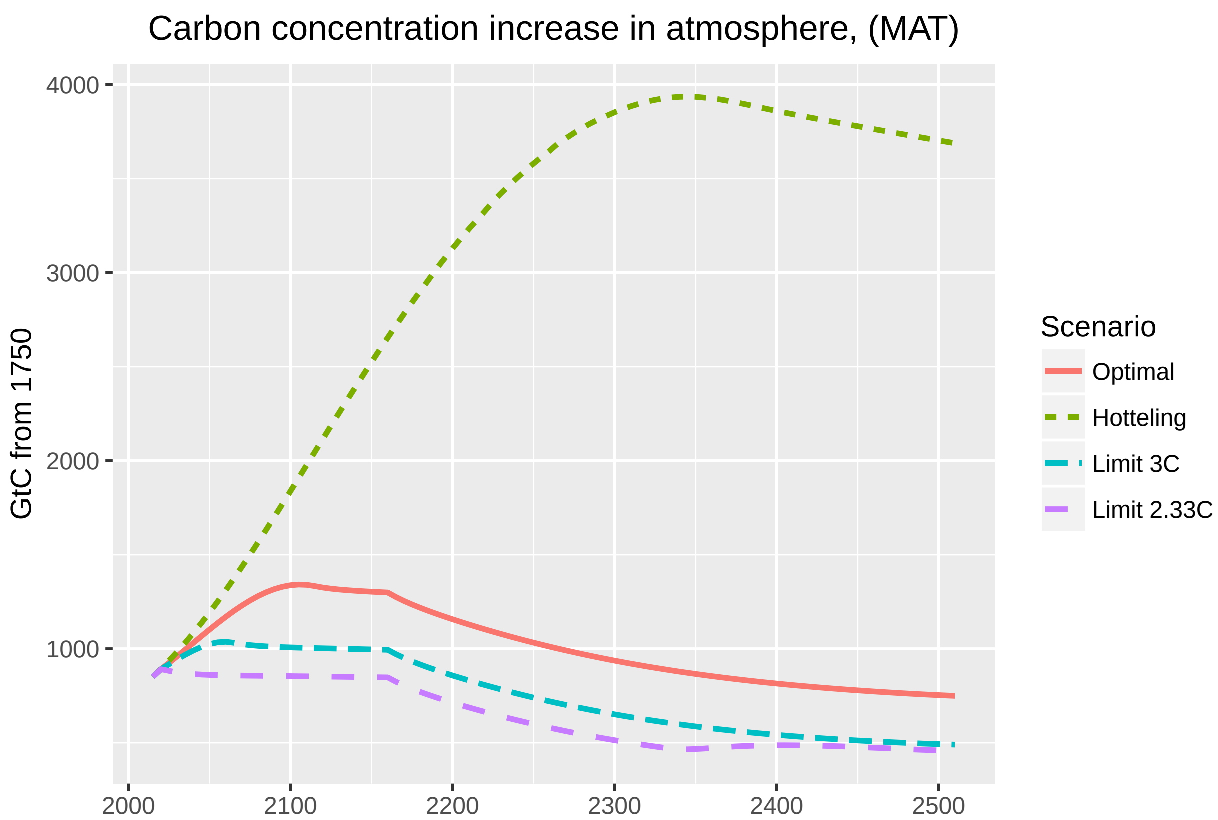

```
ggdice(scen = scn, y = "MIU", select_t = seq(2015, 2200, by = 5))
```



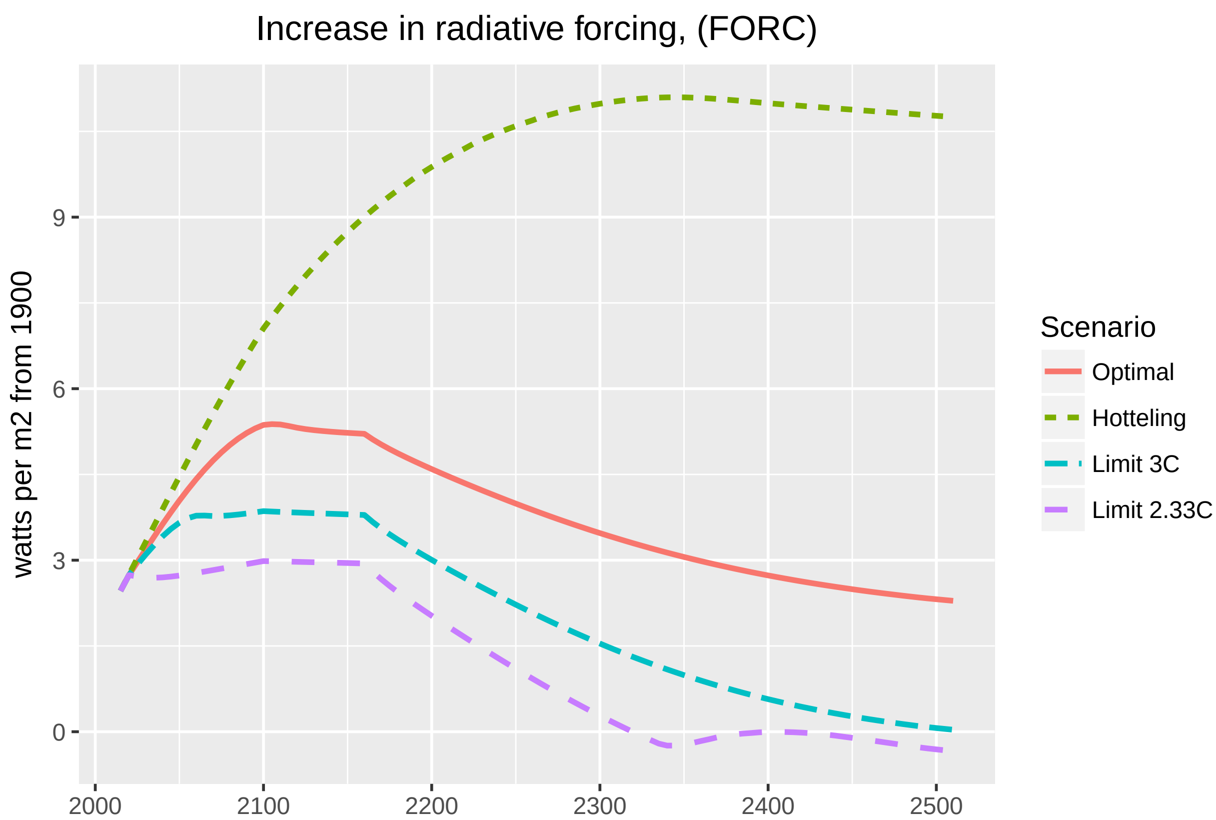

```r
ggdice(scen = scn, y = "E")
```



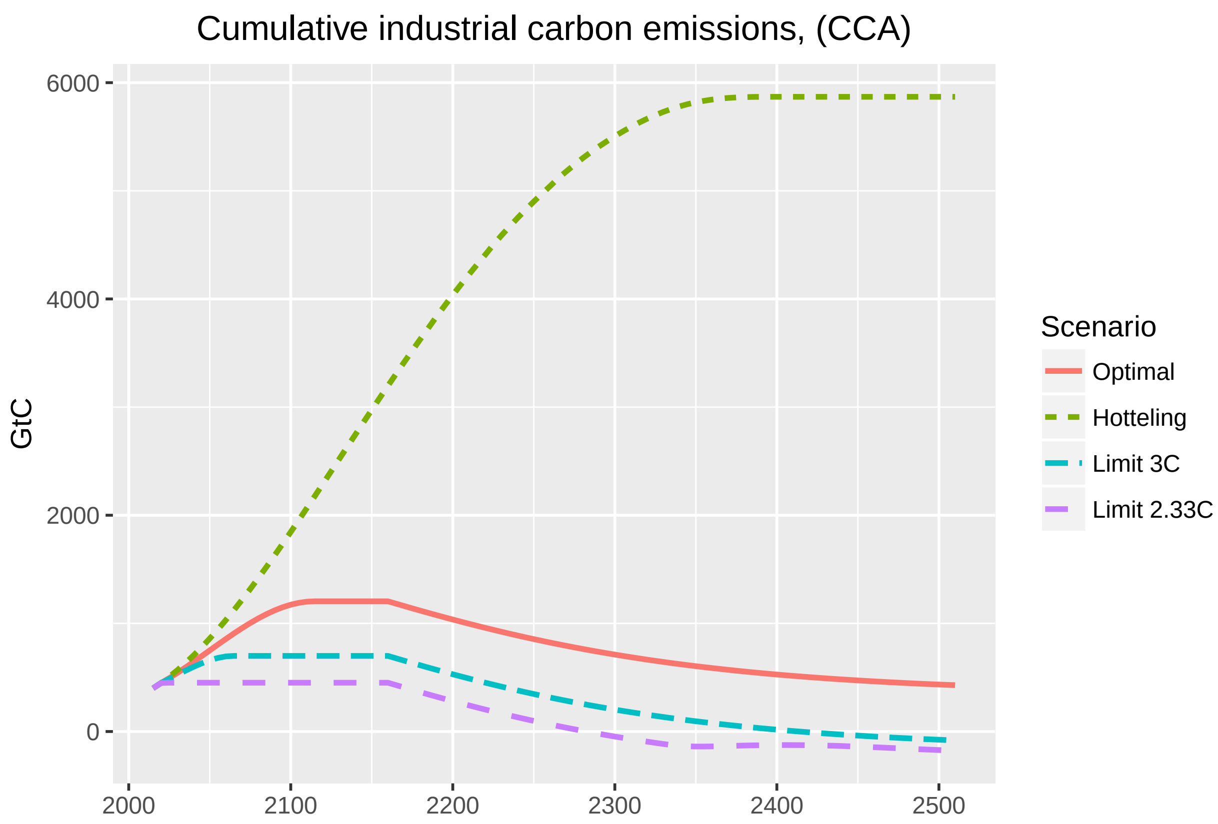

```
ggdice(scen = scn, y = "MAT")
```



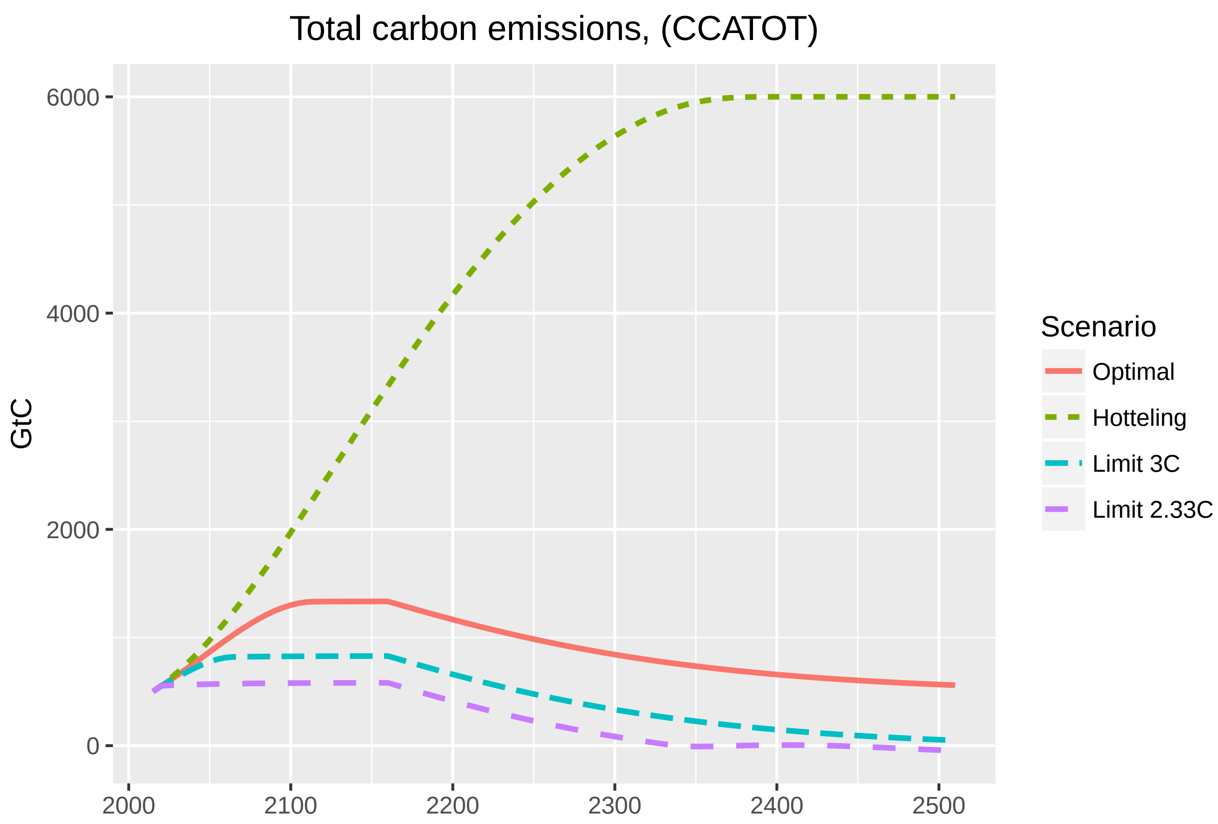

```r
ggdice(scen = scn, y = "FORC")
```




```
ggdice(scen = scn, y = "CCA")
```

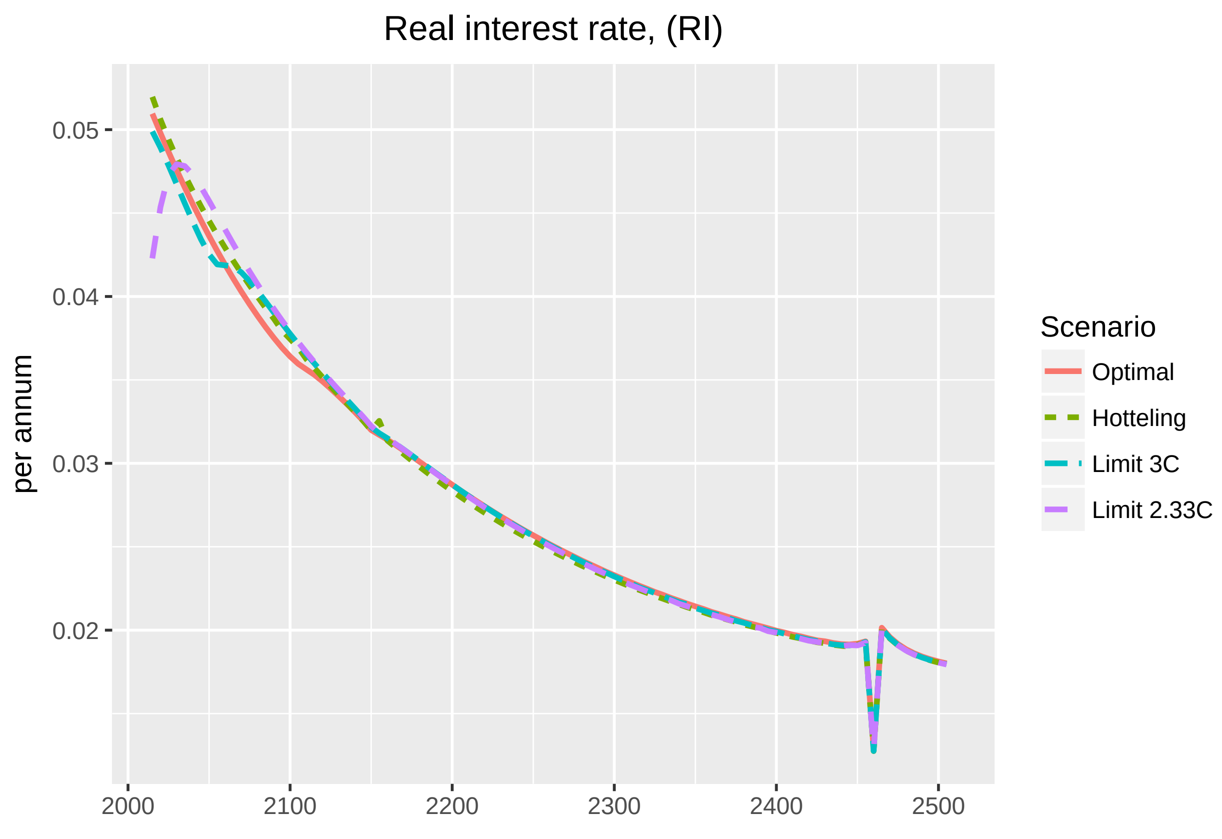



```
ggdice(scen = scn, y = "CCATOT")
```

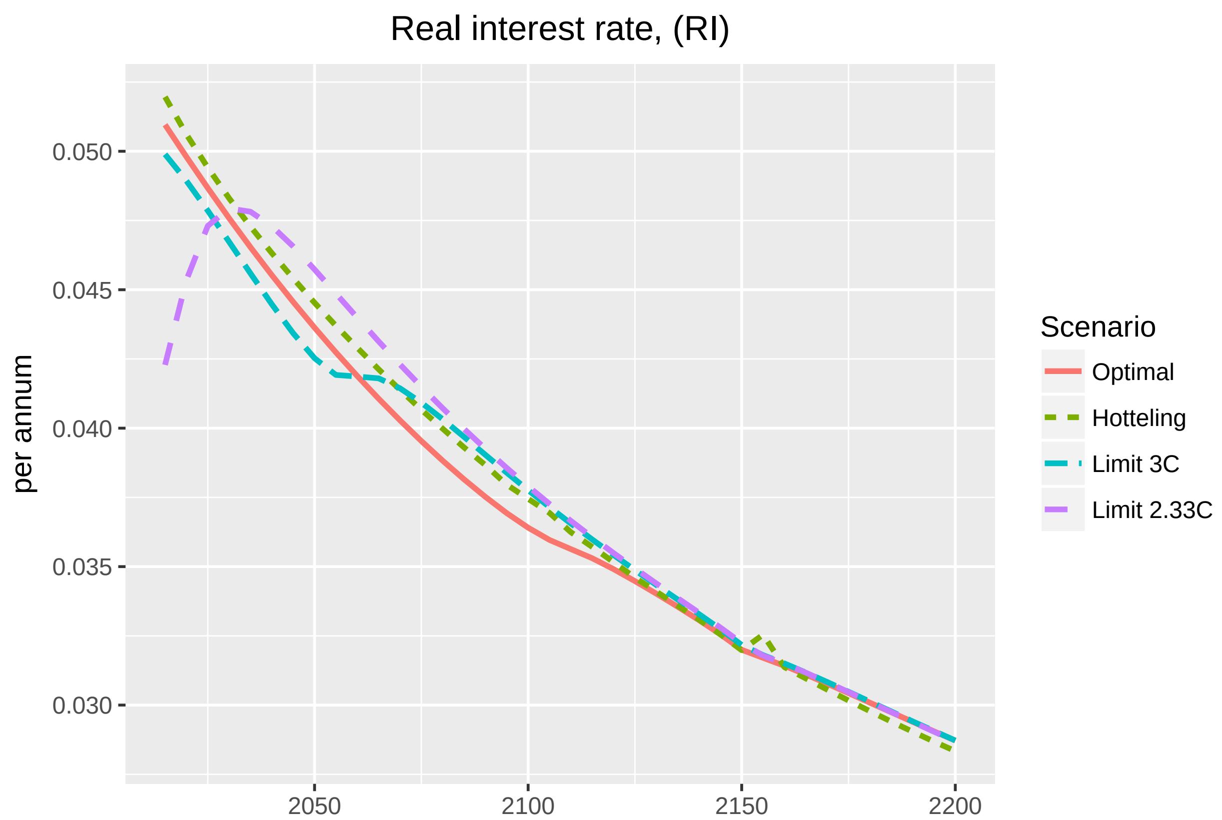



```r
ggdice(scen = scn, y = "RI")
```

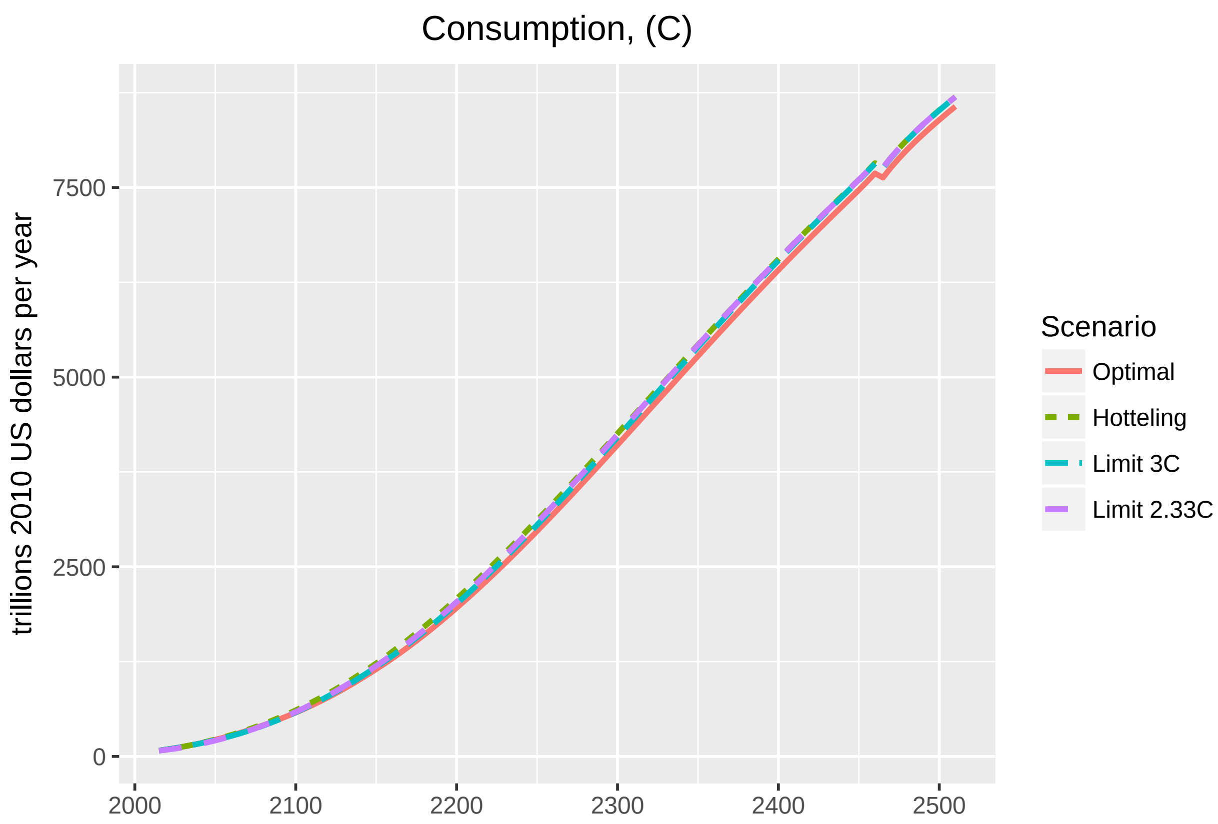
```
## Warning: Removed 4 rows containing missing values (geom_path).
```



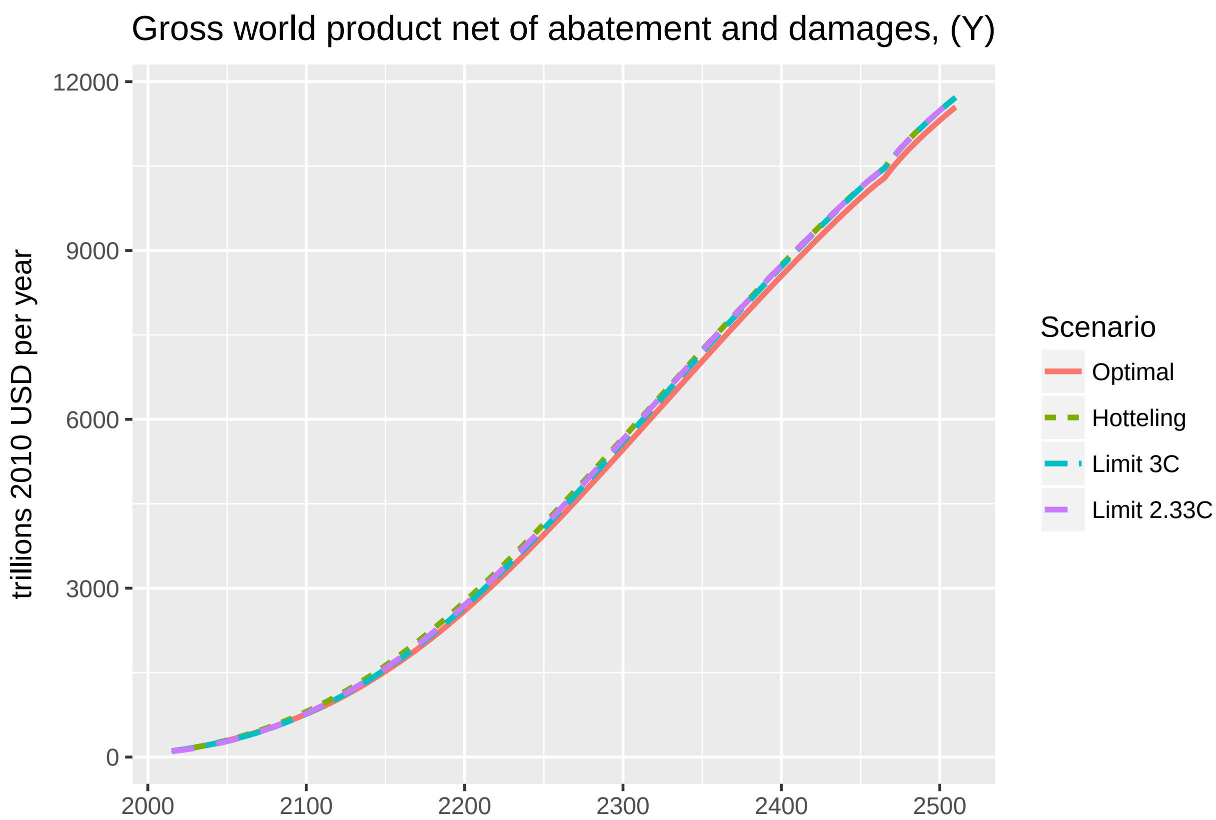

```
ggdice(scen = scn, y = "RI", select_t = seq(2015, 2200, by = 5))
```



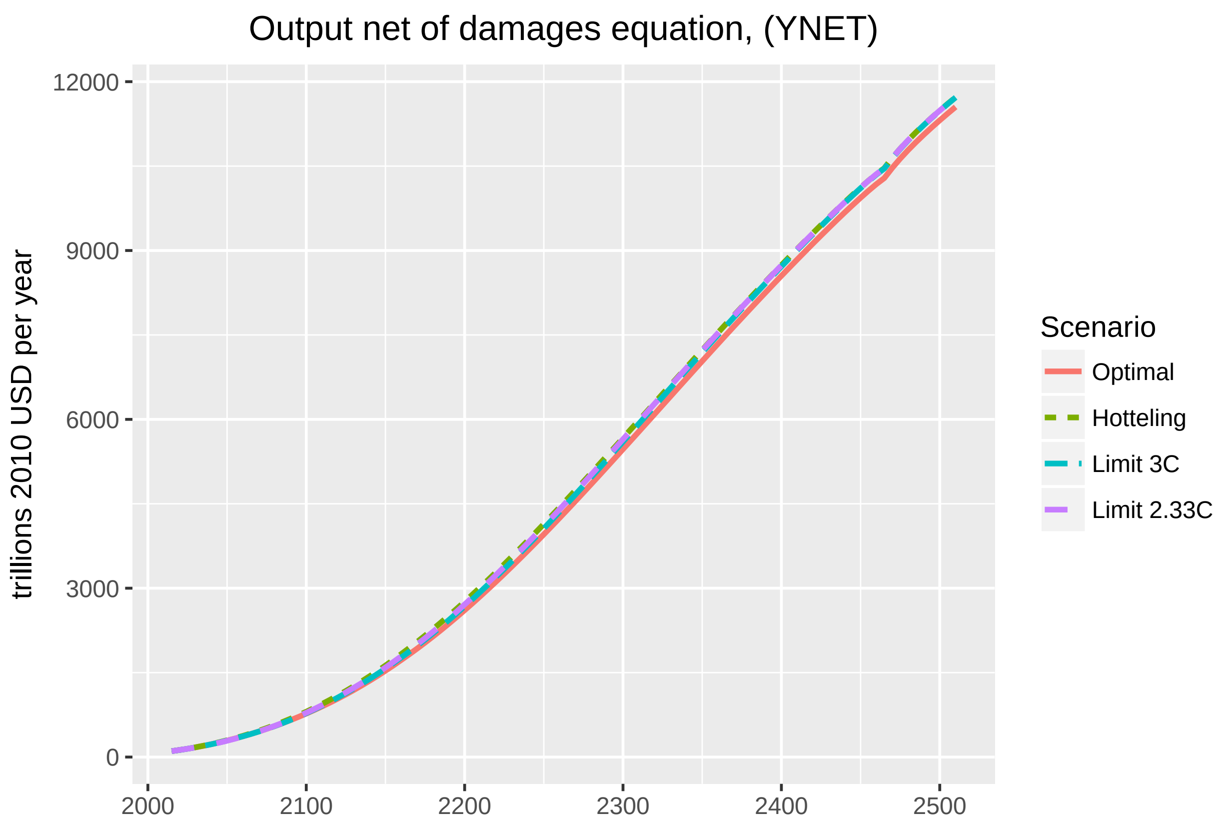

```
ggdice(scen = scn, y = "C")
```



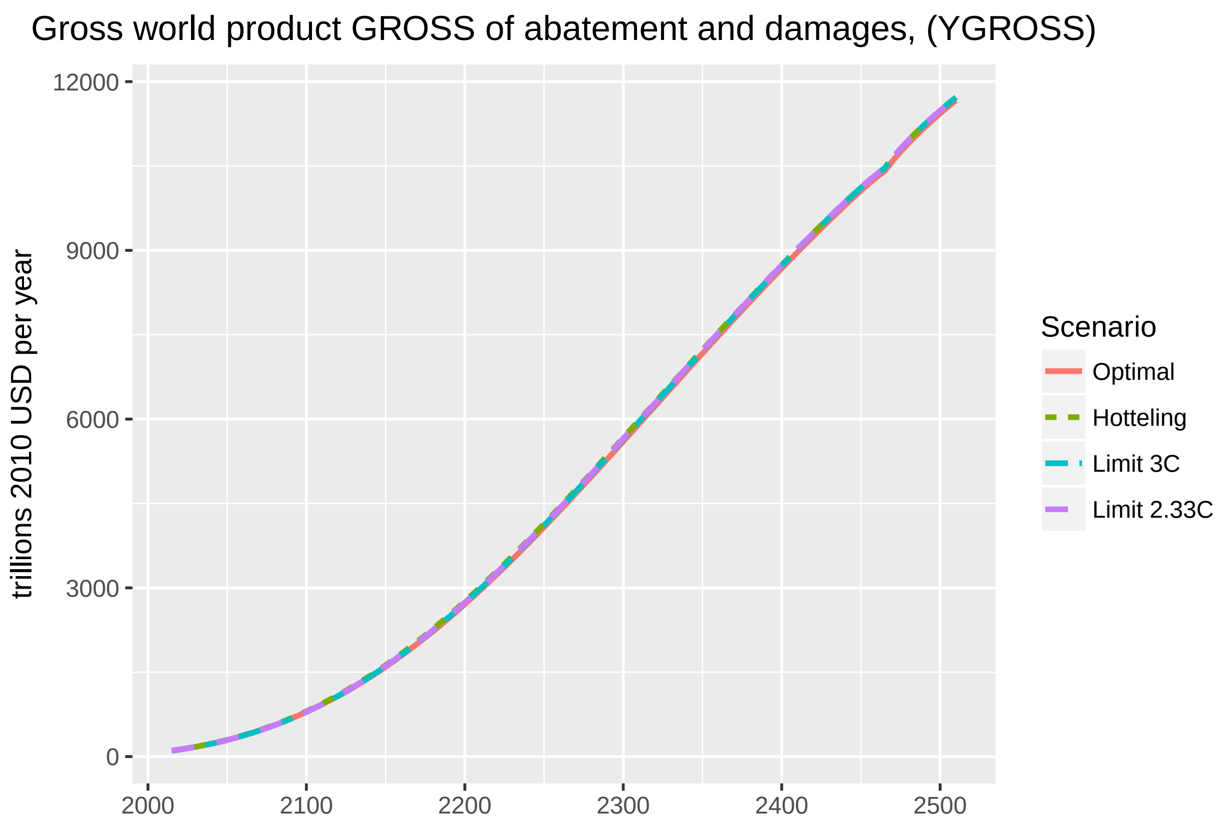

```r
ggdice(scen = scn, y = "Y")
```



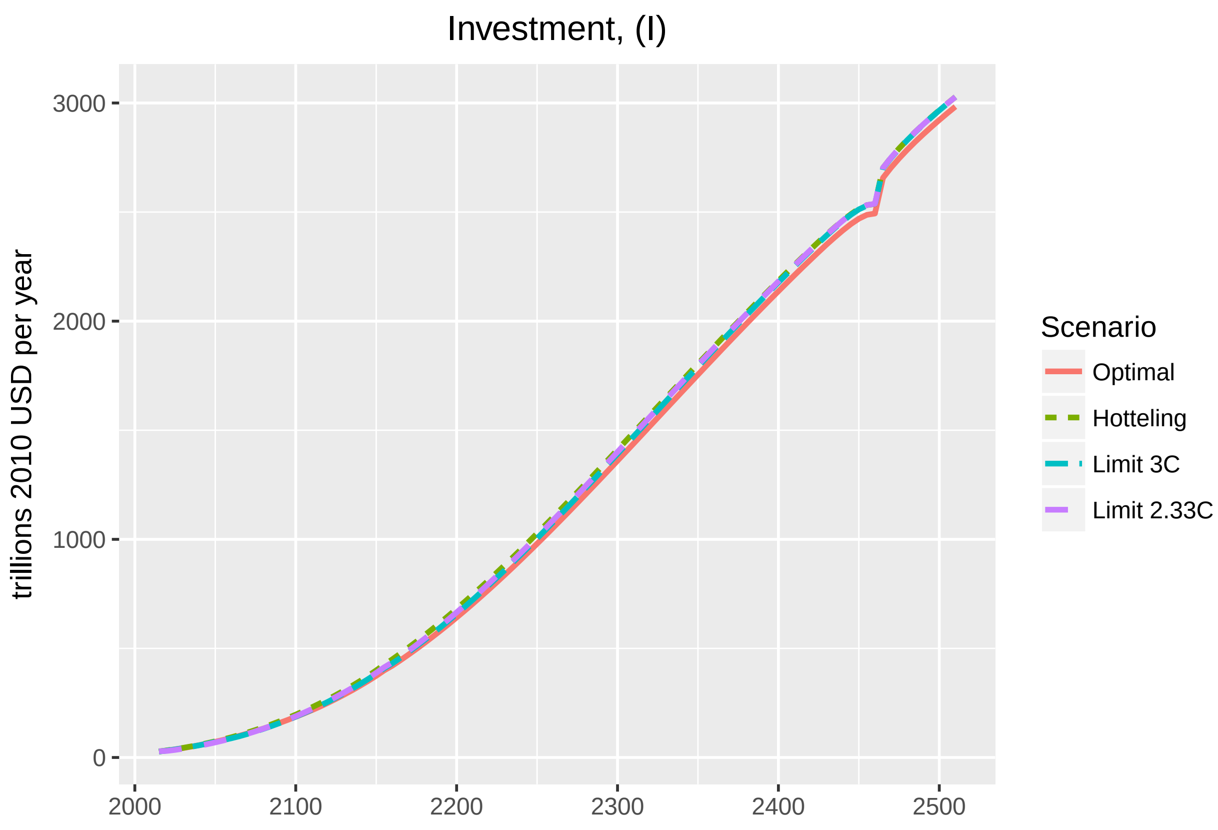

```
ggdice(scen = scn, y = "YNET")
```



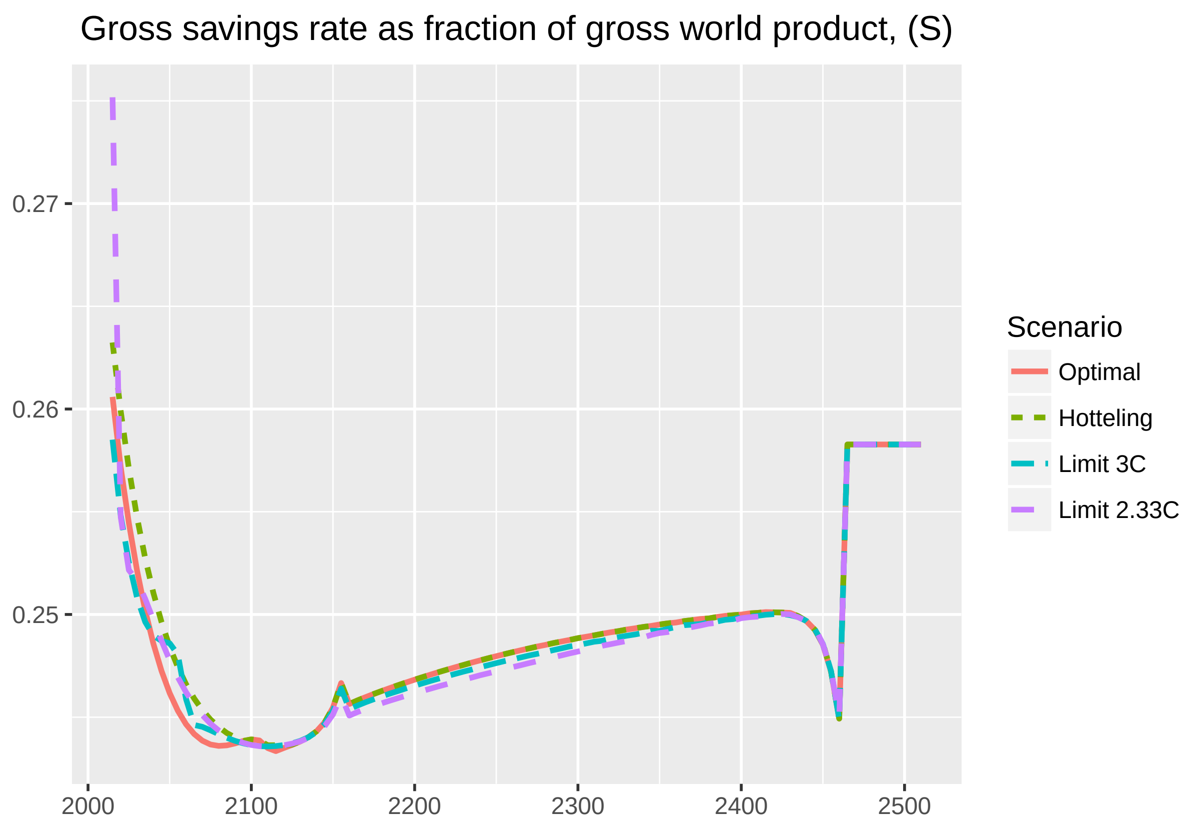

```r
ggdice(scen = scn, y = "YGROSS")
```




```
ggdice(scen = scn, y = "I")
```




```r
ggdice(scen = scn, y = "S")
```



Gross savings rate as fraction of gross world product, (S)
0.27
0.26
0.25
2000
2100
2200
2300
2400
2500
Scenario
Optimal
Hotteling
Limit 3C
Limit 2.33C