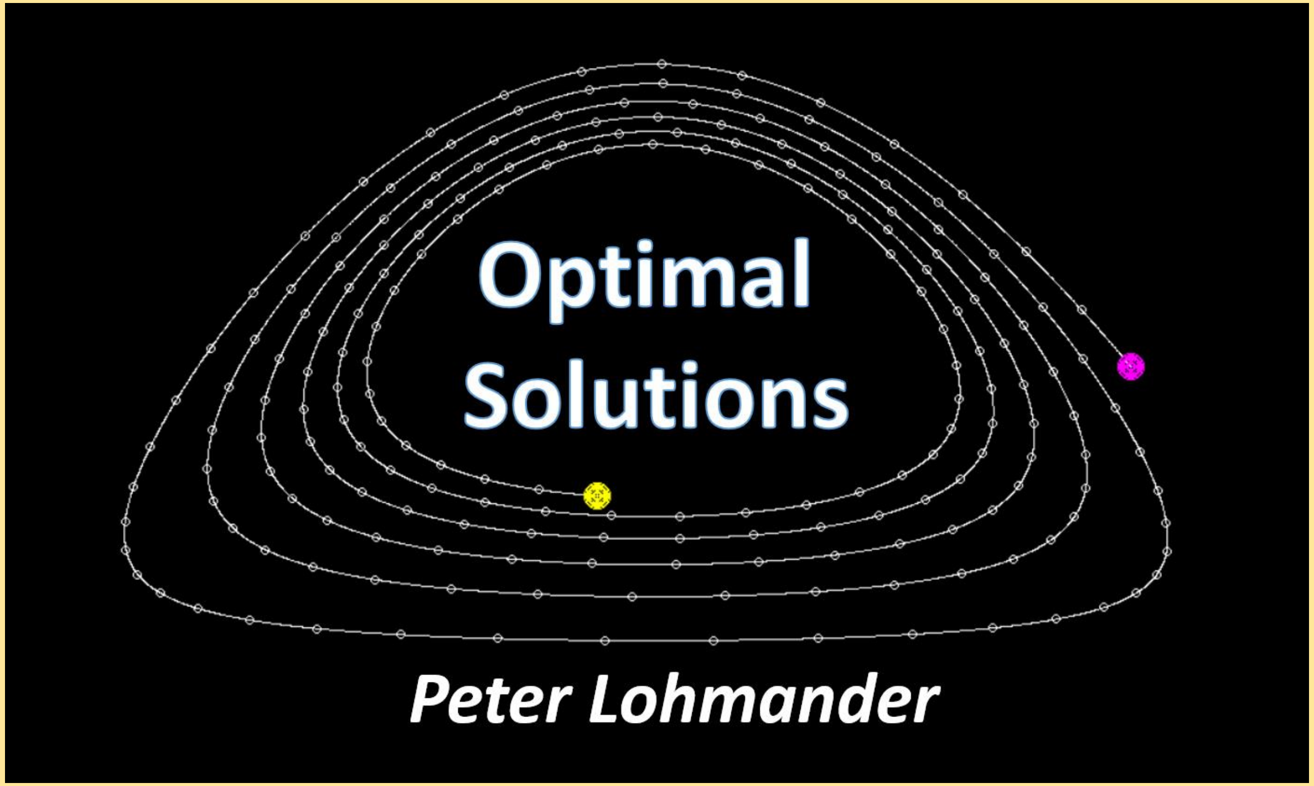
Global Stability via the Forced Global Warming Equation, Fire Control with Joint Fire Fighting Resources, and Optimal Forestry (Edition 210330_1846)



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March 31, 10.00 GMT.

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International Conference on

Applied Science & Engineering

March 31 - April 01, 2021

Day 1 - March 31, 2021

Keynote Forum

10:00 - 10:30	Title: Global Stability via the Forced Global Warming Equation, Fire Control with Joint Fire Fighting Resources and Optimal Forestry **Peter Lohmander,** Optimal Solutions in Cooperation with Linnaeus University, Umea, Sweden

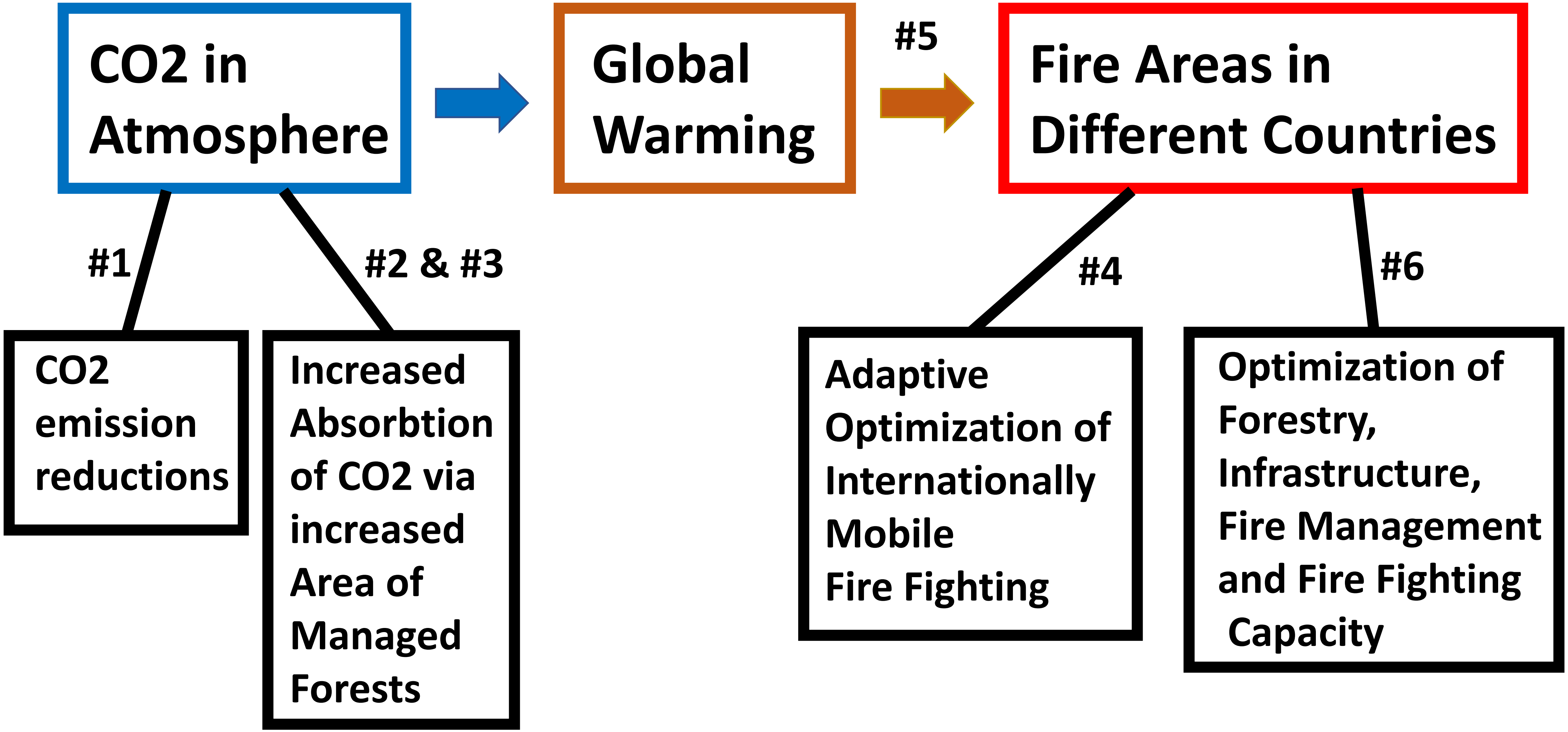
Global Stability via the Forced Global Warming Equation, Fire Control with Joint Fire Fighting Resources and Optimal Forestry

Peter Lohmander

[1]Optimal Solutions in cooperation with Linnaeus University, Umea, Sweden

Our world presently contains several severe conflicts and sources of instability. We face large scale geopolitical tensions with local and global disturbances such as the covid-19 pandemia, large streams of refugees, global warming and expanding wild fires. The technology options of energy systems and environmental problems rapidly develop. International control, such as global taxes on CO_2, are discussed and environmental initiatives of many kinds are introduced in different regions. Combined heat and power expands in the Nordic countries. New ways to continuously and sustainably manage the global forest resources have been developed that not only optimize profits but also contribute to the CO_2 management problem. Furthermore, carbon capture and storage can make several kinds of energy systems sustainable. In six new scientific articles, fundamental processes and optimal solutions have been defined, derived and presented.

General Problem Structure and the Six Articles



References to this presentation

#1. Lohmander, P., Dynamics and control of the CO2 level via a differential equation and alternative global emissions strategies, International Robotics & Automation Journal, Volume 6, Issue 1, 2020, pages 7-15.
https://medcraveonline.com/IRATJ/IRATJ-06-00197.pdf

#2. Lohmander, P., Optimization of continuous cover forestry expansion under the influence of global warming, International Robotics & Automation Journal, Volume 6, Issue 3, 2020, 127-132.

https://medcraveonline.com/IRATJ/IRATJ-06-00211.pdf

https://medcraveonline.com/IRATJ/IRATJ-06-00211A.pdf

References to this presentation

#3. Lohmander, P., Fundamental principles of optimal utilization of forests with consideration of global warming, Central Asian Journal of Environmental Science and Technology Innovation, Volume 1, Issue 3, May and June 2020, 134-142. http://www.cas-press.com/article_111213.html

#4. Lohmander, P., Adaptive mobile firefighting resources, stochastic dynamic optimization of international cooperation, International Robotics & Automation Journal, Volume 6, Issue 4, 2020, pages 150-155.

https://medcraveonline.com/IRATJ/IRATJ-06-00213.pdf

References to this presentation

#5. Lohmander, P., Forest fire expansion under global warming conditions: multivariate estimation, function properties and predictions for 29 countries, Central Asian Journal of Environmental Science and Technology Innovation, Volume 1, Issue 5, 2020, 134-142. doi:10.22034/CAJESTI.2020.05.03.

http://www.cas-press.com/article_122566.html

#6. Lohmander, P., Optimization of forestry, infrastructure and fire management, Caspian Journal of Environmental Sciences (Forthcoming. Accepted for publication).
http://www.lohmander.com/PL_CJES_21_MANUS.pdf

#1. The fundamental theory of the CO_2 level in the atmosphere, under the influence of changing CO_2 emissions, is modeled as a first order linear differential equation with a forcing function, describing industrial emissions.

Observations of the CO_2 level at the Mauna Loa CO_2 observatory and official statistics of global CO_2 emissions, from Edgar, the Joint Research Centre at the European Commission, are used to estimate all parameters of the forced CO_2 differential equation. The estimated differential equation has a logical theoretical foundation and convincing statistical properties. It is used to reproduce the time path of the CO_2 data from Mauna Loa, from year 1990 to 2018, with very small errors. Furthermore, the differential equation shows that the global CO_2 level, without emissions, has a stable equilibrium at 280 ppm. This value has earlier been reported by IPCC as the pre-industrial CO_2 level.

The differential function is applied to derive four dynamic cases of the global CO_2 level, from the year 2020 until 2100, conditional on four different strategies concerning the development of global CO_2 emissions.

The natural CO2 dynamics

$$\dot{x} = \frac{dx}{dt} = a_0 + a_x x$$

Change of the CO2 level in the atmosphere

Natural emissions from vulcanos etc.

Net absorbtion of CO2 by the sea and natural environment

$$\dot{x} = \frac{dx}{dt} = a_0 + a_x x$$

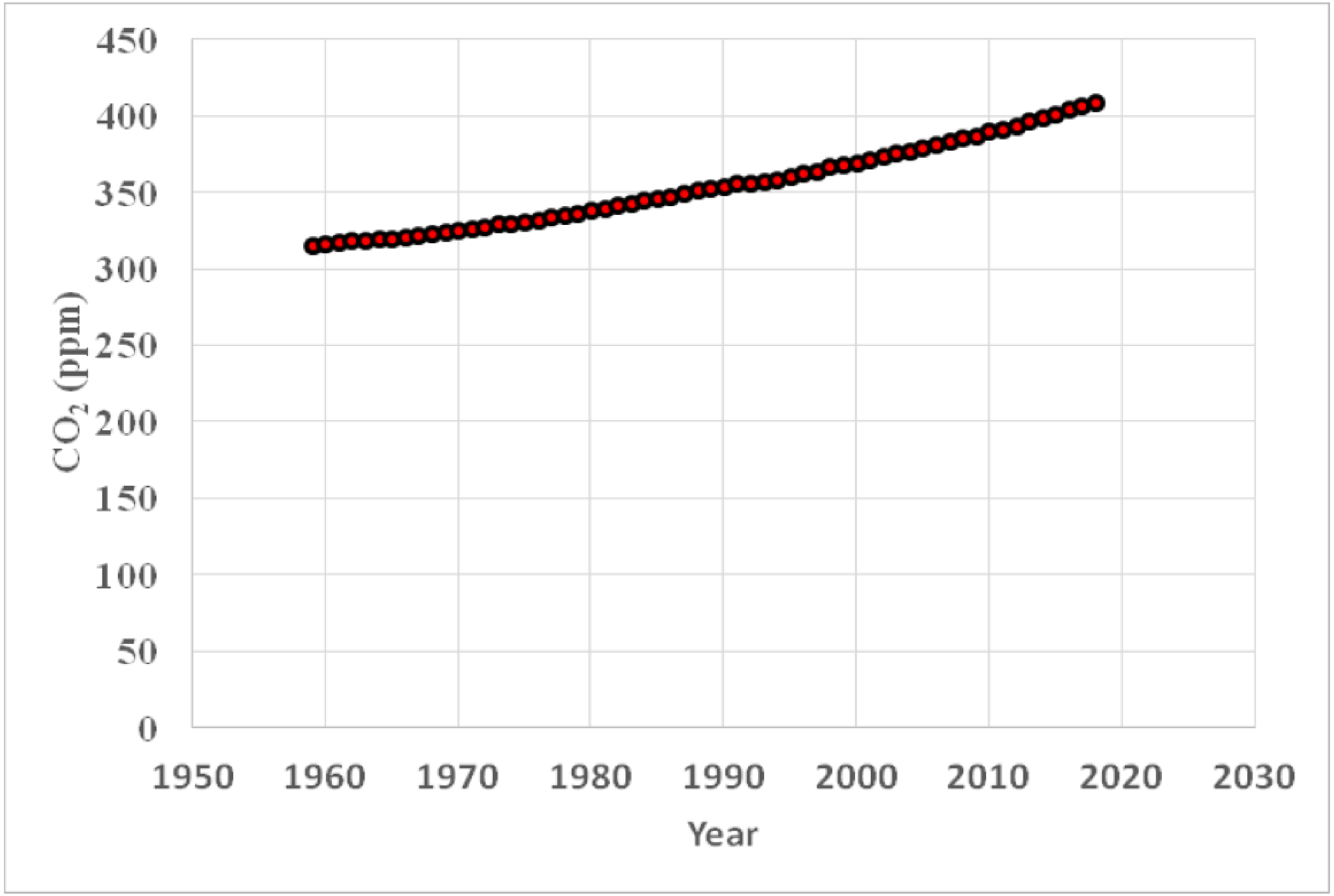
> 0 < 0

$$\left(\dot{x} = 0\right) \Rightarrow \left(a_0 + a_x x_{eq} = 0\right)$$

$$x_{eq} = \frac{-a_0}{a_x} \approx 280\,(?)$$

Natural "pre- industrial" equilibrium

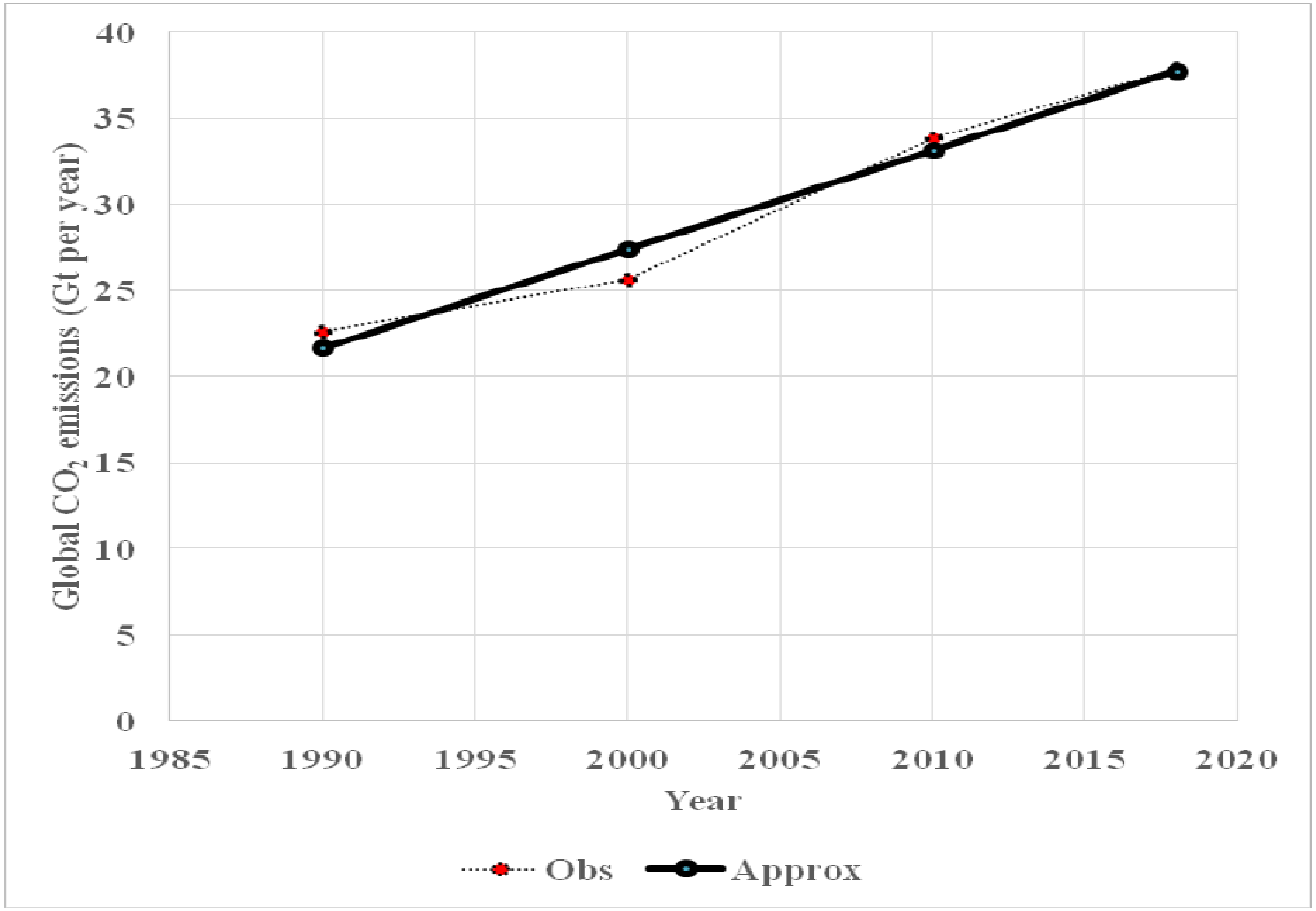
x = CO2 in atmosphere, ppm



Year

Figure 1 CO_2 in the atmosphere, annual mean values, Mauna Loa, (ppm). Source: Tans and Keeling.[2]

φ = Emissions, Gt per year



Year

Figure 2 Obs=Observations of global CO_2 emissions from fossil fuels combustion and processes. Source: European Commission.[4] Approx=Linear approximation via the least squares method, by the author of this paper. Compare equation (47). Approx $= 21.672 + 0.57366(Year - 1990)$. $R \approx 0.984$.

x $\dot{x}$

Table 1 Atmospheric CO_2 data

i (period)	t (year)	ψ_t (ppm)	Δx_i (ppm)	Δt (years)	x_i (ppm)	x_i (Gt CO_2)	$\dot{x}_i \approx \frac{\Delta x}{\Delta t}$ (ppm per year)	$\dot{x}_i \approx \frac{\Delta x}{\Delta t}$ (Gt Co_2 per year)
	1990	354.39						
1			15.16	10	361.97	2824.9	1.516	11.831
	2000	369.55						
2			20.35	10	379.725	2963.5	2.035	15.882
	2010	389.90						
3			18.62	8	399.21	3115.6	2.3275	18.165
	2018	408.52						

Definitions in table 1: $\psi_t = CO_2$ in atmosphere, annual mean value of observations, Mauna Loa

$x_i = CO_2$ in atmosphere, calculated mean value

Gt denotes Giga tonnes and ppm denotes parts per million

The CO2 dynamics affected by industrial emissions

Industrial emissions of CO2

$$\dot{x} = a_0 + a_x x + \varphi(t)$$

$$y(t) = \dot{x} - \varphi(t) = a_0 + a_x x$$

$$\varphi(t) \qquad \varphi(t) - \dot{x}$$

Table 2 Atmospheric CO_2 data transformations

i (period)	t (year)	γ_t (Gt CO_2)	φ_i (Gt CO_2 per year)	ϕ_i (Gt CO_2 per year)	ϕ_i (ppm per year)
	1990	22.637			
1			24.119	12.288	1.5745
	2000	25.601			
2			29.7185	13.8365	1.7729
	2010	33.836			
3			35.8615	17.6965	2.2675
	2018	37.887			

Definitions in table 2: γ_t = Global total CO_2 emission, observation

φ_i = Global total CO_2 emission, calculated mean value

$\phi_i = \varphi_i - \dot{x}_i$

Emissions

Reduction of CO2 in atmosphere in the absence of emissions.

We want to determine the parameters (a_0, a_x) in this function:

$$y = a_0 + a_x x \qquad (8)$$

We minimize the sum of squares of the residuals:

$$\min_{a_0, a_x} Z = \sum_{i=1}^{N} (y_i - a_0 - a_x x_i)^2 \qquad (9)$$

These are the first order optimum conditions:

$$\begin{cases} \dfrac{dZ}{da_0} = \sum_{i=1}^{N} \left(2(y_i - a_0 - a_x x_i)(-1)\right) = 0 \\ \dfrac{dZ}{da_x} = \sum_{i=1}^{N} \left(2(y_i - a_0 - a_x x_i)(-x_i)\right) = 0 \end{cases} \qquad (10)$$

i	x_i (ppm)	y_i ($Gt\ CO_2$ per year)
1	361.97	-12.288
2	379.725	-13.8365
3	399.21	-17.6965

Period

X

$\dot{x} - \varphi(t)$

Change of CO2 in atmosphere
(in the absence of emissions)

Determination of a solution of the form

$$x(t) = Ae^{bt} + k_0 + k_1 t$$

to the differential equation

$$\dot{x} = a_0 + a_x x + \varphi(t)$$

based on the historical emissions.

A general functional form of the emission function is used here

Specific form of emission function

The differential equation with specific emission function

Solution of the homogenous differential equation.

This is the differential equation in general form:

$$\dot{x} = a_0 + a_x x + \varphi(t) \tag{28}$$

We will consider the special case of emissions that grow with a linear trend, since that is supported by the available empirical data. (Note that the forcing function could be generalized to almost any form, if considered relevant.)

$$\varphi(t) = m_0 + m_1 t \tag{29}$$

The differential equation becomes:

$$\dot{x} - a_x x = a_0 + m_0 + m_1 t \tag{30}$$

Solution of the homogenous equation:

$$\dot{x}_h - a_x x_h = 0 \tag{31}$$

$$x_h = Ae^{st} \tag{32}$$

$$\dot{x}_h = sAe^{st} \tag{33}$$

$$(s - a_x)x_h = 0 \tag{34}$$

$$(x_h \neq 0) \Rightarrow s = a_x \quad (35)$$

$$x_h(t) = Ae^{a_x t} \quad (36)$$

Determination of the particular solution:

$$x_p = k_0 + k_1 t \quad (37)$$

Determination of the particular solution.

$$\dot{x}_p - a_x x_p = a_0 + m_0 + m_1 t \quad (38)$$

$$k_1 - a_x(k_0 + k_1 t) = a_0 + m_0 + m_1 t \quad (39)$$

$$\begin{cases} k_1 - a_x k_0 = a_0 + m_0 \\ -a_x k_1 = m_1 \end{cases} \quad (40)$$

$$(-a_x k_1 = m_1) \Rightarrow k_1 = \frac{-m_1}{a_x} \quad (41)$$

$$(k_1 - a_x k_0 = a_0 + m_0) \wedge \left(k_1 = \frac{-m_1}{a_x}\right) \Rightarrow \left(\frac{-m_1}{a_x} - a_x k_0 = a_0 + m_0\right) \quad (42)$$

$$k_0 = \frac{-\left(a_0 + m_0 + \frac{m_1}{a_x}\right)}{a_x} \quad (43)$$

Determination of the numerical parameter values based on the historical data.

$$\varphi(t) = 21.672 + 0.57366\, t \qquad (47)$$

$$k_1 = \frac{-m_1}{a_x} = \frac{-0.57366}{-0.0187191} \approx 30.646 \qquad (48)$$

$$k_0 = \frac{-\left(a_0 + m_0 + \frac{m_1}{a_x}\right)}{a_x} = \frac{-(40.951 + 21.672 - 30.646)}{-0.0187191} \approx 1708.27 \qquad (49)$$

$$x(t) = Ae^{-0.0187191\,t} + 1708.27 + 30.646\, t \qquad (50)$$

$$x(0) = A + 1708.27 \qquad (51)$$

$$A = x(0) - 1708.27 \qquad (52)$$

$$A = 354.39 \cdot 2.13 \cdot 3.664 - 1708.27 \qquad (53)$$

$$A \approx 1057.52 \qquad (54)$$

The solution based on the historical emissions:

$$x(t) = 1057.52e^{-0.0187191\,t} + 1708.27 + 30.646\ t \qquad (Gt) \qquad (55)$$

If the function is divided by (2.13*3.664), the unit becomes ppm.

$$x(t) = 135.50e^{-0.0187191\,t} + 218.89 + 3.927\ t \qquad (ppm) \qquad (56)$$

The solution based on the historical emissions:

$$x(t) = Ae^{bt} + k_0 + k_1 t \qquad (ppm)$$

$$A = 135.50$$

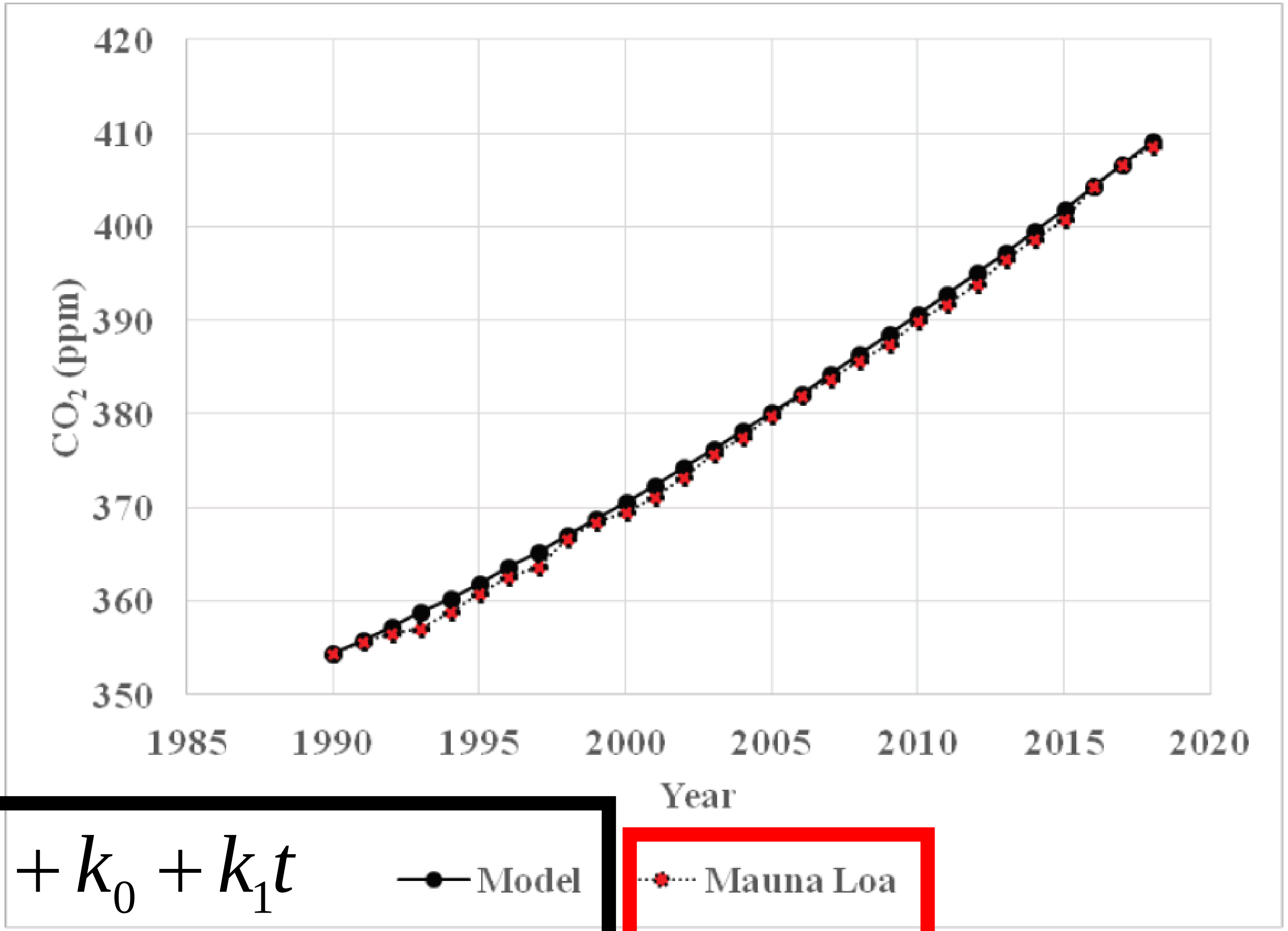
$$b = -0.0187191$$

$$k_0 = 218.89$$

$$k_1 = 3.927$$

x

(ppm)



Year

$$x(t) = Ae^{bt} + k_0 + k_1 t$$

Figure 4_Mauna Loa= CO_2 observations from 1990 to 2018. Model= CO_2 prediction model. The empirical CO_2 observations from Mauna Loa, compare Figure 1 and the prediction according to the derived differential equation model are almost identical. The graph was derived with the following equation: $x(t) = 135.50e^{-0.0187191\,t} + 218.89 + 3.927\,t(ppm)$.

If we express $\dot{x}$ in the unit Gt CO_2/year, and x in the unit ppm, we have this equation:

$$\dot{x} = 40.951 - 0.14609x \quad (23)$$

The estimated differential equation leads to stability.

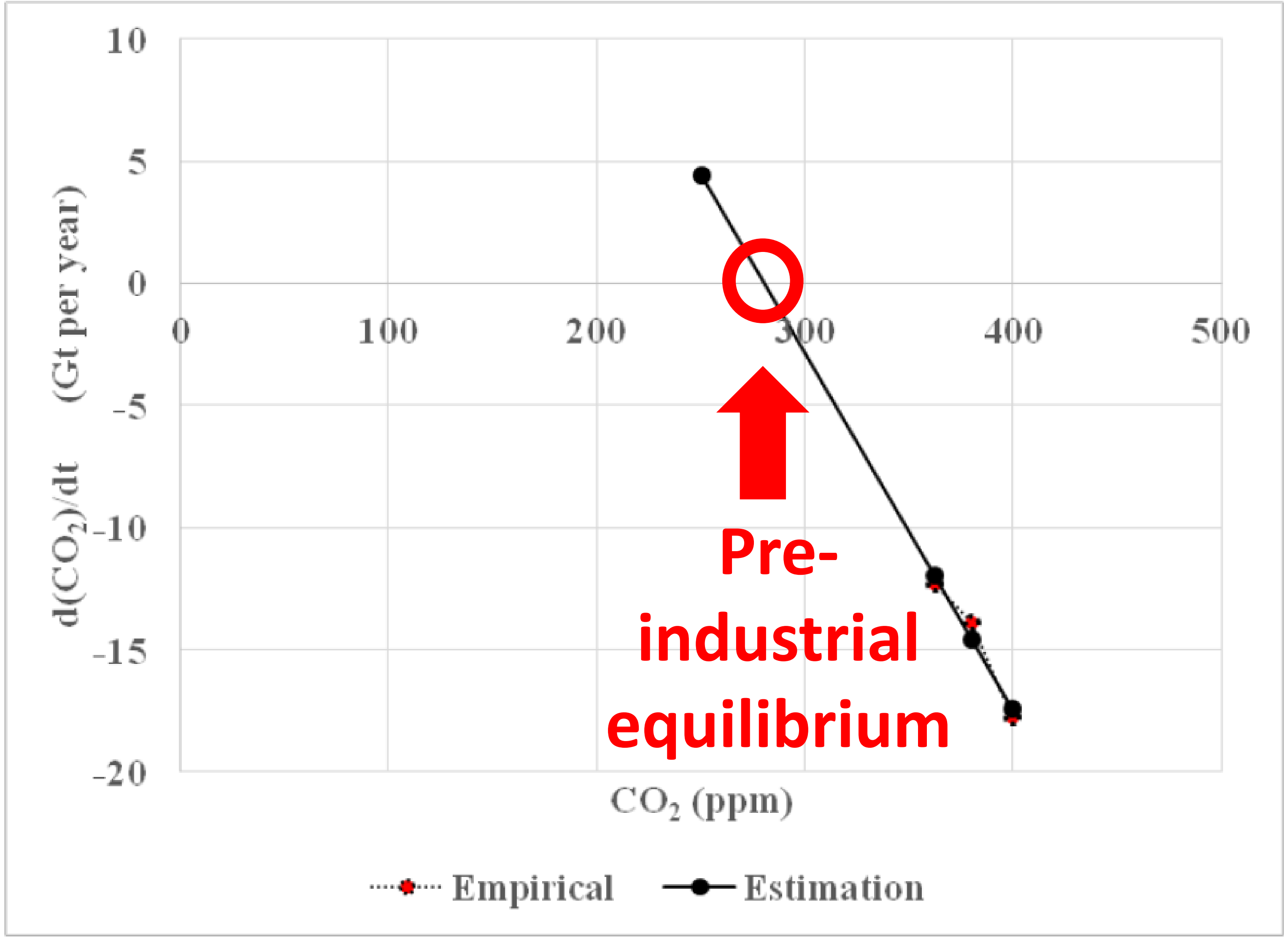
$$\dot{x} = \frac{dx}{dt} = a_0 + a_x x_{eq} = 0$$

$$x_{eq} = \frac{-a_0}{a_x} \approx 280.31 \quad (ppm)$$

The estimated equilibrium is equal to the pre-industrial level.

Change of CO2 in atmosphere
(in the absence of emissions)

The differential equation determines the pre-industrial equilibrium correctly.



X

The differential function is applied to derive four dynamic cases of the global CO_2 level, from the year 2020 until 2100, conditional on four different strategies concerning the development of global CO_2 emissions:

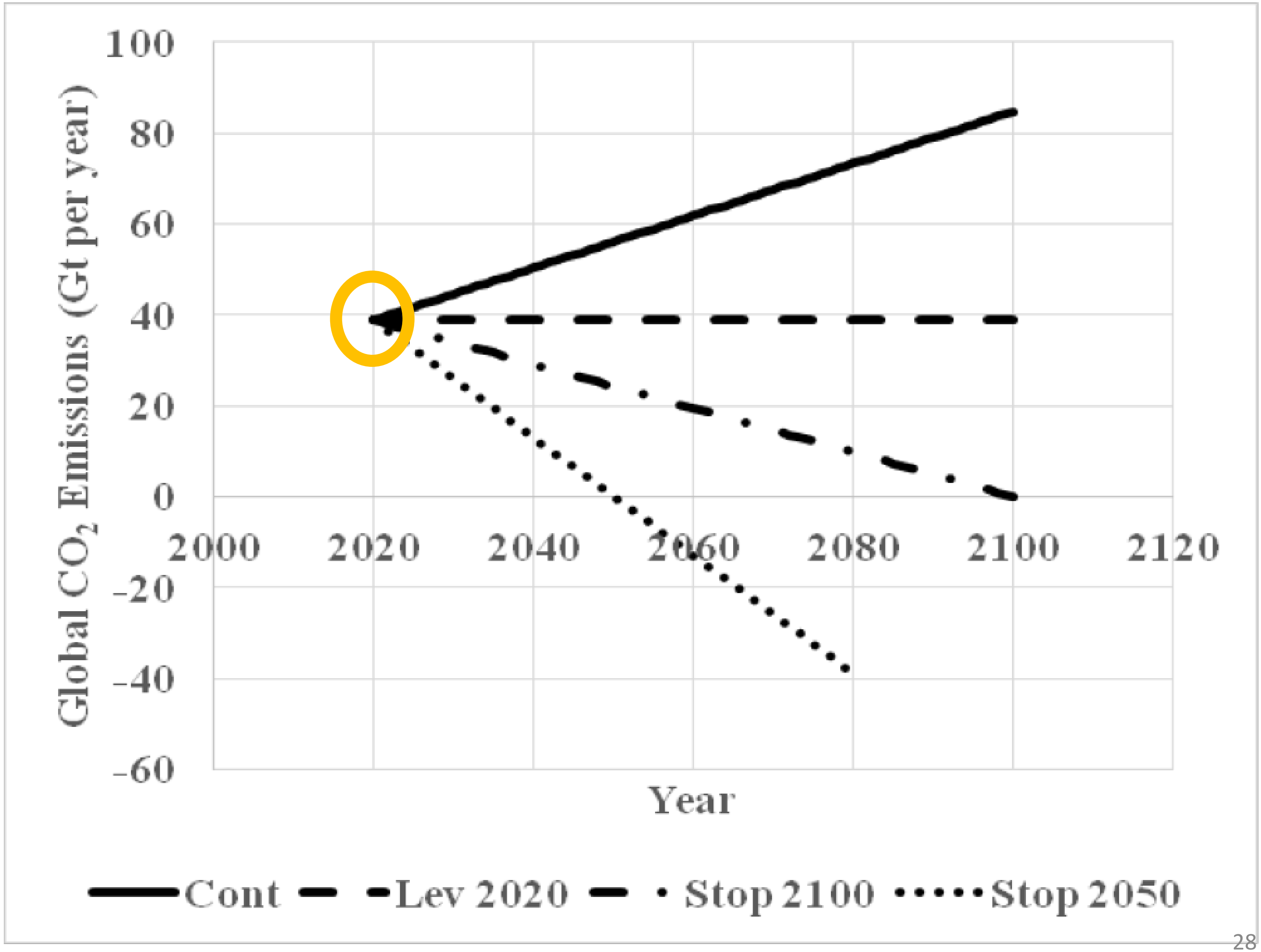
i. **Emissions continue to increase according to the trend during 1990–2018.**

ii. **Emissions stay for ever at the 2020 level.**

iii. **Emissions are reduced with a linear trend to become zero year 2100.**

iv. **Emissions are reduced with a linear trend to become zero year 2050.**

Alternative Emission Strategies



Determination of a prediction model

$$x(t) = Ae^{bt} + k_0 + k_1 t$$

based on the differential equation

$$\dot{x} = a_0 + a_x x + \varphi(t)$$

and the different emission strategies.

Table 7 Parameter values for predictions

Alternative	Year when t=0	x(0)_ppm	a0	ax	m0	m1
Cont	1990	354,39	40,951	-0,01872	21,672	0,57366
Lev 2020	2020	413,96911	40,951	-0,01872	38,8818	0
Stop 2100	2020	413,96911	40,951	-0,01872	38,8818	-0,48602
Stop 2050	2020	413,96911	40,951	-0,01872	38,8818	-1,29606

Table 8 Parameter values for predictions

Alternative	k0 (Gt)	k1 (Gt)	A (Gt)
Cont	1708,271011	30,64570412	1057,501954
Lev 2020	4264,777687	0	-1034,030282
Stop 2100	5651,809577	-25,96398865	-2421,062173
Stop 2050	7963,529394	-69,23730308	-4732,781989

Alternative emission strategies

Parameters in the Gt prediction function

Parameters in the ppm prediction function

Alternative emission strategies

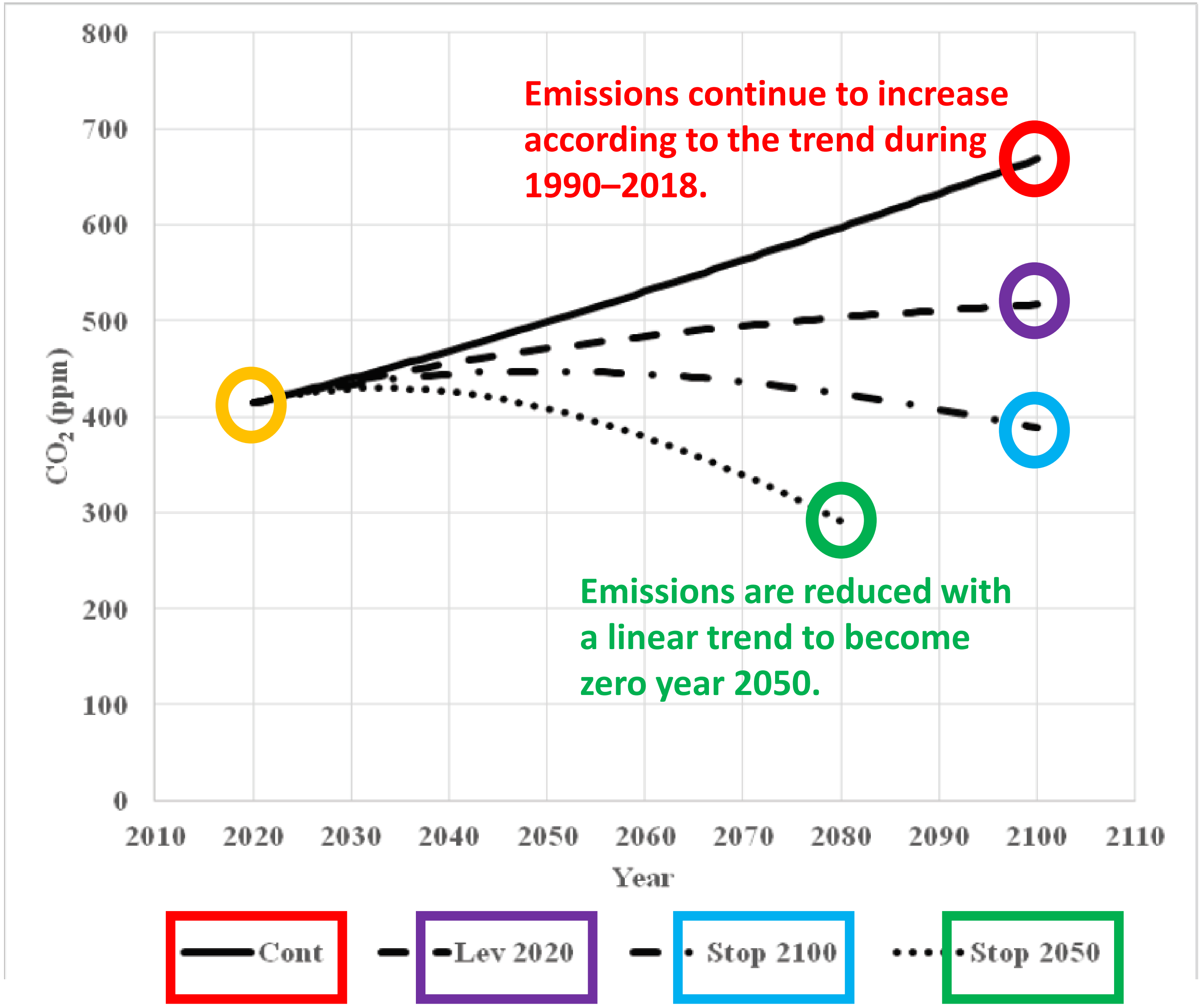
Alternative	k0 (ppm)	k1 (ppm)	A (ppm)
Cont	218,8878738	3,926761604	135,5021262
Lev 2020	546,4637133	0	-132,4946033
Stop 2100	724,1898816	-3,326873918	-310,2207716
Stop 2050	1020,400162	-8,871663781	-606,4310522

$$x(t) = Ae^{-0.0187191\,t} + k_0 + k_1\,t \qquad (ppm)$$

Prediction model

X

The different emission strategies give different future developments of the CO2 level in the atmosphere.



Conclusions

#1. Now, it is possible to understand the dynamics of the CO2 level of the atmosphere, under the influence of global emissions.

#2. A first order differential equation with emission forcing has been able to explain the development of the dynamics of the CO2 level in the atmosphere, with very high precision.

#3. The function shows that the CO2 equilibrium level, before the industrial revolution, was 280 ppm, which confirms earlier empirical research.

#4. The model has predicted how the global CO2 level can be dynamically changed via different emissions strategies.

#2. & #3. Reduced global industrial emissions of CO_2 can solve a large part of the global warming problem. However, there are more control options available. Our world is covered by large areas of primary (natural) forests that are almost not managed at all. They do not contribute very much to the net absorption of CO_2. Parts of these natural forests may be transformed to continuous cover forests, which mean that the absorption of CO_2 increases so that the CO_2 level in the atmosphere can be further reduced. This transformation can be made without severely damaging the environmental conditions. We define an optimization problem with two objectives with different weights in the objective function. These objectives are the economic present value of profits and the utility of the climate. The optimal transformation of natural forests to managed continuous cover forests is affected by the relative weights of the utility of the climate and of the present value of the profits. If the relative weight of the utility of the climate increases, the optimal area of natural forests that should be transformed to managed continuous cover forests increases. If 600 M hectares are transformed during 60 years, from 2020 until 2080, then the concentration of CO_2 in the atmosphere can be reduced by 8 ppm until the year 2100.

#2. will now be described in more details. (The complete open access article #3. can be studied at any time.)

Planet Earth faces the problem of global warming. Recent research on the dynamics of the CO_2 concentration in the atmosphere has shown how reductions of global industrial emissions of CO_2 can solve a large part of the global warming problem. However, there are more control options available.

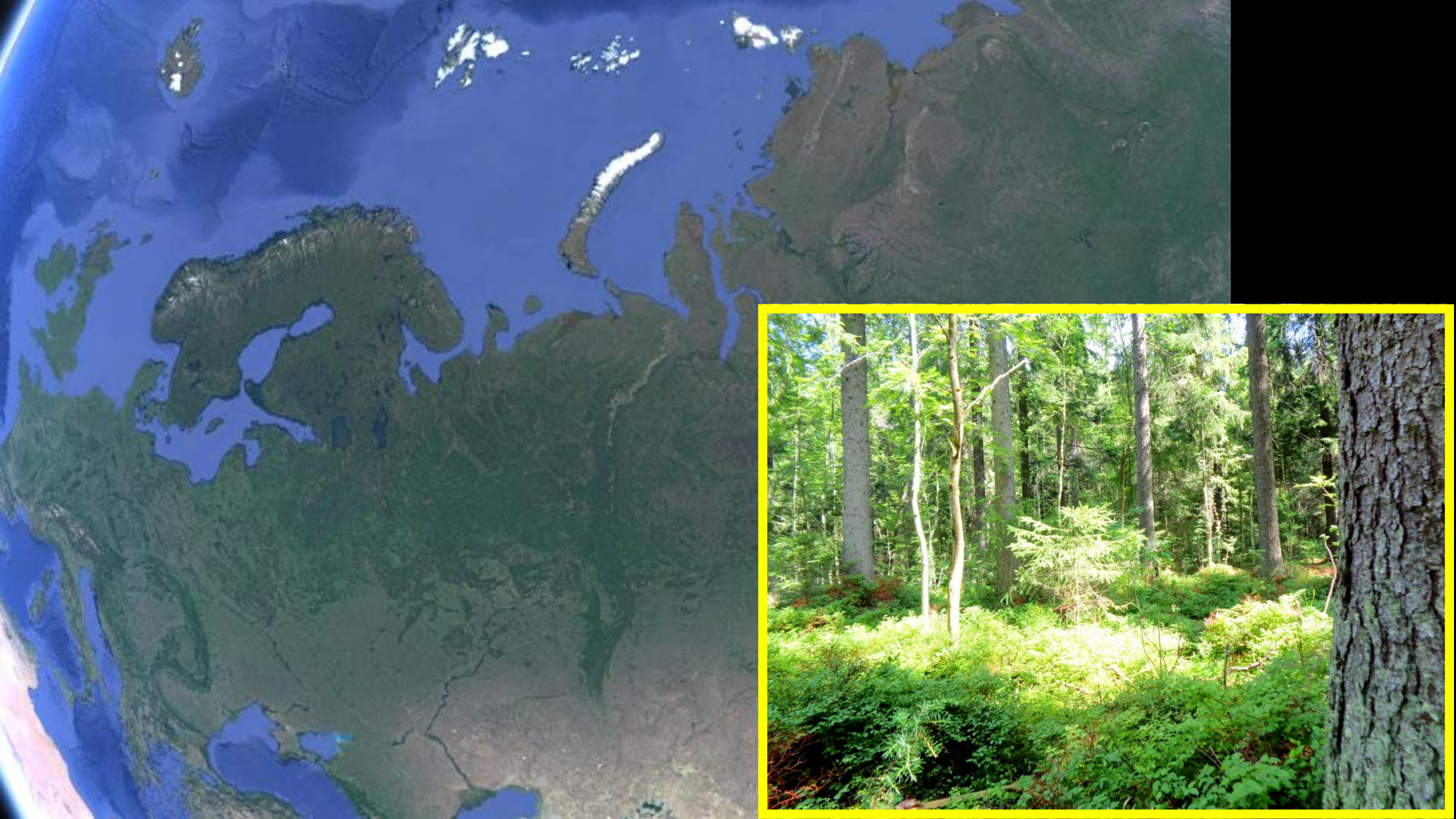
Our world is covered by large areas of primary (natural) forests that are almost not managed at all. They do not contribute very much to the net absorption of CO_2.

According to FAO, 2020, the world presently has at least 1.11 billion ha of primary forest. In these primary forests, of particular interest and relevance to the analysis developed in the later part of this paper, there are practically no human activities such as forest harvesting.

The forests are almost undisturbed by human industrial projects and have native forest species and original ecological processes. In the three countries Brazil, Russian Federation and Canada, we find 61% of these primary forests, which represents approximately 677 M ha.

Our world contains very large areas of mixed species forests with trees of different sizes.

By Phil P Harris. - Own work, CC BY-SA 2.5, https://commons.wikimedia.org/w/index.php?curid=717267



Parts of these natural forests may be transformed to continuous cover forests, which mean that the absorption of CO_2 increases so that the CO_2 level in the atmosphere can be further reduced. This transformation can be made without severely damaging the environmental conditions.

The analysis in this paper shows how to define an optimization problem with two objectives with different weights in the objective function. These objectives are the economic present value of profits and the utility of the climate.

Continuous cover forest harvesting in the Swedish mountains, December 2014

Multi objective optimization

The optimization problem contains the objective function OBJF:

$$OBJF = kW * W + kR * PVR - kC * PVC$$

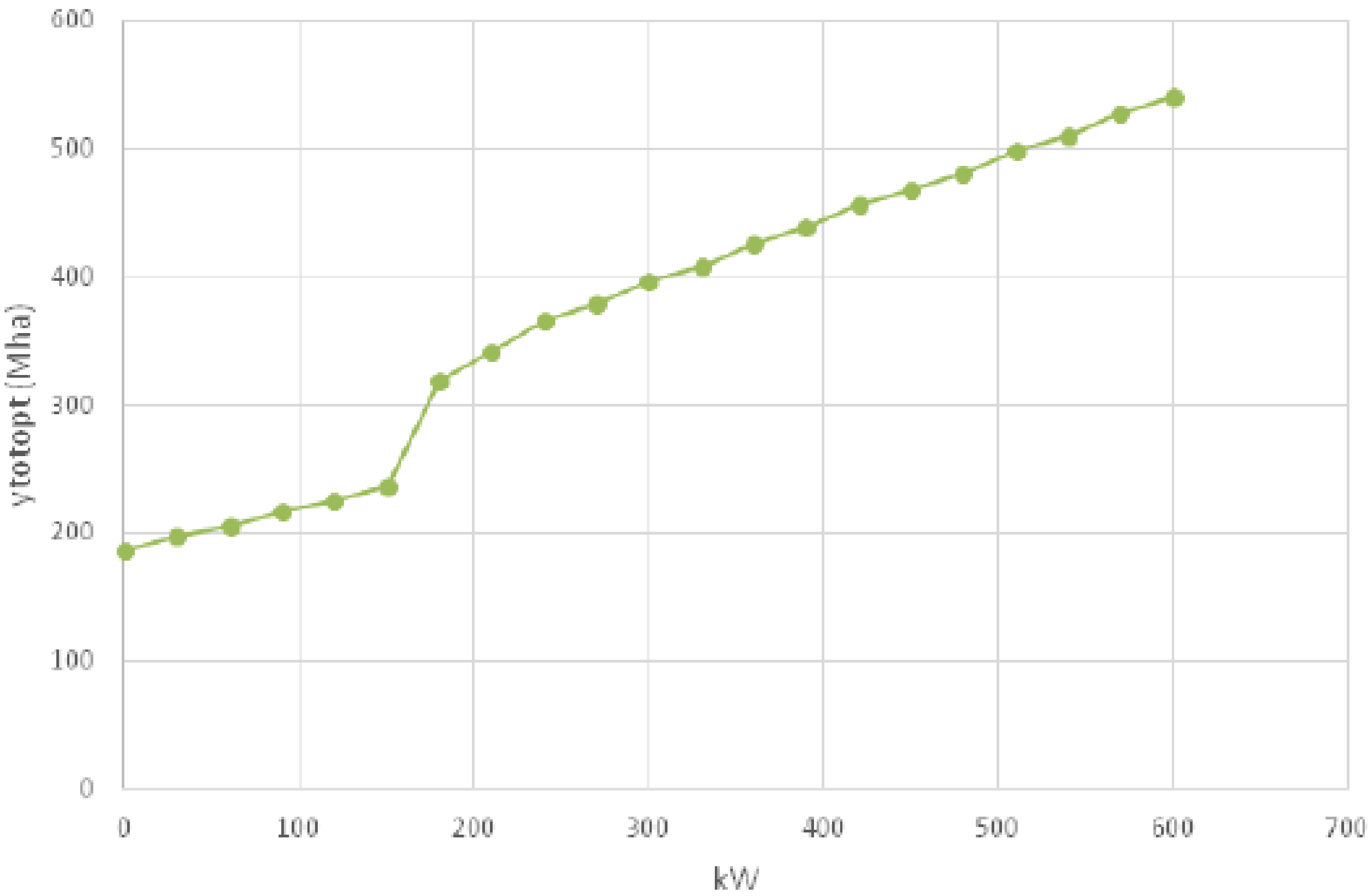
Present value of all profits

Time is denoted by t, in years. t = 0 in year 2020. The analysis is concerned with the time interval year 2020 until year 2100, which means that t goes from 0 to 80. The time horizon is denoted T. T = 80.

W(t) is the utility of the climate as a function of time. W = W(T), is the utility of the predicted climate at the time horizon, T. The utility is assumed to be a strictly concave function of the CO_2 concentration in the atmosphere. This utility function has a unique maximum at the CO_2 level 280 ppm, which is assumed to be the "preindustrial level".

```
FOR y1 = 0 TO 10 STEP 0.1            (y1 = CCF area expansion per year)
    FOR yt = 10 TO 60 STEP 0.1       (yt = number of years of CCF area expansion)

        Determinations of the CO2 differential equation parameters and solutions
        from year 2020 until 2100.

        Derivations of forestry profits and forest dependent CO2 change during
        80 years via the solution to the differential equation.

        Selection of the optimal combination of y1 and yt based on the objective
        function parameters.

    NEXT yt
NEXT y1
```

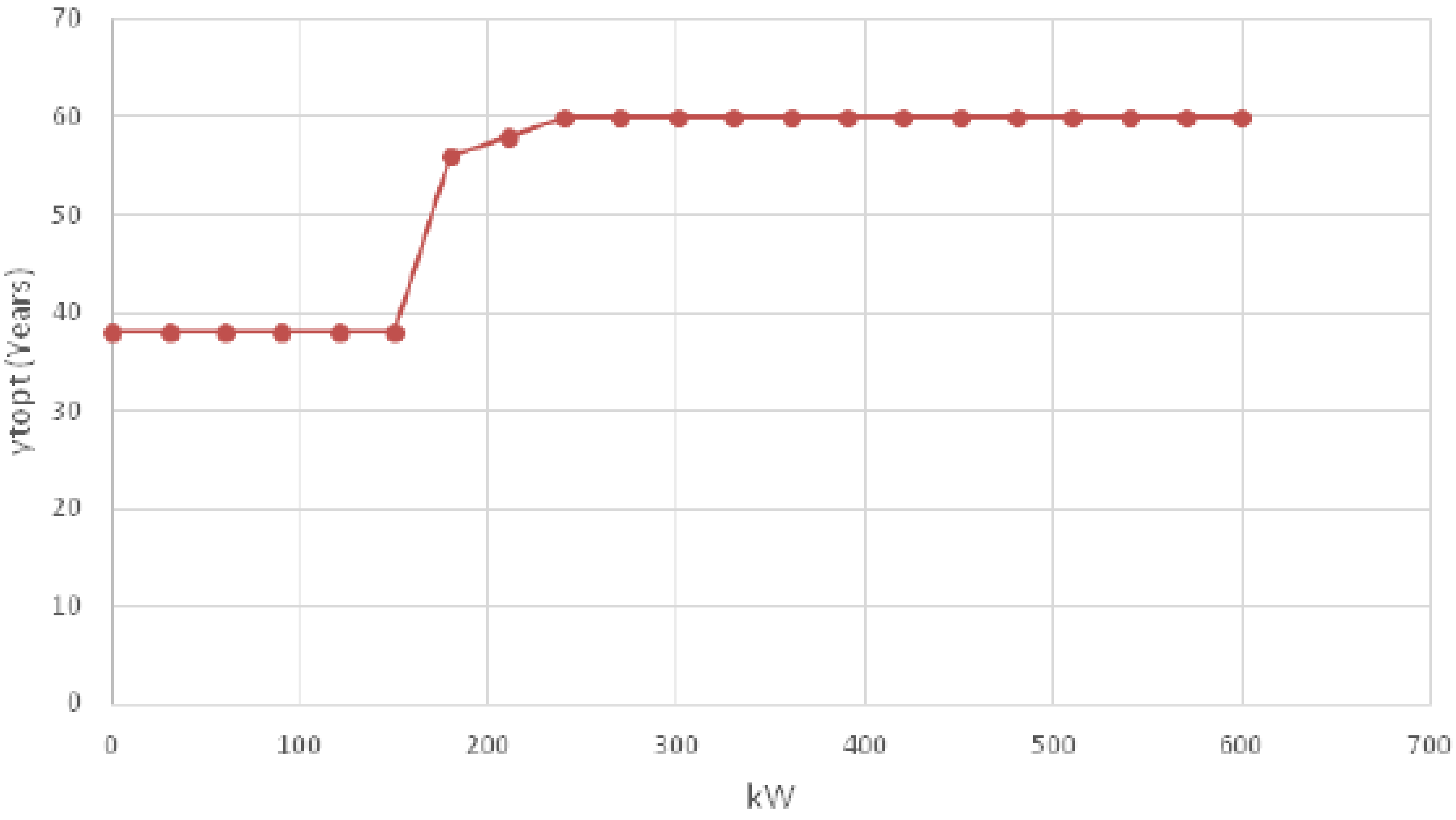
Optimal Total Area Expansion (Mha)



kW

Figure 1 ytotopt, the optimal total area of CCF expansion, as a function of kW, the weight of W in the objective function. ytotopt is a function of ytopt and y1opt. These are found in Figures 2 & 3.

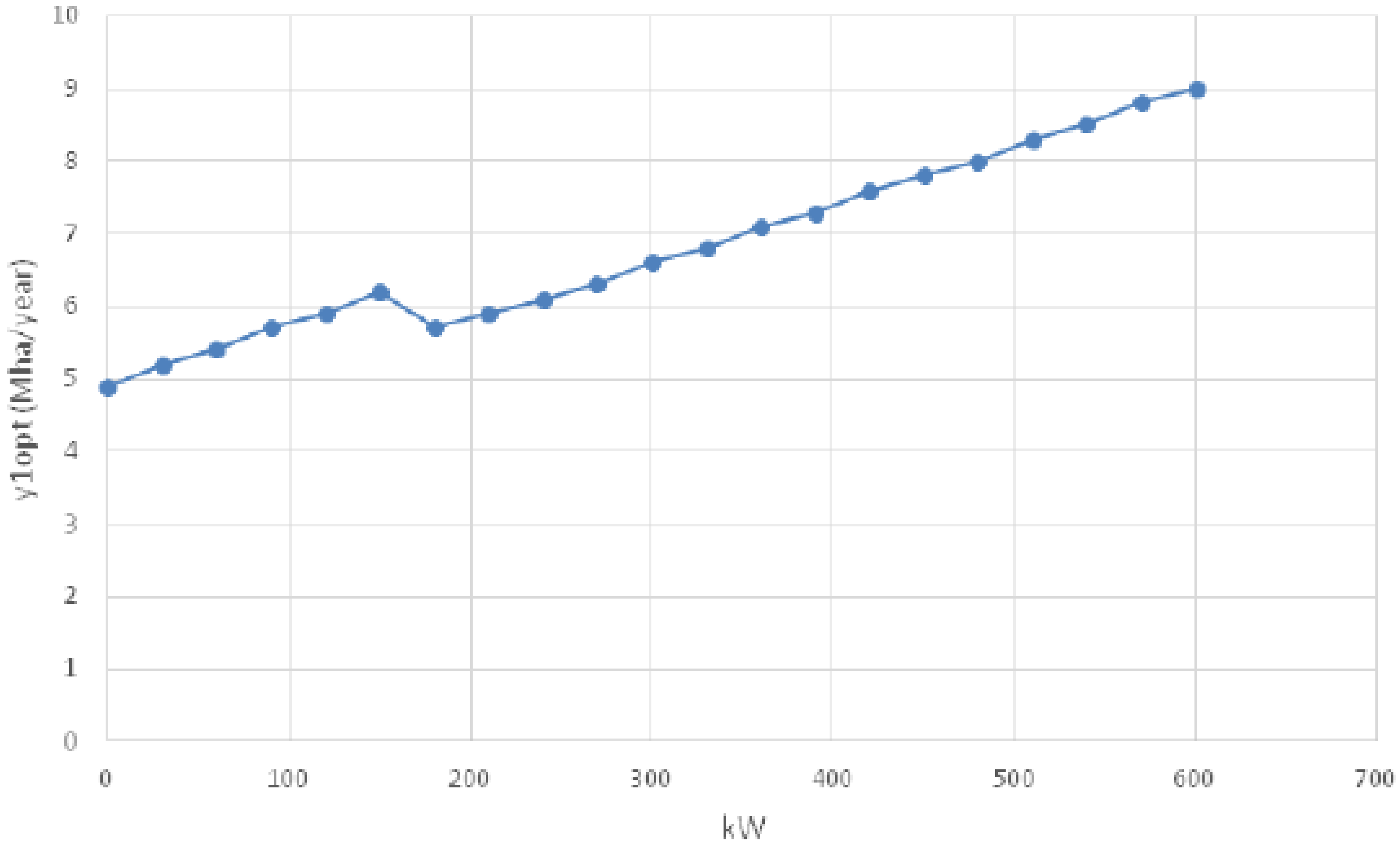
Optimal time of area expansion (Years)



kW

Figure 2 ytopt, the optimal number of years to continue the CCF expansion, as a function of kW, the weight of W in the objective function.

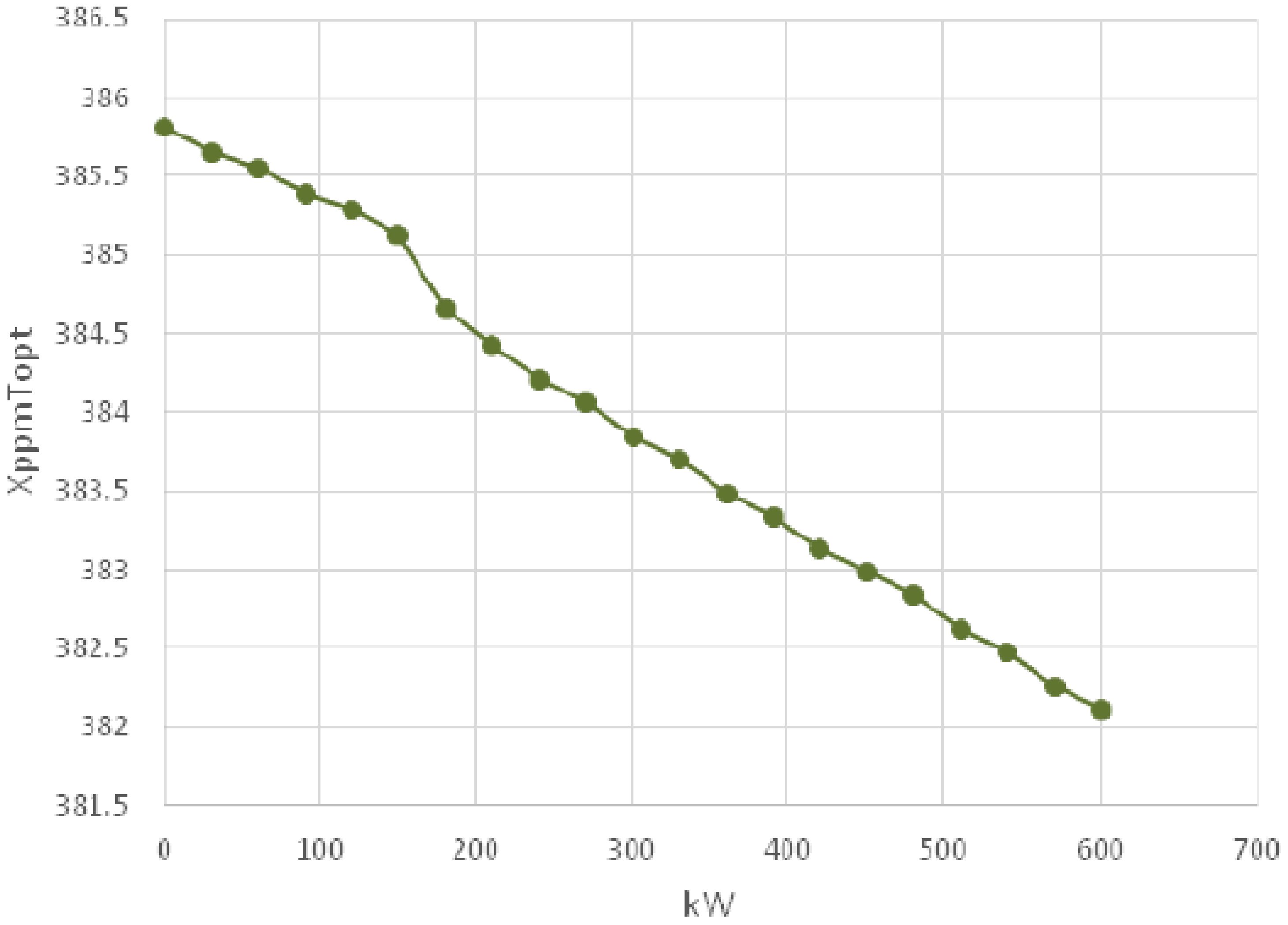
Optimal area expansion per year (Mha/year)



kW

Figure 3 y1opt, the optimal area expansion of CCF per year, until year ytopt, as a function of kW, the weight of W in the objective function.

Optimal CO2 level in year 2100 (ppm)



kW

Figure 4 XppmTopt, the optimal ppm value of CO_2 at time T, (the year 2100), as a function of kW, the weight of W in the objective function.

Present values of optimal revenues, costs and profits (Relevant currency)

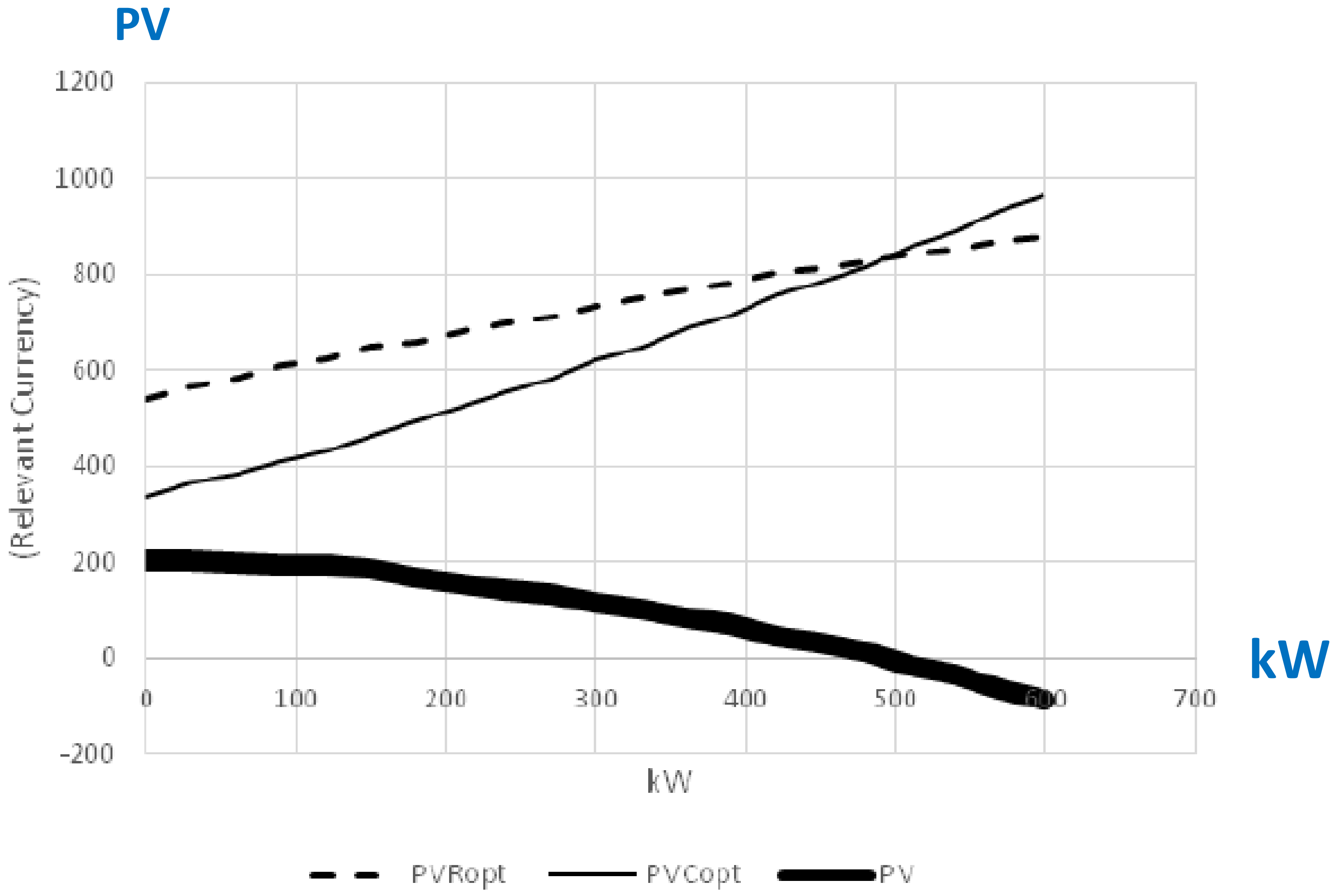
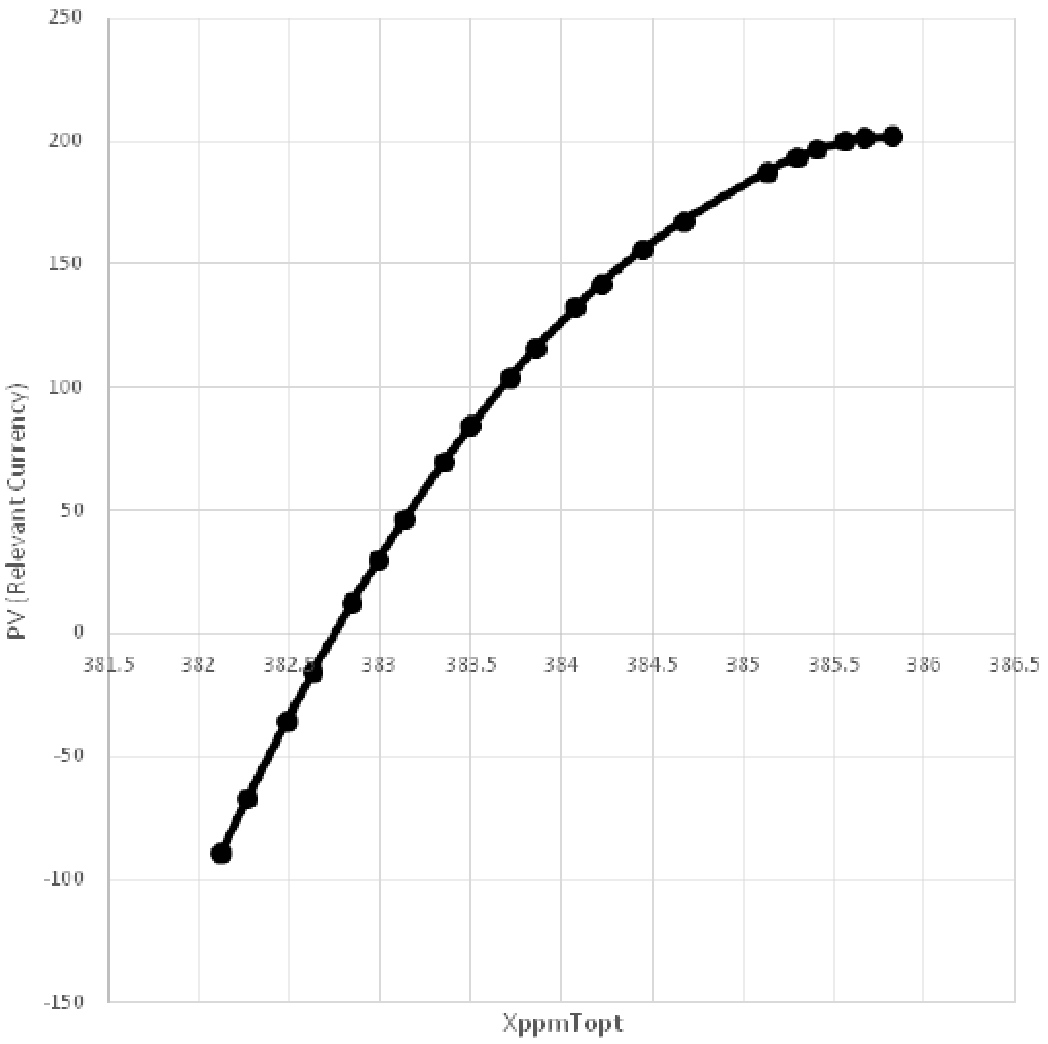


Figure 5 PVRopt, The optimal present value of net revenues, PVCopt, the optimal present value of investment costs and PV, the optimal present value of the profits, as functions of kW, the weight of W in the objective function.

The frontier of optimal combinations of the present value of total profits and the CO2 level in year 2100 (Relevant currency & ppm)

PV

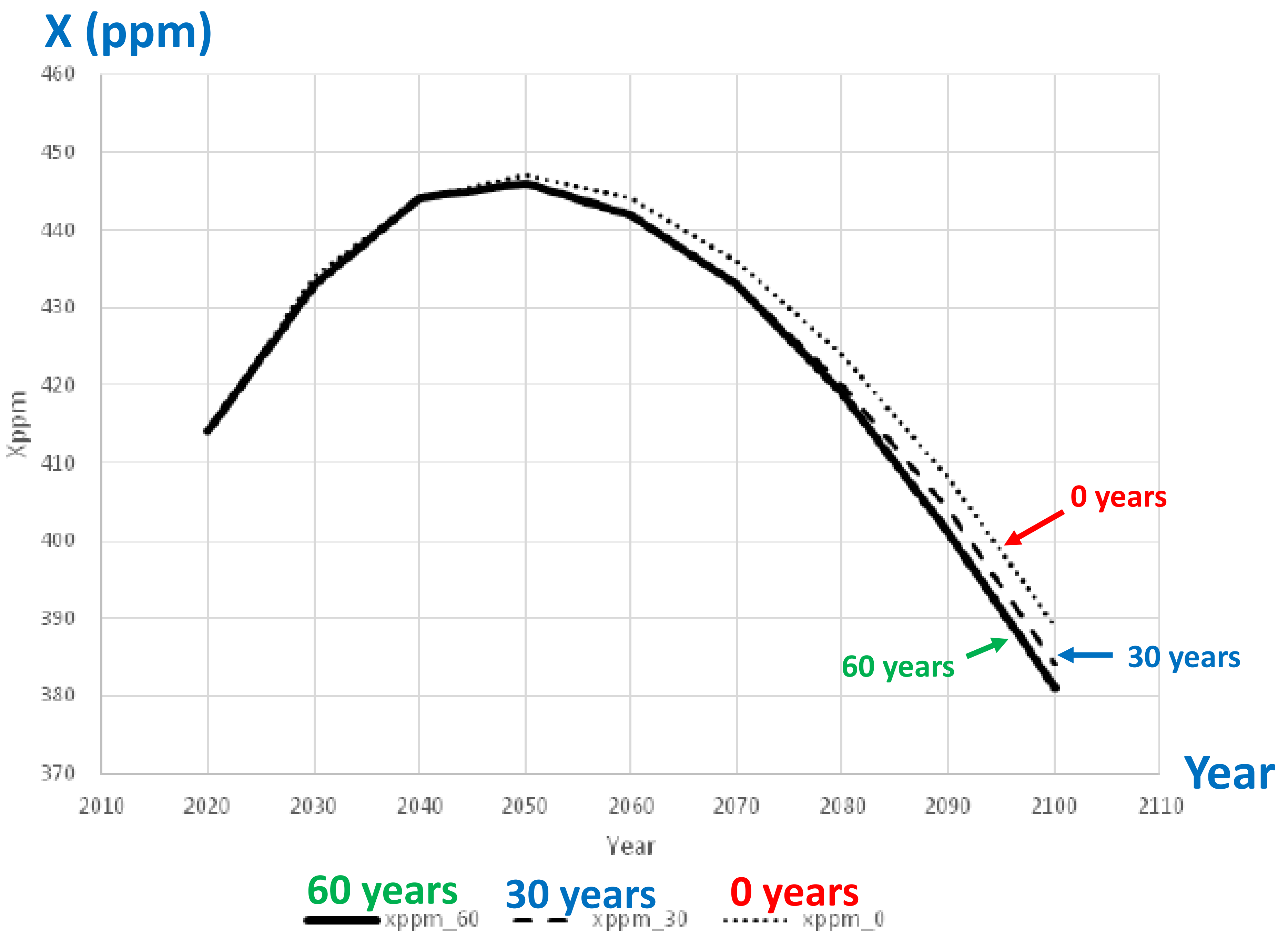


X(t=80) (ppm)

Figure 6 The frontier of optimal combinations of PV, the present value of the profits, and XppmTopt, the concentration of CO_2 in the atmosphere at time T (year 2100). In different points along the curve, the relative weights of the different objectives in the objective function are different.

The time path of the CO2 level (ppm) as a function of the time of area expansion. (years).

(In all three cases in the graph, the area expansion per year is 10 Mha.)



The analysis shows how the optimal transformation of natural forests to managed continuous cover forests is affected by the relative weights of the utility of the climate and of the present value of the profits.

If the relative weight of the utility of the climate increases, the optimal area of natural forests that should be transformed to managed continuous cover forests increases.

If 600 M hectares are transformed during 60 years,
from 2020 until 2080,

then the concentration of CO_2 in the atmosphere
can be reduced by 8 ppm until the year 2100.

Conclusions

#5. Large areas of primary (natural) forests do not contribute very much to the net absorption of CO_2. They may be transformed to CCF.

#6. Then, the absorption of CO_2 increases and the CO_2 level in the atmosphere can be reduced. This transformation can be made without severely damaging the environmental conditions.

#7. If the weight of the utility of the climate increases, the optimal area of natural forests that should be transformed to CCF increases.

#8. If 600 M hectares are transformed during 60 years, from 2020 until 2080, the CO_2 level in the atmosphere is reduced by 8 ppm year 2100.

#5. The average relative burned area has been studied, as a function of different conditions, in 29 countries. Detailed international statistics of forest fires, published by FAO and European Commission, are used as empirical data. A multivariate fire area function with empirically very convincing statistical properties is defined, tested, and estimated. A set of hypotheses was created based on three fundamental factors. The hypotheses could not be rejected on statistical grounds, and the estimated parameters obtained the expected signs with very low P-values. The residual analysis supports the selected functional form. Future fire areas are predicted for 29 countries, conditional on three alternative levels of global warming conditions. The estimated fire area function can explain the forest fire areas in different countries via three fundamental factors. Global warming is predicted to make future forest fire problems even more severe.

#5. is illustrated with a few pictures on the following slides. The complete open access article can be studied at any time.

Table 6. Predictions of average fire areas as functions of the level of change of the average temperature.

	dT= 0	dT= +1	dT= +2	dT= +3
Country	**Average Fire Area (kha)**	**Average Fire Area (kha)**	**Average Fire Area (kha)**	**Average Fire Area (kha)**
Algeria	32.105	49,651	76,786	118.750
Austria	0.072	0.111	0.171	0.265
Bulgaria	5.227	8.084	12.502	19.334
Croatia	12.248	18.942	29.293	45.303
Cyprus	1.673	2.587	4.001	6.187
Czech Republic	0.328	0.507	0.784	1.213
Estonia	0.055	0.086	0.132	0.205
Finland	0.519	0.802	1.241	1.919
France	10.906	16.867	26.084	40.340
Germany	0.541	0.837	1.294	2.002
Greece	25.894	40.046	61.931	95.778
Hungary	4.540	7.022	10.859	16.794
Italy	62.286	96.326	148.970	230.383

Table 6. Predictions of average fire areas as functions of the level of change of the average temperature.

	dT= 0	dT= +1	dT= +2	dT= +3
Country	**Average Fire Area (kha)**	**Average Fire Area (kha)**	**Average Fire Area (kha)**	**Average Fire Area (kha)**
Latvia	0.591	0.913	1.413	2.185
Lithuania	0.087	0.134	0.208	0.321
Morocco	2.916	4.510	6.974	10.786
North Macedonia	4.433	6.856	10.603	16.398
Norway	0.844	1.306	2.019	3.123
Poland	2.966	4.588	7.095	10.972
Portugal	144.555	223.555	345.730	534.674
Romania	1.757	2.717	4.201	6.497
Russian Fed.	2218.100	3430.311	5305.007	8204.239
Slovakia	0.424	0.655	1.013	1.567
Slovenia	0.283	0.438	0.678	1.048
Spain	95.686	147.979	228.851	353.921
Sweden	5.085	7.864	12.162	18.809
Switzerland	0.116	0.180	0.278	0.429
Turkey	6.885	10.648	16.468	25.468
Ukraine	3.625	5.606	8.670	13.408

#4. Forest fires cause severe problems in many countries. Forest fire areas in nine European countries are investigated with respect to yearly averages, standard deviations and correlations between nations. In the region IFPS (Italy, France, Portugal and Spain), the average yearly burned area during the years 2010 to 2018 was 313.4 kha and in FGLNS (Finland, Germany, Latvia, Norway and Sweden) the corresponding area was only 7.6 kha. The correlations between the regions are strictly negative and the correlations within the regions are strictly positive.

Since forest fires usually do not occur in every country at the same time, there is a potential expected gain from international cooperation, where easily mobile firefighting resources such as water bombing airplanes are moved between nations. A general stochastic dynamic programming approach to adaptive moves of such resources is defined and suggested. General properties of the solution are derived. A particular version of the model is created and analytical derivations are performed. It is demonstrated that the expected objective function value, the expected present value of total costs, is a strictly increasing function of the fire correlation between nations. Adaptive moves of mobile resources between the regions IFPS and FGLNS have the advantage of negative correlations between these regions. Some adaptive moves can also be motivated within the regions even with positive correlations, thanks to the low costs of short moves.

#4. is illustrated with a few pictures on the following slides. The complete open access article can be studied at any time.

Table 1 The average yearly burned areas in different countries and regions during nine years (from 2010 until 2018). The standard deviations and the relative standard deviations have also been calculated. "IFPS" denotes the region including Italy, France, Portugal and Spain. "FGLNS" denotes the region including Finland, Germany, Latvia, Norway and Sweden. Source of the list of burned areas: San-Miguel-Ayanz et al., 2019[8]

	Average Burned Area (kha)	Standard Deviation (kha)	Relative Standard Deviation
Italy	62,3	43,1	0,7
France	10,9	6,8	0,6
Portugal	144,6	156,3	1,1
Spain	95,7	66,3	0,7
Finland	0,5	0,4	0,7
Germany	0,5	0,7	1,3
Latvia	0,6	0,9	1,5
Norway	0,8	1,1	1,3
Sweden	5,1	8,5	1,7
IFPS	313,4	240,1	0,8
FGLNS	7,6	11,1	1,5

Table 2 Correlations of burned areas in different countries during nine years (from 2010 until 2018). The original data that were used to calculate these correlations are available in the official statistics by San-Miguel-Ayanz et al., 2019[8]

	Italy	France	Portugal	Spain	Finland	Germany	Latvia	Norway	Sweden
Italy	1,000								
France	0,634	1,000							
Portugal	0,657	0,859	1,000						
Spain	0,944	0,464	0,482	1,000					
Finland	-0,492	-0,313	-0,230	-0,651	1,000				
Germany	-0,349	-0,238	-0,184	-0,369	0,666	1,000			
Latvia	-0,459	-0,291	-0,280	-0,467	0,742	0,951	1,000		
Norway	-0,427	-0,081	-0,158	-0,531	0,682	0,824	0,864	1,000	
Sweden	-0,464	-0,377	-0,356	-0,521	0,894	0,767	0,888	0,762	1,000

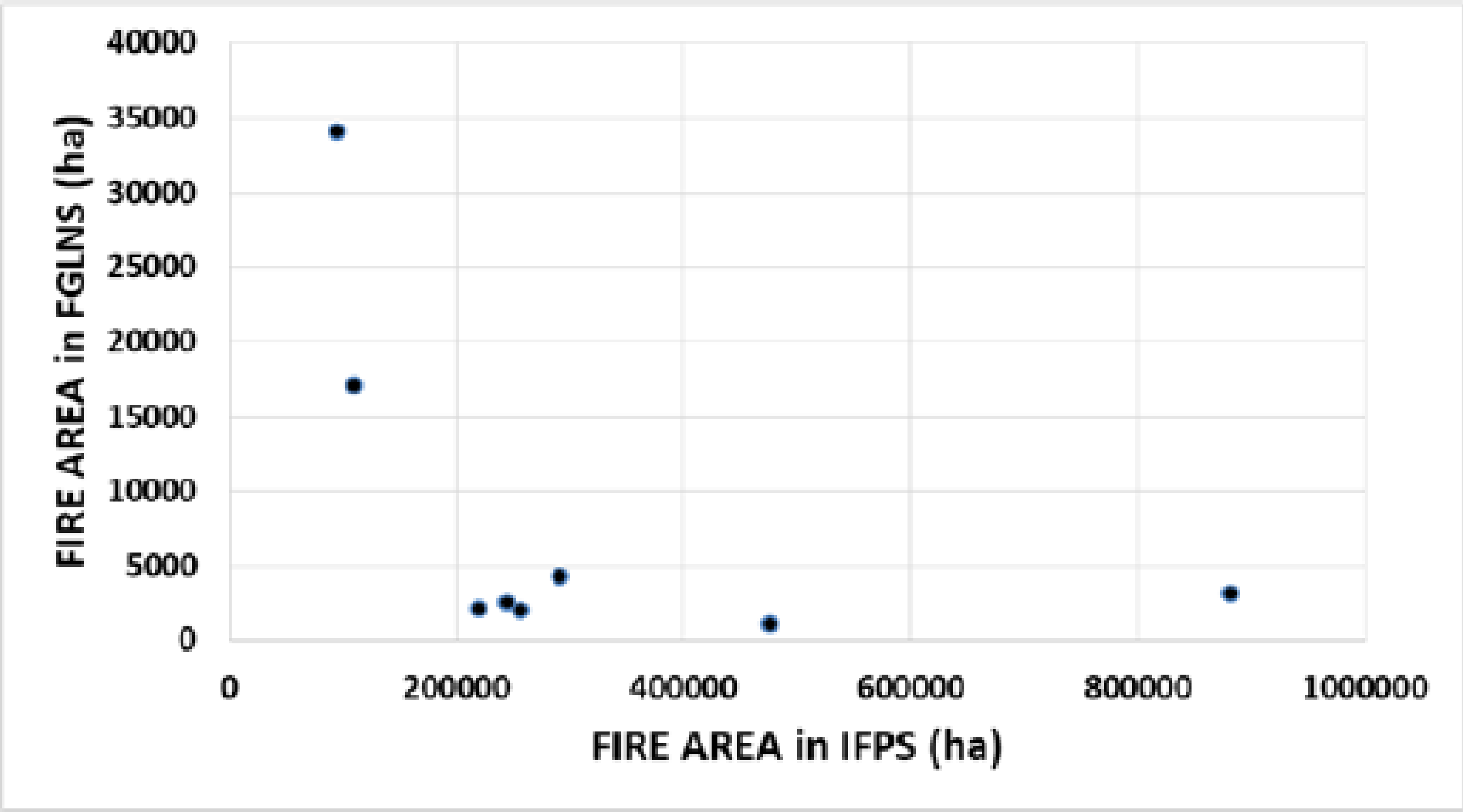


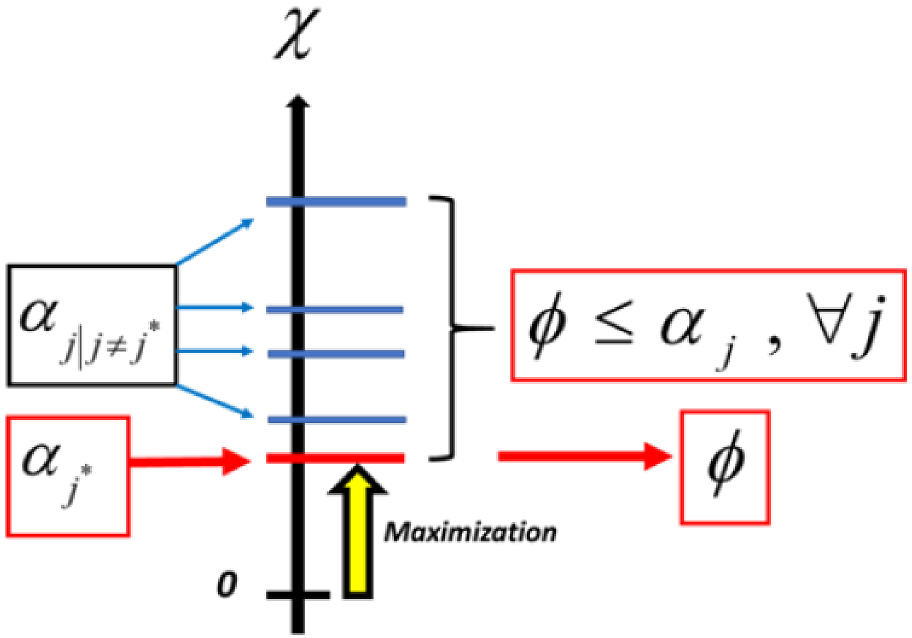
Figure 1 Observations of combinations of burned areas in two regions during nine years (from 2010 until 2018). The raw fire data are available in San-Miguel-Ayanz et al., 2019.[8]

For $t\big|_{0\le t<T}$, we have:

$$\phi\left(t,i_t,f_{1,t},\dots,f_{n,t}\right)=$$

$$=\min_{j_t\in J_t(i_t)}\left\{\begin{array}{l} e^{-rt}C\left(t,i_t,j_t,f_{1,t},\dots,f_{n,t}\right) \\ +\sum_{f_{1,t}-1}^{F_{1,t}}\cdots\sum_{f_{n,t}-1}^{F_{n,t}}\left[\tau\left(f_{1,t+1},\dots,f_{n,t+1}\middle|t,i_t,j_t,f_{1,t},\dots,f_{n,t}\right)\cdot\phi\left(t+1,i_{t+1},f_{1,t+1},\dots,f_{n,t+1}\right)\right]\end{array}\right\}$$

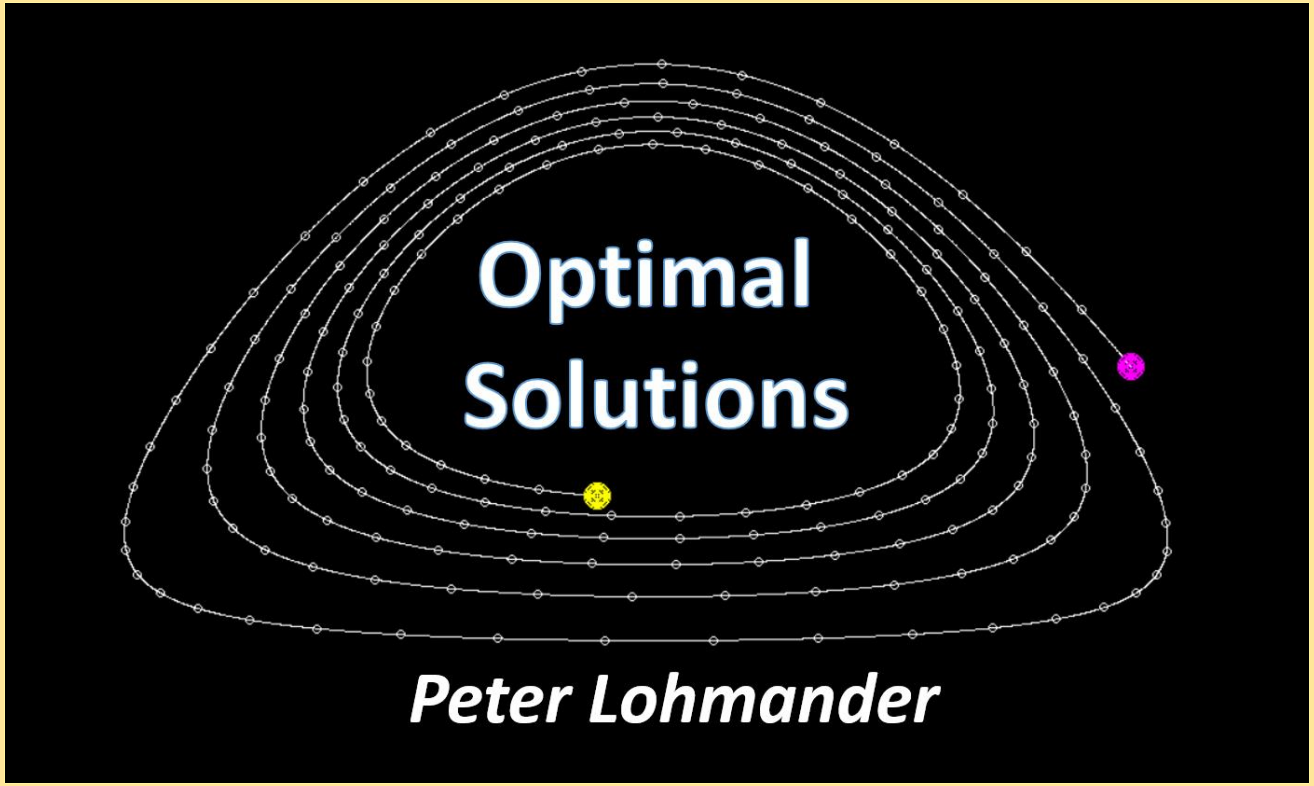
$$\forall t\big|_{0\le t<T},i_t,f_{1,t},\dots,f_{n,t}$$



#6. Forests, sensitive to fires, cover large parts of our planet. Rational protection of forests against fires, forest fire management, is a very important topic area. Our planet is facing the serious problem of global warming. The probabilities of long dry periods and strong winds are increasing functions of a warmer climate. Heat, dry conditions and strong winds increase the probabilities that fires start. Furthermore, if a fire starts, the stronger winds make the fires spread more rapidly and the destruction increases. Under the influence of global warming, we may expect more severe problems in forestry caused by wild fires. For all of these reasons, it is essential to investigate and optimize the general principles of the combined forestry and wild fire management problem. In this process, we should integrate the infrastructure and the firefighting resources in the system as decision variables in the optimization problem. First, analytical methods are used to determine general results concerning how the optimal decisions are affected by increasing wind speed. The total system is analyzed with one dimensional optimization. Then, different combinations of decisions are optimized. The importance of optimal coordination is demonstrated. Finally, a particular numerical version of the optimization problem is constructed and studied. The main results, under the influence of global warming, are the following: In order to improve the expected total results, we should reduce the stock level in the forests, increase the level of fuel treatment, increase the capacity of firefighting resources and increase the density of the road network. The total expected present value of all activities in a forest region are reduced even if optimal adjustments are made. These results are derived via analytical optimization and comparative statics analysis. They have also been confirmed via a numerical nonlinear programming model where all decisions simultaneously are optimized.

The complete open access article #6. can be studied later.

Global Stability via the Forced Global Warming Equation, Fire Control with Joint Fire Fighting Resources, and Optimal Forestry (Edition 210330_1846)



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