A Report on

MODELLING OF THE KAYA IDENTITY CLIMATE MODEL

Submitted in the partial fulfillment of the requirements for the award of degree of

MASTER OF TECHNOLOGY

(Environmental Engineering)

by

Shubham Suyash

(2K15/ENE/12)

under supervision of

Dr Anubha Mandal	Dr Anubha Agrawal
(Coordinator)	(Co-coordinator)

DEPARTMENT OF ENVIRONMENTAL ENGINEERING

DELHI TECHNOLOGICAL UNIVERSITY

2015-17

Certificate

*This is to certify that Shubham Suyash, MTech. student in the Department of Environmental Engineering has submitted a project report "***Modelling Of The Kaya Identity Climate Model***" in partial fulfillment of the requirement for award of degree of Master of Technology in Environmental Engineering, during the academic year 2015-17.*

It is a record of the student's research work prepared under my supervision and guidance.

Dr. Anubha Mandal

(Professor)

Department of Environmental Engineering,

Delhi Technological University

Declaration of Originality

I hereby undertake that I , Shubham Suyash , am the sole author of this report. I undertake that this report neither infringes upon anyone's copyright nor violates any proprietary rights to the best of my knowledge. Any ideas, techniques, quotations, or any other material form of work of other people included in this report, published or otherwise, are fully acknowledged in accordance with the standard referencing practices.

I declare that this is the true copy of my report, including all revisions, as approved by my supervisors, and that this report has not been submitted for any other degree to any other University or Institution.

Shubham Suyash

(2K15/ENE/12)

Acknowledgement

From this project's inception I had the opportunity to learn and work with immensely talented people and I gained a lifetime experience.

I am thankful to my guide ***Dr. Anubha Mandal,*** *Professor, Department of Environmental Engineering, Delhi Technological University for extending all the facilities during the course of study, for her valuable inspiration, able guidance and untiring help which enabled me to carry out and complete this work*

I wish to express my deep sense of gratitude to, ***Dr. AK Gupta,*** *Head, Department of Environmental Engineering, Delhi Technological University for giving me the permission to use the campus and equipments which were needed to carry out this project.*

I would also record my gratitude towards my co-guide ***Dr Anubha Agrawal,*** *DST-SERB National Post-Doctoral fellow at DTU, for giving her valuable time and input.*

I also take this opportunity to thank my parents, friends and all the colleagues and everyone who helped me directly or indirectly during the entire span of this project.

ABSTRACT

Excessive emission of carbon has emerged as the single most dangerous threat in recent times towards the earth's environment and well being. A fair bit of damage has already been caused to the environmental ecology and a continuous deterioration is being seen in the climatic behaviour all over the world. A lot of scientific research has being going to study these emissions effectively which will help in reducing its concentration in the future without hampering the fast economic advancements going on. Through this thesis, I intend to predict the carbon emissions as carbon dioxide by the end of this century with the help of a carbon emission climate model known as the Kaya Identity which states that the emissions can be predicted on the basis of four factors namely population, gross domestic poduct per capita, energy and carbon intensities. I have also tried to provide a stabilization pathway to limit the carbon dioxide concentrations to values around 450 parts per million, which, otherwise is predicted to reach far greater values. The best fit values of all the four individual parameters have also been arrived at. Accurate predictions can lay the groundwork for future carbon policies across the globe which coupled with effective implementation can go a long way in deciding the environmental health of planet earth.

KEYWORDS: Carbon emissions, Energy intensity, Carbon intensity, Kaya Identity.

Contents

List of Tables

List of Figures

List of Abbreviations

PPM	PARTS PER MILLION
IPCC	INTERGOVERNMENTAL PANEL ON CIMATE CHANGE

CHAPTER 1

INTRODUCTION

1.1 WHAT IS KAYA IDENTITY

Kaya Identity states that the emission of carbon dioxide can be said to be the multiplication of four variables which are as follows:

1) Population

2) Gross Domestic Product Per Capita

3) Energy Intensity

4) Carbon Intensity

The model has been developed by Yoichi Kaya who was an energy economist hailing from Japan.

Carbon Emission = Population ×GDP Per Capita × Energy Intensity × Carbon Intensity

It is being used extensively to forecast the carbon emissions as carbon dioxide and has been mentioned in IPCC fifth assessment report published in 2014. Carbon dioxide is released in the atmosphere due to a lot of energy producing activities. Thus, there has been a continuous spike in the concentration of carbon dioxide throughout the past decades. More and more energy is being produced as industrialization and economic development of all the economies across continents is taking place. This model is a product of the ever growing need to forecast and predict carbon emissions with a reasonable degree of precision so that necessary policies related to carbon can be made and effectively implemented. Proper emission cuts need to be made as well to combat this menace of greenhouse emissions, all of which comes down to the proper study and prediction of emissions. Emission amounting to zero is of course the ideal scenario that one should strive for but it is extremely difficult to achieve in real life. The first step in reducing emissions is to have a proper understanding on how it is produced. After extensive research in the field of carbon emissions at University Of Tokyo, Kaya along with a group of other carbon experts and scientists put together this identity for calculation of carbon emissions. As can be seen from the identity, to create a situation where the emissions of carbon is zero, one of the four terms needs to be zero which is impossible to achieve in practicality. The energy use can be reduced or cut but can never be eliminated at the same time. So, proper altering of the values of energy and carbon intensities can help achieve our aim. We are free to enter any values in the boxes for the individual variables and can see the emission scenarios after the model draws a curve for the specific values entered. The thing we have to keep in mind is that for realistic predictions, values entered should be fairly reasonable and not too far off from reality. The road ahead is definitely tough for cutting the emissions to a very low value as a lot of things would have to give in order to achieve this target. What the model does is that it gives us a set of guidelines to be followed and specific values needed to be able to bring down the concentration levels of carbon to a desired lower value. There has been a group of scientists who have criticised the model and have questioned its effectiveness in predicting the emissions with a fair degree of accuracy but still, it is being used extensively all over as the problem is severe and solutions are needed at the earliest otherwise the planet is doomed and there would be some very serious repercussions of it. The fifth assessment report of IPCC has made use of the kaya identity in identifying various scenarios by the end of 21st century to paint a picture in front of the world regarding our emissions and how drastic policies need to be not only framed but acted upon as well for the safeguarding of our future generations as well as our planet earth. Several scientific studies have also been done to study the trends of involved parameters like the energy and carbon intensities which would be the most pivotal ones in determining the future course of actions and emission predictions. We can definitely hope for the best in the future regarding all the emission scenarios. But, one thing is very certain that it is extremely difficult to contain as well as limit the emissions as we will see in the next chapters, so, a lot of things need to be tweaked in order to achieve our targets including a whole bunch of technological advancements for proper sequestration of carbon along with other things.

1.2 VARIABLES INVOLVED IN THE KAYA IDENTITY

We will discuss the parameters involved in the identity in detail. The first parameter involved is the gross domestic product per capita –

1) GDP Per Capita – It shows the net output of a country by dividing GDP with the population. A high value indicates that an economy is booming and there has been an increase in productivity and overall health of the economy. The monetary market value of all final goods and services generated in a specific time span is called as the GDP of a particular country or economy. As all the economies round the globe are making progress and becoming progressive specially the under developed ones, more emissions are taking place which are spiking the concentration of carbon dioxide in the atmosphere. The energy needs have become very vast due to this rapid development and industrialization all across the world. The overall trend for this particular parameter is that it has increased over the decades as can be seen in the model data set by hovering the mouse on the box below the GDP value. It is expected to rise in the future as well because of the obvious reason of economic progress and development. It can be expressed as thousands of US$(1990)/person year. This value has to be entered according to the scenario we are dealing with while computing the emissions as for a normal or usual scenario, it would be different as compared to the worst case framework for emissions both of which have been dealt separately in the next chapters. There is no certainty or objectivity on how this particular variable will evolve in the future as we are dealing with the GDP Per Capita of the whole world but a fair idea can be taken from the best fit values of the past data which are already fed in the model. After entering this particular value, we can fix the other three values in the model and it will draw the curve for concentrations as well as emissions which can be studied and suitable conclusions can be drawn for further actions.

2) ENERGY INTENSITY – It indicates the energy efficiency of a nation's economy. In our case, it is denoting the energy efficiency of the whole world as we are dealing with the emissions by the end of 2100 for the entire earth. It can also be explained as units of energy generated per unit of GDP. The amount of energy produced or generated for a dollar (watts/$). Higher energy intensity values show that a higher price is required to convert energy into GDP. On the other hand, lower values of energy intensity indicate that for conversion of energy into GDP, a lower cost is required. Also, lower values indicate a labour intensive economy unlike higher values which show a non labour intensive economy. A number of factors affect this particular variable but two of the decisive ones are the climate of a particular place and the standard of living of its occupants. Suppose a place has a very hot climate or a very cold one, then, there would be excessive consumption of energy in that particular place due to the usage of cooling or heating equipments required. For example, there would be a spike in the use of heaters and furnaces to beat the extreme heat or the use of air conditioning units and coolers to get relief from the cold. All of this would require extra units of energy which in turn if generated from fossil fuels would increase the carbon emitted in the atmosphere as carbon dioxide. That is why there has to be a decisive switch from fossil fuels which are already scarce to renewable sources of energy. Now, let us consider a place which has a moderate climate. Due to the mild temperatures there would be no need for air conditioning units as well as heating units which would lead to a lower energy consumption demanding a lower energy generation. All of it would result in lower energy intensity of that particular place. Similarly, low standard of living of the occupants of a place would result in lower values of this particular variable. That is the reason why the values of energy intensity of a place like the United States or England is greater than an undeveloped or a developing nation like those of Asia and Africa. The historical trend of this particular value as can be seen from the model has been that of a declining nature as we have been getting energy efficient over the past years. This trend will continue in the future as well because of continuous innovative techniques being designed and efforts being made to make us more energy efficient at a faster rate. Since, this particular variable shows a declining trend, therefore, values entered in the energy intensity box would be negative ones to account for the decline. After that, other values can be entered and the results can be read and conclusions can be drawn.

3) CARBON INTENSITY - It indicates the amount of carbon produced per dollar of economic activity carried out in order to contribute to the GDP. Greater growth and economic boom implies a greater value of carbon intensity if the energy needs are met through fossil fuel usage and not through renewable sources of energy. It is another very important aspect to be considered while trying to speculate the future carbon emissions. This value can also be improved upon by creating new technologies for the capture of carbon also known as carbon sequestration or any other means to generate energy in a non carbon intensive manner. Several scientific studies are going on to achieve this particular target. It has seen a decline over the past century just like the energy intensity values which show that we have been getting carbon efficient but that is not enough to bring down the emission values to a very low value nearing zero by the end of this century which we would see in the results and discussion chapters. The values of carbon efficiency of the fossil fuels can be improved too through proper energy extracting techniques which in turn would improve the carbon intensity as a whole. The use of compressed natural gas in the vehicles in delhi region is an example of a step taken towards the reduction in the quantities of carbon being emitted in the atmosphere. Also, it means lesser use of petroleum derived from fossil fuels which are already scarce and also emit harmful gases in amounts harmful to humans. The values of carbon intensity have to be entered with a negative sign in the box provided in the model to account for the declining trend. The last variable left in the Kaya Identity model is the population factor. The carbon intensity value will play an important role in the worst case scenario of carbon emissions which will be seen in the results and discussion chapters.

4) Population – The population of the whole world has been increasing over the years although the rate of growth has declined over the past decades. The more the population, greater will be the emissions of carbon in the atmosphere because of the greater energy needs etc. The population to be entered in the climate model for the prediction of emissions is the value in billions at which the world population is expected to plateau. This is not an easy task to decide the plateau population. Several population forecasting methods have been used and various trends regarding fertility rates have been studied across all continents by the United Nations. The UN has said that the population would plateau around 11.2 billions. A prediction with a hundred percent accuracy is not possible but a fair idea can be taken through this report. The two most important factors deciding the population are life expectancy and fertility rate. The population has kept increasing because of the increase in life expectancy because of various reasons like development in health care facilities. But, there has been a reduction in the fertility rates as well which accounts for the decrease in percentage growth per decade in the past few decades. Like the other three variables, any value of plateau population can be entered in the population box of the climate model. For a reasonable and fairly accurate prediction, we will have to be realistic and take cue from the UN report on population. Based on that value, assumptions have been taken for the normal course as well as for the worst case scenario which will be seen in the next chapters. So, these are the four variables which have to be considered and taken into account for the prediction of carbon emissions as carbon dioxide. Care has to be taken while entering the values as two of them are negative and two are positive.

1.3 NEED FOR CARBON EMISSION FORECASTING

The concentration of carbon dioxide has reached to over 400 parts per million as compared to pre industrial values of 280 parts per million. Due to the economic progress coupled with population increase and other factors, there has been a growth in the emissions of greenhouse gases by 2% per year which accelerated in the period of 2000 – 2010 and became three percent per year. According to carbon researchers, a two percent growth doubles the emissions every 3.5 decades. The IPCC has recently published its fifth assessment report in 2014 in which it has examined over 900 possibilities to explore and predict possible climate scenarios. A lot of assumptions and uncertainties are there in these scenarios, but a reduction of the current greenhouse gas emissions to half by 2050 and then continuing the downward trend would be a rational proposition. If the emissions are not forecasted properly, appropriate policy measures would be very difficult to take to curb the emissions. The detrimental effects of a huge amount of carbon dioxide in the atmosphere would mean extreme temperatures with fluctuations along with an increase in sea level which would pose a severe threat to the coastal areas regarding submergence. Other harmful effects include acidification of the oceans and other water bodies threatening a lot of flora and fauna which are already on the verge of getting extinct. With billions of people living below the poverty line and dying of hunger, food security is of prime importance. The harsher weather conditions generated would lead to loss of crops and threaten the food safety of the entire earth. Also, global warming would lead to a host of other problems. So, we can say that life would become untenable for the coming generations. The Kaya Identity model helps in this direction by giving us a picture of the future growth trends along with the concentrations of carbon dioxide and the carbon free energy required for the stabilization pathways created etc. The various scenarios of IPCC would be discussed in the following chapters along with the stabilization requirements to bring down the carbon dioxide level to a particular value by the end of this century.

AIM AND OBJECTIVES

- Finding the best fit values for the different variables in the carbon emission Kaya Identity Model by eyeball fit.

- Presenting a worst case scenario for carbon emission using the uncertainties in the best fit values by the end of 21^{st} century.

- Present a stabilization pathway limiting atmospheric carbon dioxide to 450 parts per million by 2100 which is currently projected to be way beyond that.

CHAPTER 2

LITERATURE REVIEW

Carbon emission is the release of carbon into the atmosphere. To talk about carbon emissions is simply to talk of greenhouse gas emissions; the main contributors to climate change. Since greenhouse gas emissions are often calculated as carbon dioxide equivalents, they are often referred to as “carbon emissions” when discussing global warming or the greenhouse effect. Since the industrial revolution the burning of fossil fuels has increased, which directly correlates to the increase of carbon dioxide levels in our atmosphere and thus the rapid increase of global warming. But what are the specific greenhouse gases involved, other than the obvious culprit - CO_2, and where are these emissions actually coming from? What are the sectors of society and economy responsible for these emissions, the potential for reducing emissions in these various sectors, and the larger economic, political, and ethical considerations surrounding them? First, let us tackle the first question. What are the anthropogenic greenhouse gas emissions in the first place? Indeed, the main culprit is, as we might have expected, CO_2. In terms of the net increase in the greenhouse effect due to human-produced greenhouse gases, CO_2 is responsible for the lion's share. CO_2 from fossil fuel burning alone is more than half the net forcing. If we add CO_2 from fossil fuel burning, deforestation, and other minor sources, this comes to a little more than three fourths of the net greenhouse radiative forcing by human-caused emissions. That means, however, that a non-trivial fraction of the effect is coming from other gases. Roughly,14% is methane, mostly from agriculture, livestock raising, and damming projects which create an artificial breeding ground for methanogenic bacteria though some also escapes during natural gas recovery attempts. Another 8% is nitrous oxide, also a by-product of agriculture, and the remaining 1.1% is chlorofluorocarbons (CFCs). It is tempting to simply lump the contribution of these greenhouse gases together with that of CO_2, representing the net impact in terms of an effective CO_2 concentration called "CO_2 equivalent". Some of these gases (like methane) are considerably more short-lived in the atmosphere than CO_2, persisting for decades rather than centuries. Such complications are often dealt with through the concept of GWP also called as the Global

Warming Potential, which takes into account both the radiative properties of a particular greenhouse gas molecule and the lifetime that such a molecule typically has in the atmosphere, once emitted. In any case, such details represent a complication for greenhouse emissions mitigation policies. If we need to avoid a dangerous near-term climate tipping point, we might focus more effort on reducing methane because it is a particularly potent, if short lived, greenhouse gas. On the other hand, if our goal is stabilize long-term greenhouse gas concentrations, we would be better served by focusing purely on CO_2 emissions. So, where are these greenhouse gas emissions coming from? They come from literally every sector of our economy. The largest single source is energy supply primarily coal fired power plants, and natural gas used by consumers for electricity and heating. The next largest contribution comes from industry, which includes electricity and heating used by the industrial sector and greenhouse gases released as a by-product of cement production, chemical processing, and other industrial processes. Energy supply and industry combine for nearly half of the greenhouse gas emissions. Next, accounting for about 17% of emissions, is forestry, mostly the carbon released from forest clearing and forest burning, followed by agriculture and transport, each of which accounts for around 13% of emissions. Agricultural emissions are mostly in the form of methane released by ruminants such as cows used as livestock, and by cultivation of rice paddies which provide breeding grounds for methanogenic bacteria. Transport-related emissions are mostly in the form of petroleum-based fuels used for personal (i.e., cars and motorcycles, minivans, SUVs, small trucks, buses, airplanes) and commercial (large trucks, ships, airplanes) transportation. Finally, residential buildings (including both construction and maintenance, electricity requirements, etc.) and waste management are responsible for about 8% and 3% of emissions respectively. While it is useful to know what the historical contributions to our emissions have been from the various sectors, looking forward towards the future it is also important to know which sectors are growing most rapidly in their contribution to anthropogenic greenhouse emissions. By comparing emissions rates during the middle of the past decade with those at the beginning of the 1990s, we see that the largest absolute increase (an increase of nearly 3 gigatons/year of CO_2 released) has been in the energy sector, though other sectors such as transport and forestry have shown similar (35-40%) increases in emissions over this time frame. It is logical to conclude that these sectors might demand special attention in considering possible emissions mitigation approaches. To some extent, the economics of climate change is a matter of cost-benefit analysis. Alternatively, we can view this as balancing dueling costs. There is of course the cost of action. Some mitigation schemes actually cost nothing, and, in fact, they might even save us money, these are called no regrets strategies . They are the things we ought to do anyway: recycle, reuse, reduce our use of energy, etc., whether or not they make a difference for climate change. However, other mitigation schemes, like carbon sequestration or use of energy sources that are more expensive than relatively cheap fossil fuels, cost money. On the other hand, there is the cost of inaction. We know that there is potential harm that could be done across all sectors of society by climate change impacts. One complication is taking into account so-called externalities, hidden costs that are not, by default, taken into account in the economic decision-making process. What is the value of a coral reef? What is the value of a functioning ecosystem? What is the value of a species? What is the value of a human life and does this differ among nations, between rich and poor? Quickly, as we may gather, discussing the economics leads us into a discussion of matters that are no longer simply economic in nature, but, indeed, raise fundamental ethical questions as well. A term has been introduced by carbon scientists known as the social cost of carbon (SCC). This is the cost to society of emitting a (metric) ton of carbon. As noted above, precisely evaluating the true cost to society becomes very difficult. Economists typically resolve this difficulty by simply ignoring those costs that are not easily quantified (i.e., ignoring the externalities), and focusing purely on the more straightforward economic costs. There is quite a bit of debate among economists regarding the true value of the SCC. In part, the divergence of opinion relates to different assumptions regarding the appropriate level of what is known as discounting. Discounting, in economics, relates to the fact that a dollar a year from now is worth less to us than a dollar today, because of the lost opportunity of not having the dollar today. In typical financial markets, this discount rate is somewhere in the range of 6%. One can argue that there is a similar discounting phenomenon that applies to climate change mitigation. The argument is that money that might be spent on climate change mitigation today could be spent on other investments, and perhaps because of improvements in, e.g., energy or in emissions mitigation technology that will arise in the future, it will actually be cheaper to decrease our emissions by the same amount a year from now. What is unclear, however, is whether or not it is appropriate to apply similar discount rates to those used in financial markets to climate change mitigation. For one thing, the costs and benefits are not borne by the same individuals. The carbon we are emitting today will most likely incur the greatest costs for our children, or even our grandchildren's generation. Is it appropriate to place less value on their quality of life than we place on our own? Once again, we see that deep ethical considerations are easily hidden in the sorts of assumptions that might superficially seem to be objective economic considerations. While some economists like William Nordhaus of Yale University have argued for discount rates as high as 6% (though in recent years he has lowered his estimate of the appropriate discount rate to 3%), others such as Sir Nicholas Stern of the UK, argues, for ethical reasons, that the appropriate discount rate should be far lower (Stern favours a 1.4% discount rate). There is a direct relationship between the discount rate and SCC. A 6% discount rate gives an SCC of roughly $20/ton, while a 3% discount rate translates to $60/ton, and a 1.4% discount rate translates to an SCC of roughly $160/ton. The U.S. has used a value of $36/ton .Another complication is the possibility of tipping points. Most economic cost-benefit analyses assume that climate changes smoothly with increasing greenhouse gas concentrations. However, if there is a possibility of abrupt, large, and dangerous changes in the climate e.g., the sudden collapse of ecosystems, melting of the major ice sheets, etc. and the threshold for their occurrence is not precisely known, then any amount of future climate change could be perilous, with costs that cannot be anticipated in advance. This is one potentially crucial flaw in standard cost-benefit analysis approaches and part of the reason for the so-called precautionary principle, which advises erring on the side of caution (i.e., on the side of dramatic emissions reductions) when the potential threat great harm to civilization and our environment in this case is unacceptably costly. Mitigation efforts, nonetheless, will only proceed if they pass the cost-benefit analysis, and to do so, the estimated SCC must be greater than the cost of emissions reductions. One way to make emissions reductions cost less is to make the emissions themselves cost more, i.e., to put incentives on the reductions. Any serious effort to mitigate carbon emissions must internalize the cost of the damage to our environment that they cause. There have been fierce arguments among economists and policy experts about how best to accomplish this.

The two widely considered approaches are the so-called carbon tax, a surcharge on carbon emissions at the point of origin, e.g., automobiles and trucks, coal-fired power plants, etc., and the so called cap and trade, a system of tradable emissions permits aimed instead at end use, e.g., the automobile or airline industries, the energy industry, etc. In such a system, a limit is placed on the total allowable emissions; this is the cap for a particular industry, and the emissions rights can be traded in an open market.

Advocates of a carbon tax often see it as a market-based mechanism that is relatively free of bureaucracy, can be used to raise revenue, or can be made revenue-neutral though offsetting reductions in other taxes. Proponents of cap and trade, by contrast, might point out that it is a more effective approach for insuring that emissions remain below some specified level, something that could be particularly important when dangerous tipping points loom. The cap and trade approach, moreover, has been tested and shown viable in other contexts, such as the mandated reduction of sulphate aerosols with the clean air acts of the 1970s to combat the acid rain problem. A limited tradable system for carbon emissions has shown success in the European Union. We have already seen that, depending on discount rates and other assumptions, one can come up with vastly different estimates of the SCC. There seems to be some consensus that a reasonable estimate lies somewhere within the range of $20 to $100. As a point of reference, a 9 cents per gallon gasoline tax would amount to roughly 30$/year for the average American who drives roughly 10,000 miles a year, thus emitting a metric ton of carbon. It is evident that if we adopt a very low (e.g., $20/ton) value for the SCC, then emissions reductions will be quite modest, while at $100/ton the reductions are considerably more substantial. Carbon emissions, at least approximately a decade ago, were roughly 8.5gigatons of carbon per year; in the most recent years they are near 10gigatons per year. In terms of CO_2 equivalent that amounts to 37gigatons/year. [To convert from carbon to CO_2 equivalents, we need to consider the following: 1 mole of CO_2 contains one mole of carbon; molar weight of carbon is 12 g/mole; molar weight of oxygen is 16 g/mole; molar weight of CO_2 is 12+2*16 = 44 g/mol. Therefore, to convert from units of carbon to CO2 equivalents, units of carbon must be multiplied by 44/12 conversion factor.] To bring emissions to zero, we would need to reduce these emissions by 37gigatons per year. At a $20/ton cost, we see that the reductions over all 7 sectors (energy supply, transport, buildings, industry, agriculture, forestry, and waste removal) add up to about 13gigatons/year, a small portion of that 31gigatons/year. On the other hand, at $100/ton, the reductions add up to almost 24gigatons/year, making a quite serious dent in the 37/year that constitutes current emissions, reducing carbon emissions to 13gigatons CO_2 equivalent/year. So, the bottom line is that if we place a large enough cost on emitting carbon, it is possible to achieve the necessary reductions to stabilize CO_2 concentrations at non-dangerous levels. Stabilizing CO_2concentrations at 450 parts per million would appear to require an SCC roughly in the range of $180/ton carbon emitted, which, in turn, would amount to a roughly 4% per year improvement in carbon efficiency. How that improvement will come about, necessarily, will be dictated by government policies. Only by internalizing the true costs of carbon-based energy and fundamentally revising government incentives for developing non-carbon (or carbon neutral) based energy sources, such as wind, solar, hydro-power, bio-fuels, and potentially albeit with certain important caveats nuclear, will market mechanisms operate under rules that will increase the SCC to the necessary levels. Scientists attempt to create scenarios of future human activity that represent plausible future greenhouse emissions pathways. Ideally, these scenarios span the range of possible future emissions pathways, so that they can be used as a basis for exploring a realistic set of future projections of climate change.

In previous IPCC assessments, the most widely used and referred-to family of emissions scenarios were the so-called SRES scenarios (for Special Report on Emissions Scenarios) that helped form the basis for the IPCC Fourth Assessment Report. These scenarios made varying assumptions regarding future global population growth, technological development, globalization, and societal values. One (the A1 'one global family' storyline chosen by Michael Mann and Lee Kump in version 1 of dire predictions) assumed a future of globalization and rapid economic and technological growth, including fossil fuel intensive (A1FI), non-fossil fuel intensive (A1T), and balanced (A1B) versions. Another (A2, 'a divided world') assumed a greater emphasis on national identities. The B1 and B2 scenarios assumed more sustainable practices ('utopia'), with more global-focus and regional-focus, respectively. Let us now directly compare the various SRES scenarios both in terms of their annual rates of carbon emissions, measured in gigatons (Gt) of carbon (1Gt = 10^{12} tons), and the resulting trajectories of atmospheric CO2 concentrations. Getting the concentrations actually requires an intermediate step involving the use of simple model of ocean carbon uptake, to account for the effect of oceanic absorption of atmospheric CO2.

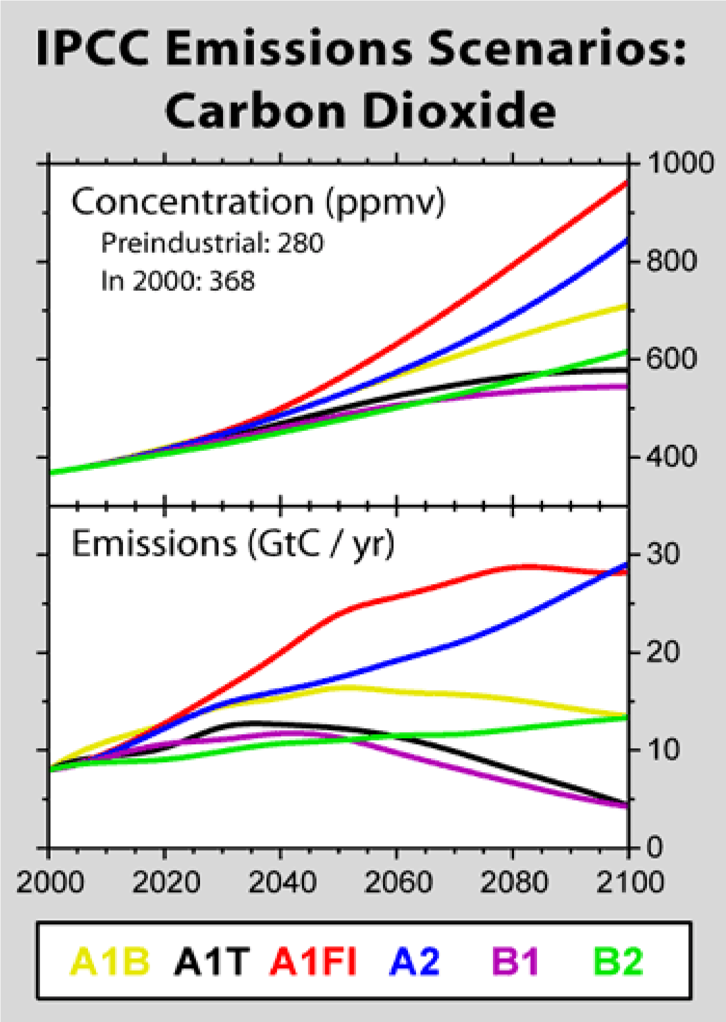

Figure 2.1: Estimated CO_2 concentrations (top) and Annual Carbon Emissions (bottom) for the Various IPCC SRES Scenarios

We can see from the above comparison how various trajectories of our future carbon emissions translate to atmospheric CO2 concentration trajectories. From the point of view of controlling future CO2concentrations, these graphics can be quite daunting. Depending on the path chosen by society, we could plausibly approach CO2 concentrations that are quadruple pre-industrial levels by 2100. Even in the best case of the SRES scenarios, B1, we will likely reach twice pre-industrial levels (i.e., around 550 ppm) by 2100. And to keep CO2 concentrations below this level, we can see that we have to bring emissions to a peak by 2040, and ramp them down to less than half current levels by 2100.

We might wonder, what scenario do we actually appear to be following? Over the past ten years, observed emissions have actually been close to the most carbon intensive of the SRES scenarios—A1FI. This gives us an idea of how challenging the problem of stabilizing carbon emissions at levels lower than twice pre-industrial actually is.

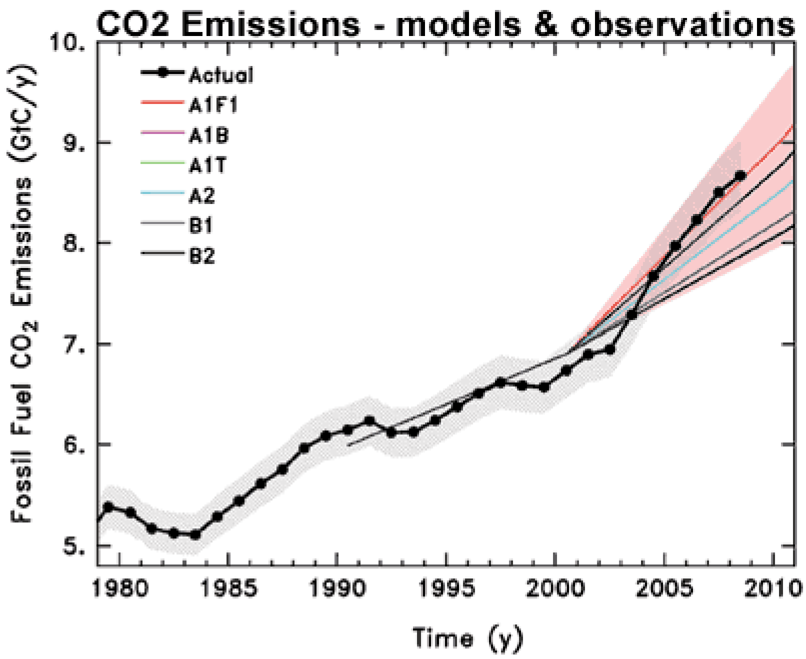

Figure 2.2: Observed Historic Emissions Comparisons with the Various IPCC SRES Scenarios.

One problem with the SRES scenarios—indeed, a fair criticism of them is that they do not explicitly incorporate carbon emissions controls. While some of the scenarios involve storylines that embrace generic notions of sustainability and environmental protection, the scenarios do not envision explicit attempts to stabilize CO2 concentrations at any particular level. For the Fifth Assessment Report, a new set of scenarios, called Representative Concentration Pathways (RCPs), was developed. They are referred to as pathways to emphasize that they are not definitive, but are instead internally consistent time-dependent forcing projections that could potentially be realized with multiple socioeconomic scenarios. In particular, they can take into account climate change mitigation policies to limit emissions. The scenarios are named after the approximate radiative forcing relative to the pre-industrial period achieved either in the year 2100, or at stabilization after 2100. They were created with 'integrated assessment models' that include climate, economic, land use, demographic, and energy-usage effects, whose greenhouse gas concentrations were then converted to an emissions trajectory using carbon cycle models. The RCP2.6 scenario peaks at 3.0 W / m^2 before declining to 2.6 W / m^2 in 2100, and requires strong mitigation of greenhouse gas concentrations in the 21st century. The RCP4.5 and RCP6.0 scenarios stabilize after 2100 at 4.2 W / m^2 and 6.0 W / m^2, respectively. The RCP4.5 and SRES B1 scenarios are comparable; RCP6.0 lies between the SRES B1 and A1B scenarios. The RCP8.5 scenario is the closest to a 'business as usual' scenario of fossil fuel use, and has comparable forcing to SRES A2 by 2100. In all RCPs global population levels off or starts to decline by 2100, with a peak value of 12 billion in RCP8.5. Gross domestic product (GDP) increases in all cases; of note, the RCP2.6 pathway has the highest GDP, though it has the least dependence on fossil fuel sources. Carbon dioxide emissions for all RCPs except the RCP8.5 scenario peak by 2100.Up through the Fourth Assessment Report, the IPCC employed, for the purpose of projecting future greenhouse gas concentrations, a set of emissions scenarios, known as the SRES scenarios. These scenarios reflect a broad range of alternative assumptions about how future technology, economic growth, demographics, and energy policies will evolve over the next century, and, therefore, plausibly reflect the diversity of potential future global greenhouse emissions pathways. The SRES scenarios embody a range of projected increases in atmospheric CO2 by 2100 from a lower end of approximately doubling the pre-industrial levels to reach 550 ppm (B1) to a near quadrupling of pre-industrial levels (A1FI). Current emissions place us on a pathway close to the upper-end A1FI scenario. In the Fifth Assessment Report, the IPCC switched to the use of Representative Concentration Pathways, or RCPs. These pathways (RCP 2.6, RCP 4.5, RCP 6.0 and RCP 8.5) were chosen to be representative scenarios named for their total radiative forcing in the year 2100 (in watts per meter squared), and reflect a range of policies, from strong mitigation (RCP 2.6) to approximately business-as-usual (RCP 8.5). They help in keeping atmospheric CO2 concentrations at a particular level. The lower the desired stabilization level, the lower and sooner the peak in emissions must be. To stabilize below twice the pre-industrial levels, emissions must be brought to a peak within the next few decades and rapidly brought down by the end of the century, falling below 1990 levels by mid-century. To stabilize below 450 ppm, CO2 levels must be brought to a peak within the next decade, and brought down to 80% below 1990 levels by mid-century.

An increasingly widely used approach to defining the required carbon emissions reductions is the Wedge approach. This approach involves freezing emissions at current rates by offsetting projected business-as-usual emissions over the next 50 years (roughly 7gigatons), envisioned, e.g., as 7 strategies for 1gigaton carbon emission reductions. After 50 years, emission rates are brought down, but the pace depends on the stabilization targets desired. Additional wedges can be used to achieve lower stabilization targets by bringing down, rather than freezing, annual carbon emission rates over the next 50 years.

CHAPTER 3

METHODOLOGY

3.1 FOR FINDING THE BEST FIT VALUES OF THE MODEL VARIABLES

On hovering the mouse over the box below each of the four individual parameters which comprise the Kaya Identity Model, we can get the past historical values of each parameter. Our aim is to find a range for each of the three variables namely GDP Per Capita, energy intensity and carbon intensity so that the model curve which is a straight line to start with is a nice eyeball fit to the data set. The future predictions can be made as well in normal course of action i.e. if the same trend continues in the future as well, though, there is no certainty about it. For GDP Per Capita, we will enter positive values whereas for the carbon intensity and energy intensities, negative values will be fed as they have been showing a declining trend over the past years. On entering the values in the box, the model draws a curve for that particular value. The range of values for which the curve shows a nice fit for the past historical data will be selected. These steps are repeated for all the three parameters except population. These ranges may vary slightly based on judgement of an individual as no value will give a perfect fit to the historical data set of the parameters. Moreover, the trends might change in the future due to new technological innovations and other factors. But, we are dealing with the business as usual scenario which means that we are operating under the assumption that the same trend continues in future.

3.2 PRESENTING A WORST CASE SCENARIO FOR CARBON EMISSIONS

Each parameter has been discussed separately:

1) Population – According to the latest UN report, the population is going to plateau somewhere between 11 to 12 billion (around 11.2 billion) by the end of the century. I have taken it as 12 billion since the value is greater than 11 billion. But, we have to create a worst case scenario. It means we have to maximise the carbon emissions , so a population of 13 billion has been considered for this particular case taking into account some factor of safety as greater the population, greater the emissions. But, in order to be realistic at the same time, I have limited it to 13 billion since values above this would be way off from real prediction.

2) GDP Per Capita – The historic best fit of the GDP data comes to a range of [1.6 – 2.2] which would be seen in the later chapters. According to IPCC Fifth Assessment report, the historic trend from 1970-2010 is 1.4% which has been obtained after applying some normalizations. So, for a worst case scenario i.e. to maximise our carbon emissions, I have taken it as 2% which also lies within our best fit range.

3) Energy Intensity – After fixing the first two values which are population and GDP Per Capita respectively, we come to the third value which is energy intensity. We will try to get a range of values of this particular variable which are not necessarily the best fit values but still manage to cover some of the past data. This step ensures worst case values within a reasonable limit.

4) Carbon Intensity – The same process is repeated for carbon intensity as well. We try to find a range of values which cover some of the past data without being the best fit values.

After all the four values are entered as explained above, the model gives the emissions of carbon as carbon dioxide in Gton carbon/year. A range of values of carbon emission would be our output.

3.3 PRESENTING A STABILIZATION PATHWAY WHICH LIMITS THE ATMOSPHERIC CARBON DIOXIDE CONCENTRATIONS UPTO 450 PPM BY THE END OF 21ST CENTURY

Each variable has been discussed separately:

1) Population – Since, it is not a worst case scenario, we have to take values according to the normal course. So, I have taken the population as 11 billion which is the projected population according to the UN latest report published last month.

2) GDP Per Capita – The value of this particular value has been taken as 1.6% which is in between the best fit values obtained. Also, the historic trend for the period between 1970-2010 is 1.4% as per the IPCC Fifth Assessment Report. So, a value very close to this has been taken. Very high values of GDP Per Capita would give such values of carbon or energy intensities which would be almost impossible to achieve.

3) Energy Intensity – The energy intensity values have been taken same as the previous one.

4) Carbon Intensity – After fixing the above three values, we now will try to find out the maximum possible rate of change in carbon intensity which would limit the carbon dioxide concentrations to around 450 ppm. The obtained values for this carbon intensity will complete the stabilization scenario. The atmospheric concentrations of carbon dioxide are predicted by using ISAM model.

CHAPTER 4

DATA ANALYSIS AND RESULT DISCUSSION

4.1 BEST FIT VALUES OF THE MODEL PARAMETERS

1) GDP Per Capita (%) = [1.6 – 2.2]

2) Energy Intensity (%) = [-1.3,-0.5]

3) Carbon Intensity (%) = [-0.35,-0.25]

The screenshots of figures generated by the model for all the parameters have been pasted in the next pages to follow as per the above mentioned order.

4.2 GDP PER CAPITA BEST FIT VALUE FIGURES

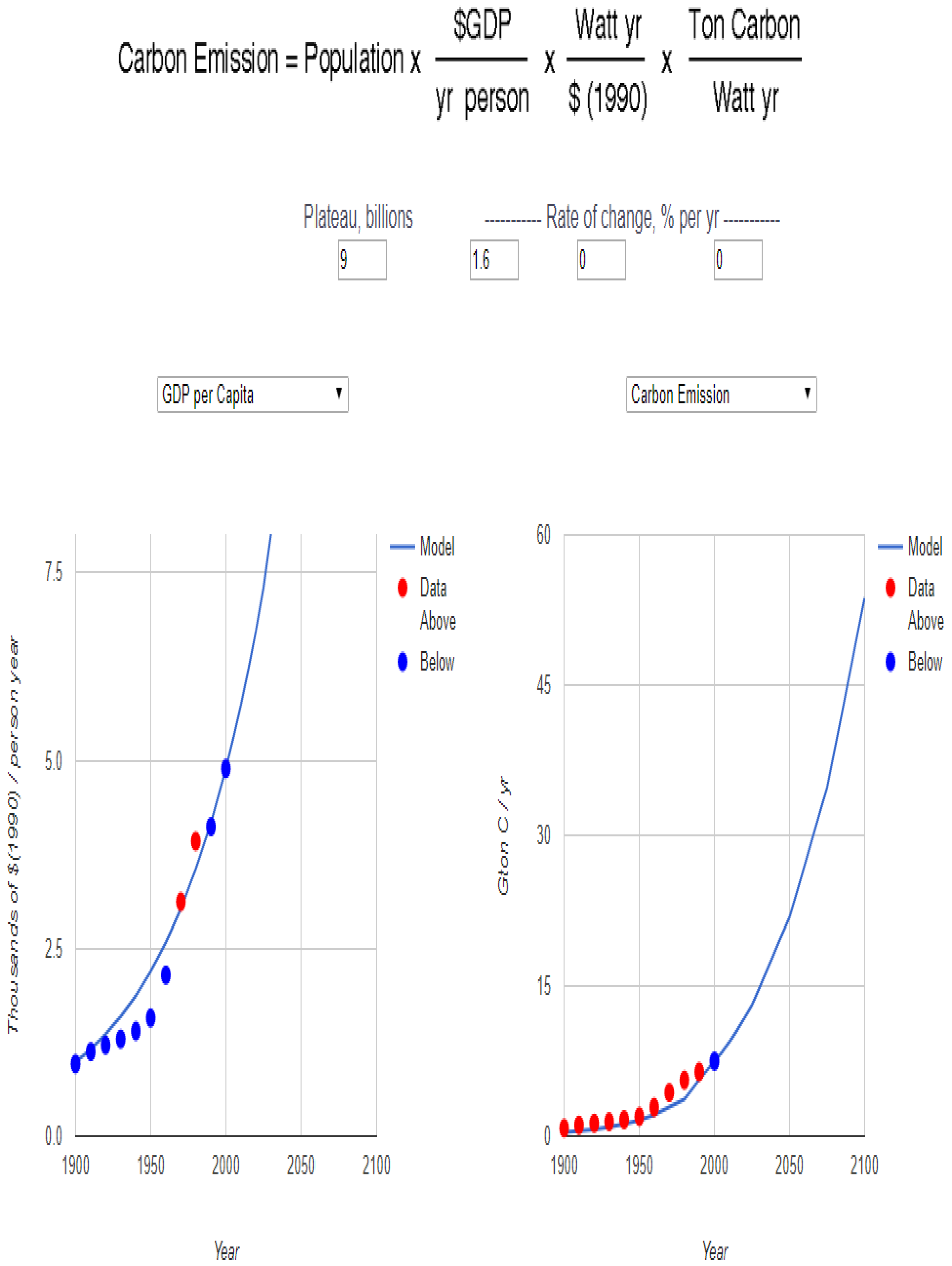

FIGURE 4.1 MODEL CURVE FOR GDP PER CAPITA VALUE OF 1.6%

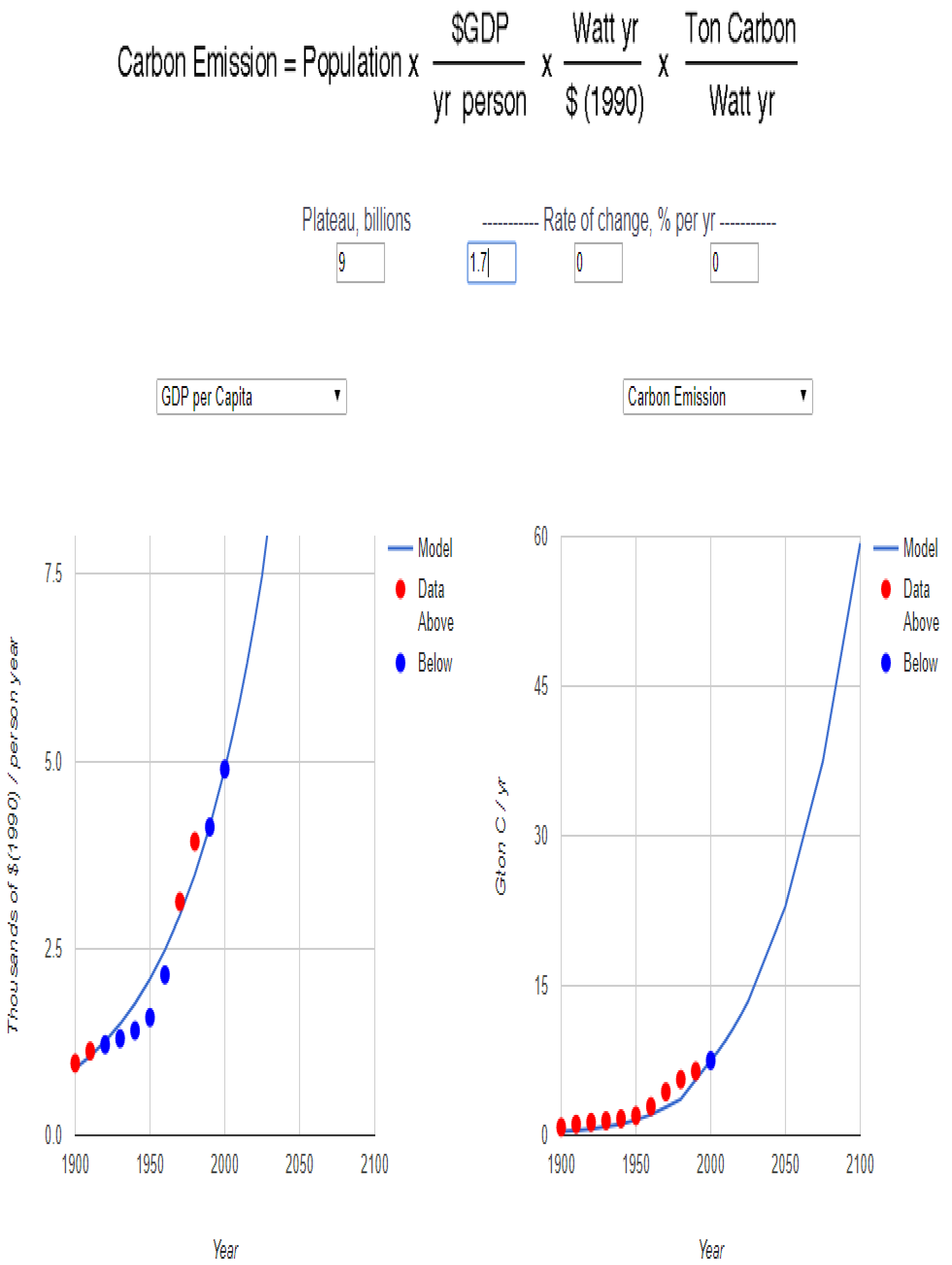

FIGURE 4.2 MODEL CURVE FOR GDP PER CAPITA VALUE OF 1.7%

$$\text{Carbon Emission} = \text{Population} \times \frac{\$GDP}{\text{yr person}} \times \frac{\text{Watt yr}}{\$ (1990)} \times \frac{\text{Ton Carbon}}{\text{Watt yr}}$$

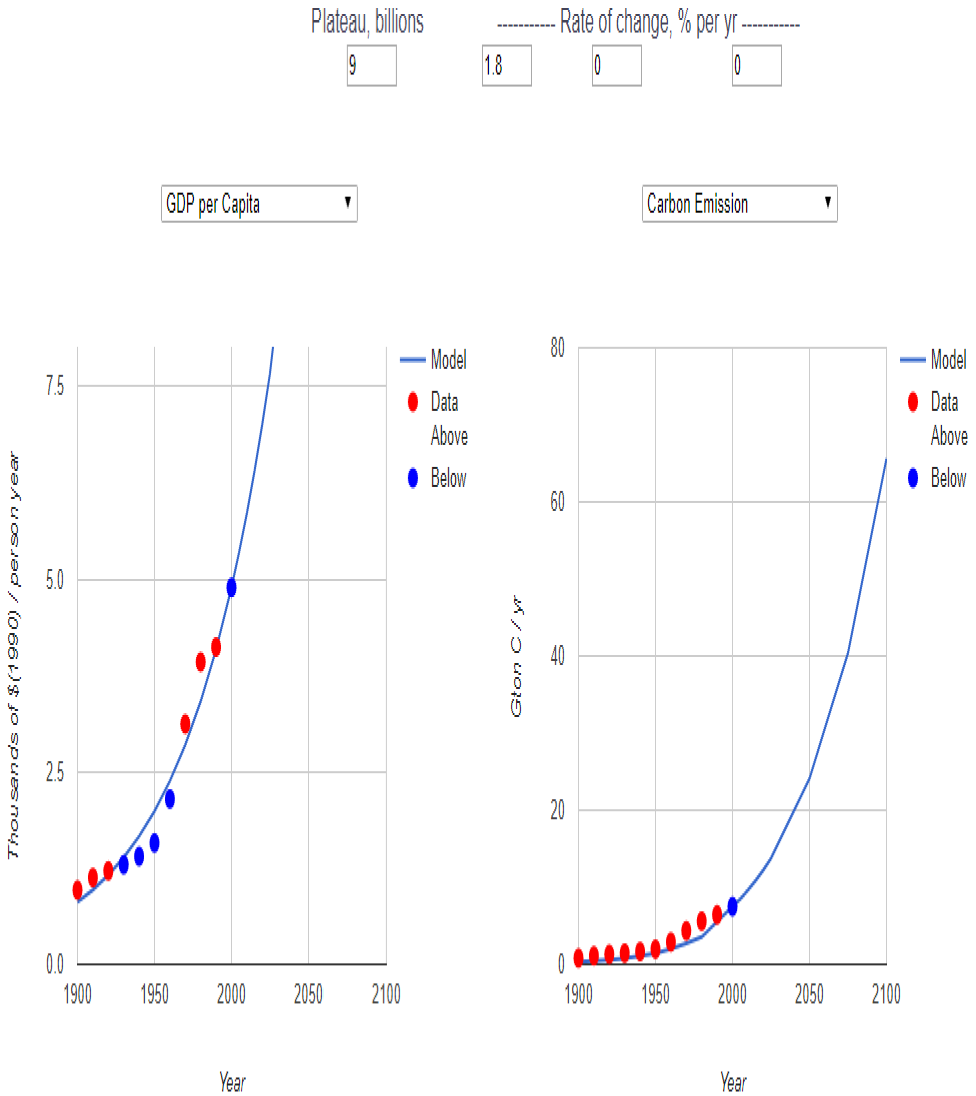

FIGURE 4.3 MODEL CURVE FOR GDP PER CAPITA VALUE OF 1.8%

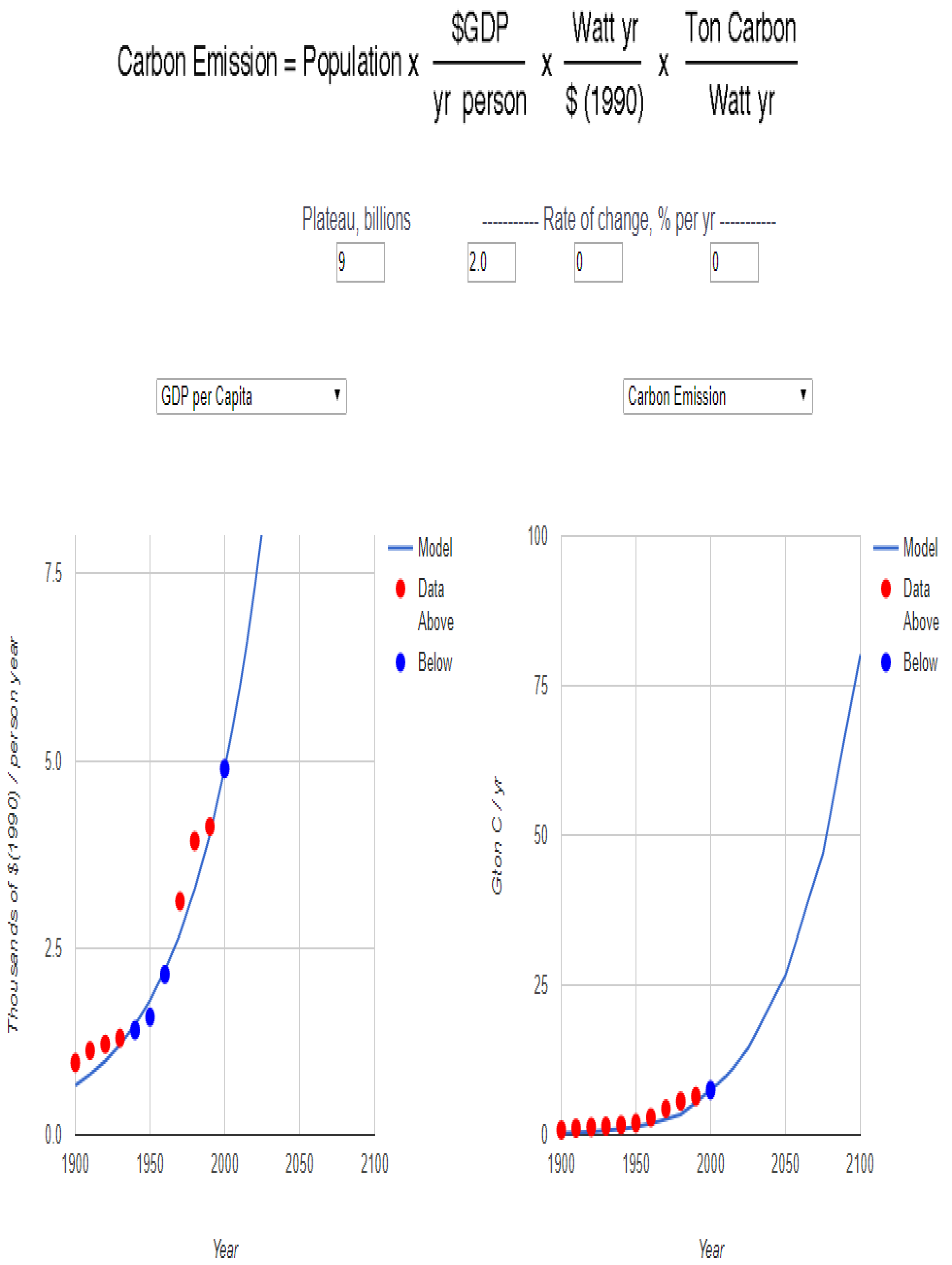

FIGURE 4.4 MODEL CURVE FOR GDP PER CAPITA VALUE OF 2.0%

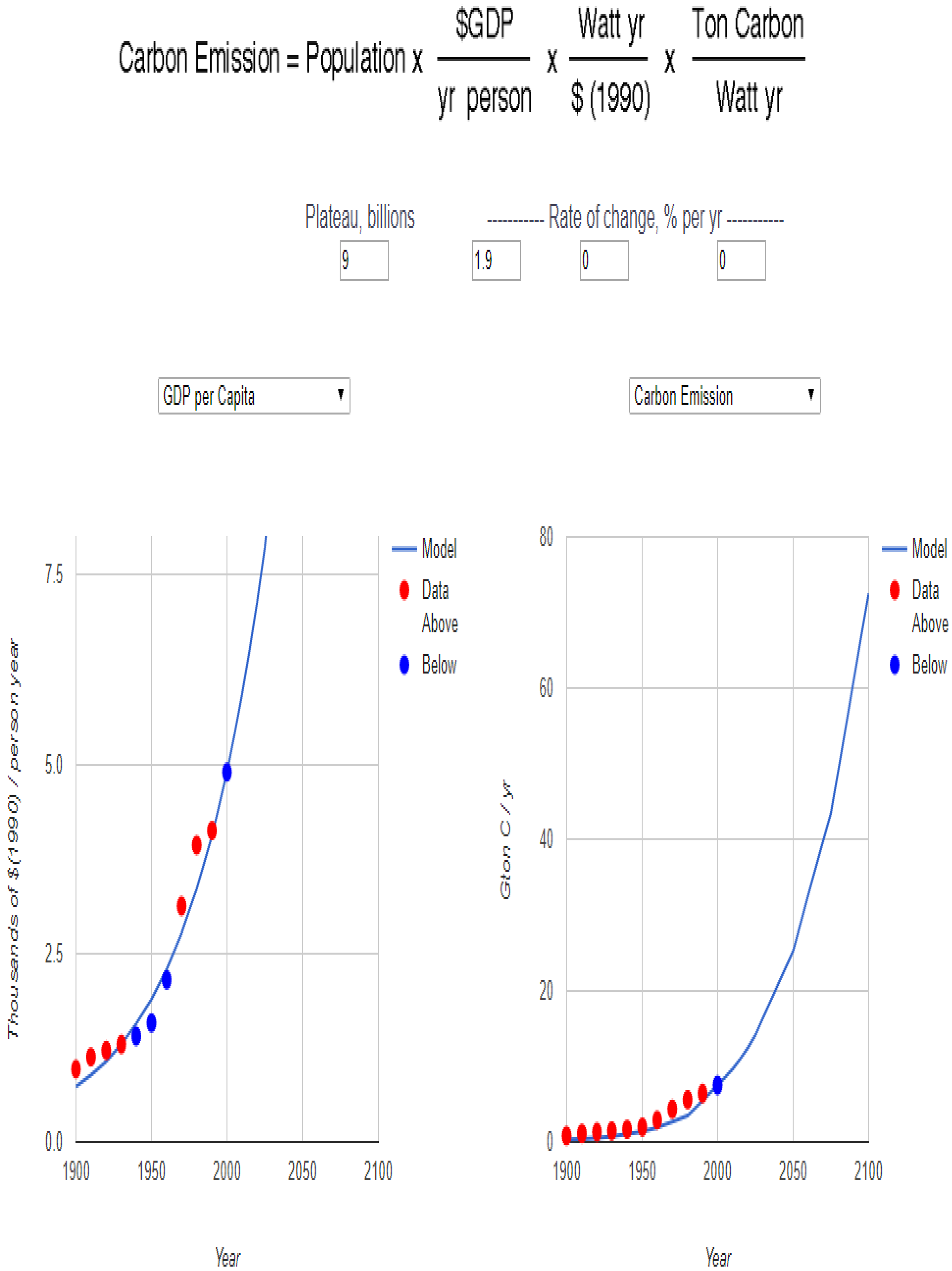

FIGURE 4.5 MODEL CURVE FOR GDP PER CAPITA VALUE OF 1.9%

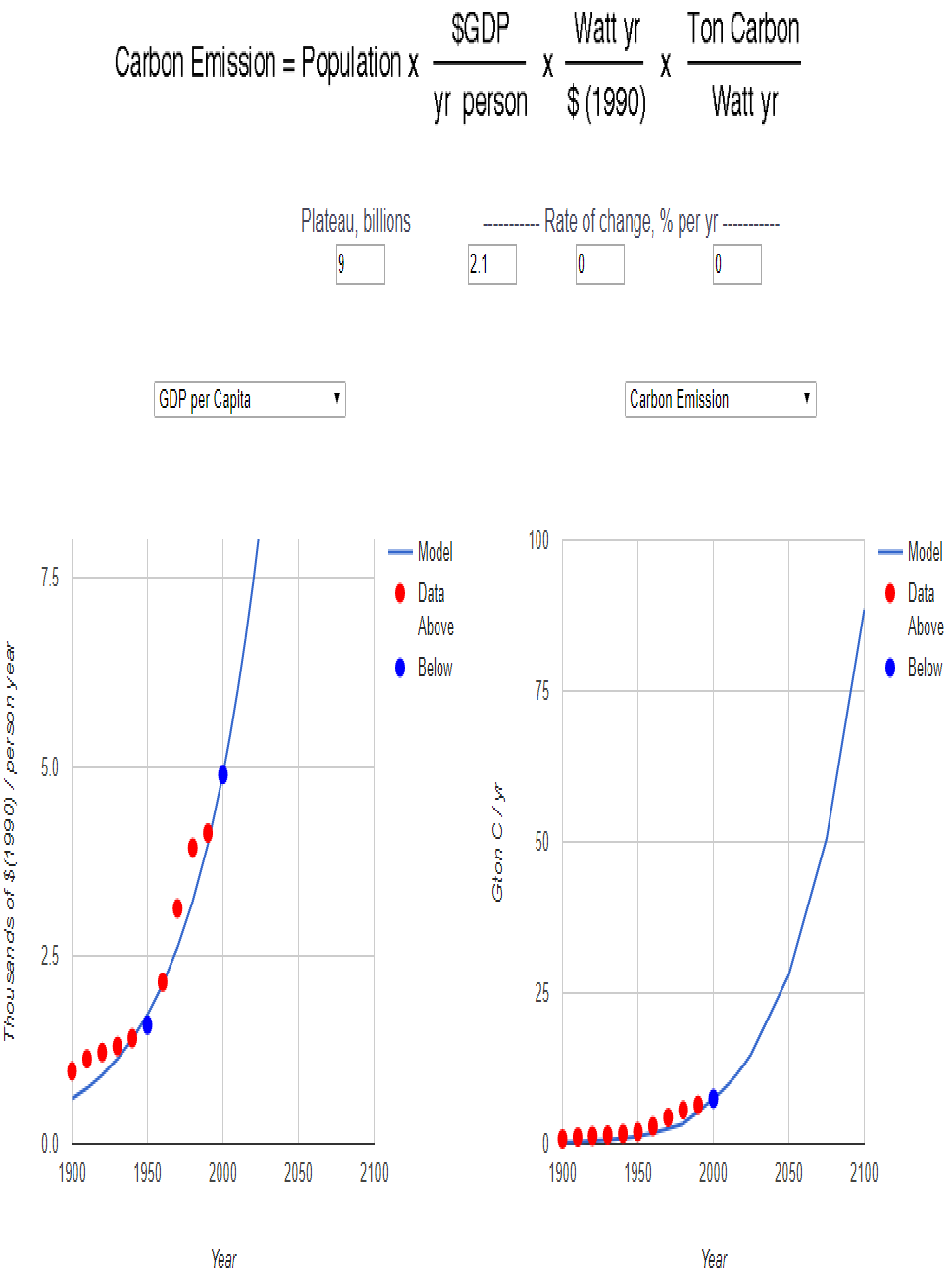

FIGURE 4.6 MODEL CURVE FOR GDP PER CAPITA VALUE OF 2.1%

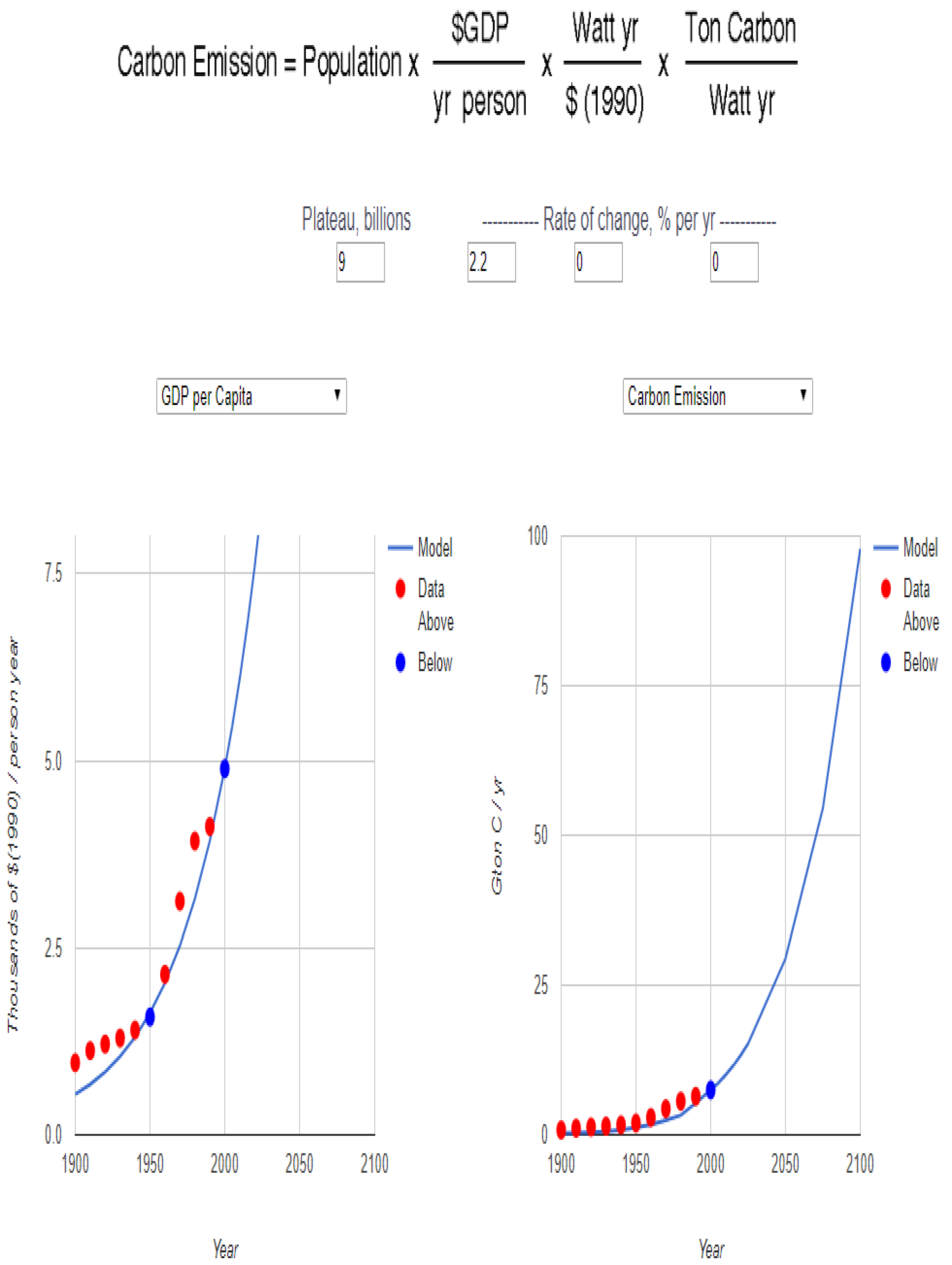

FIGURE 4.7 MODEL CURVE FOR GDP PER CAPITA VALUE OF 2.2%

4.1.2 ENERGY INTENSITY BEST FIT VALUE FIGURES

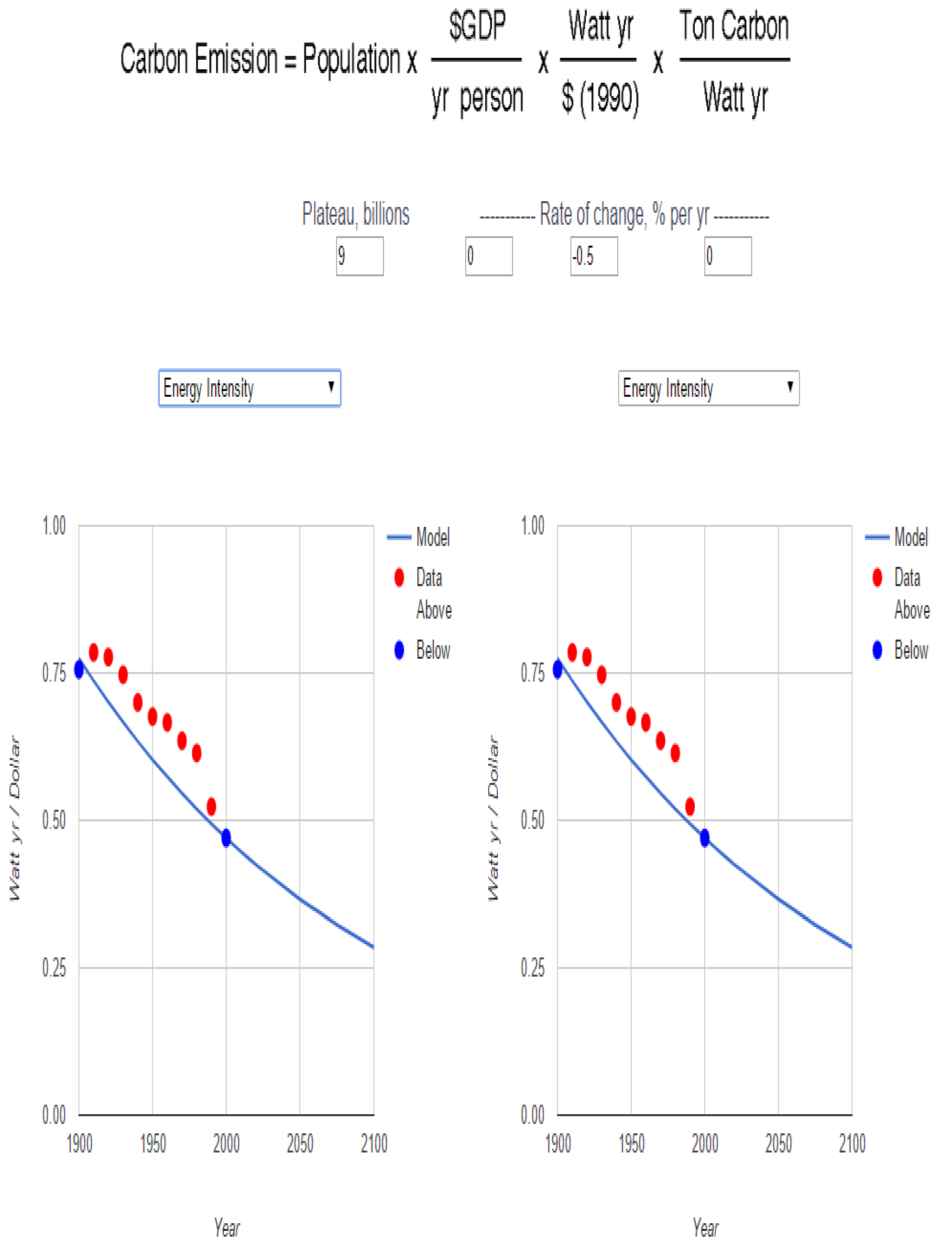

FIGURE 4.8 MODEL CURVE FOR ENERGY INTENSITY VALUE OF -0.5%

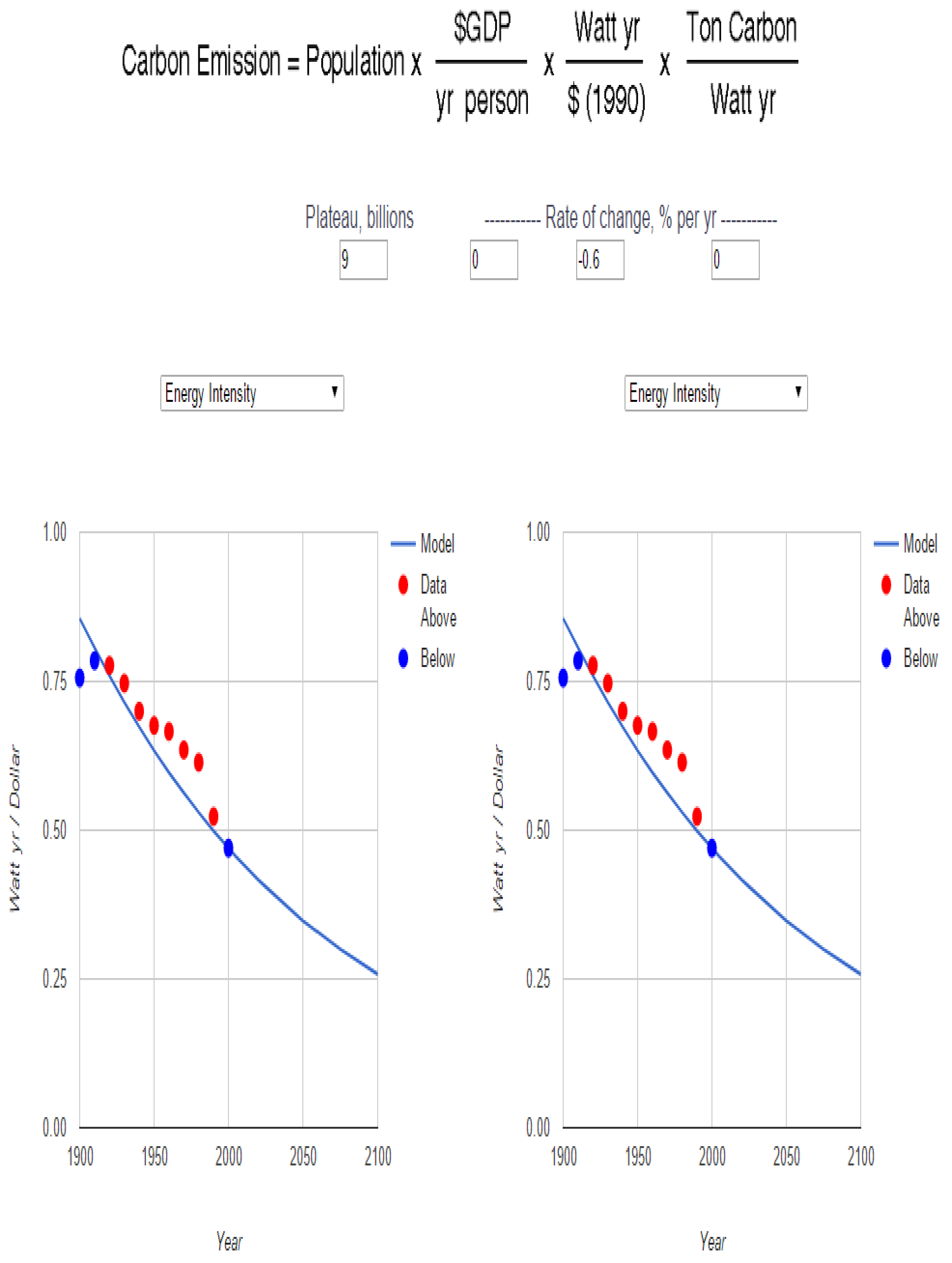

FIGURE 4.9 MODEL CURVE FOR ENERGY INTENSITY VALUE OF -0.6%

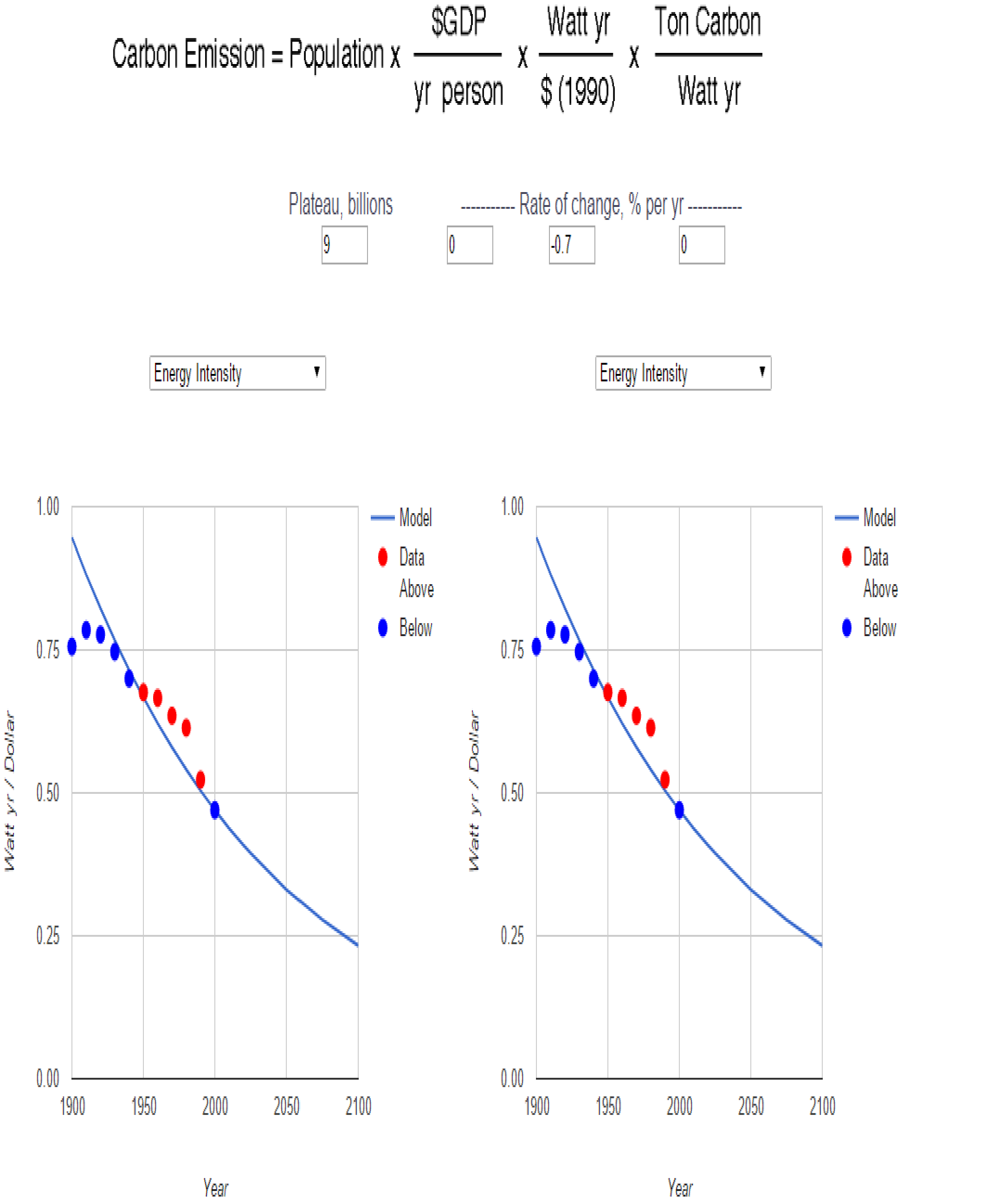

FIGURE 4.10 MODEL CURVE FOR ENERGY INTENSITY VALUE FOR -0.7%

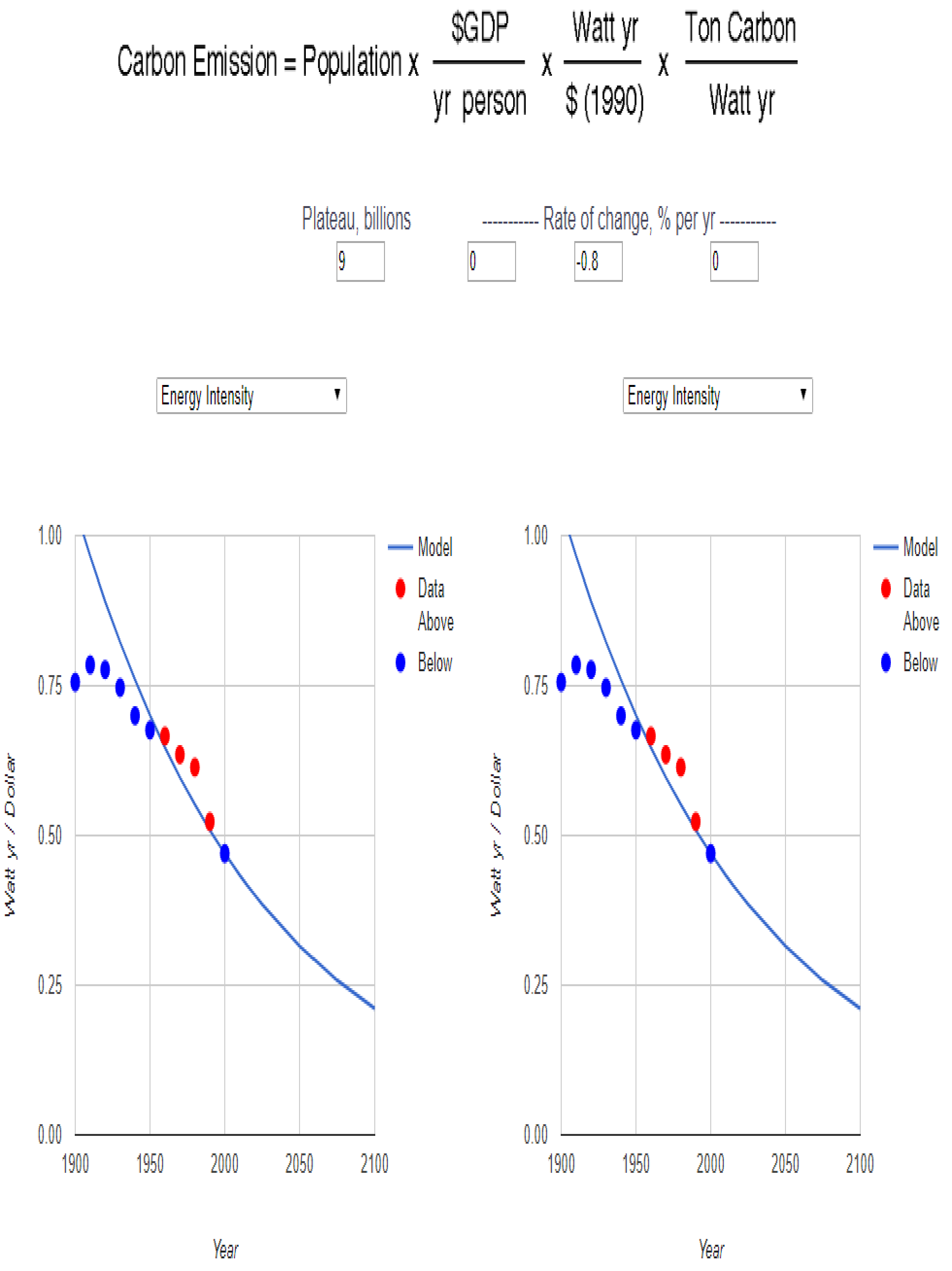

FIGURE 4.11 MODEL CURVE FOR ENERGY INTENSITY VALUE OF -0.8%

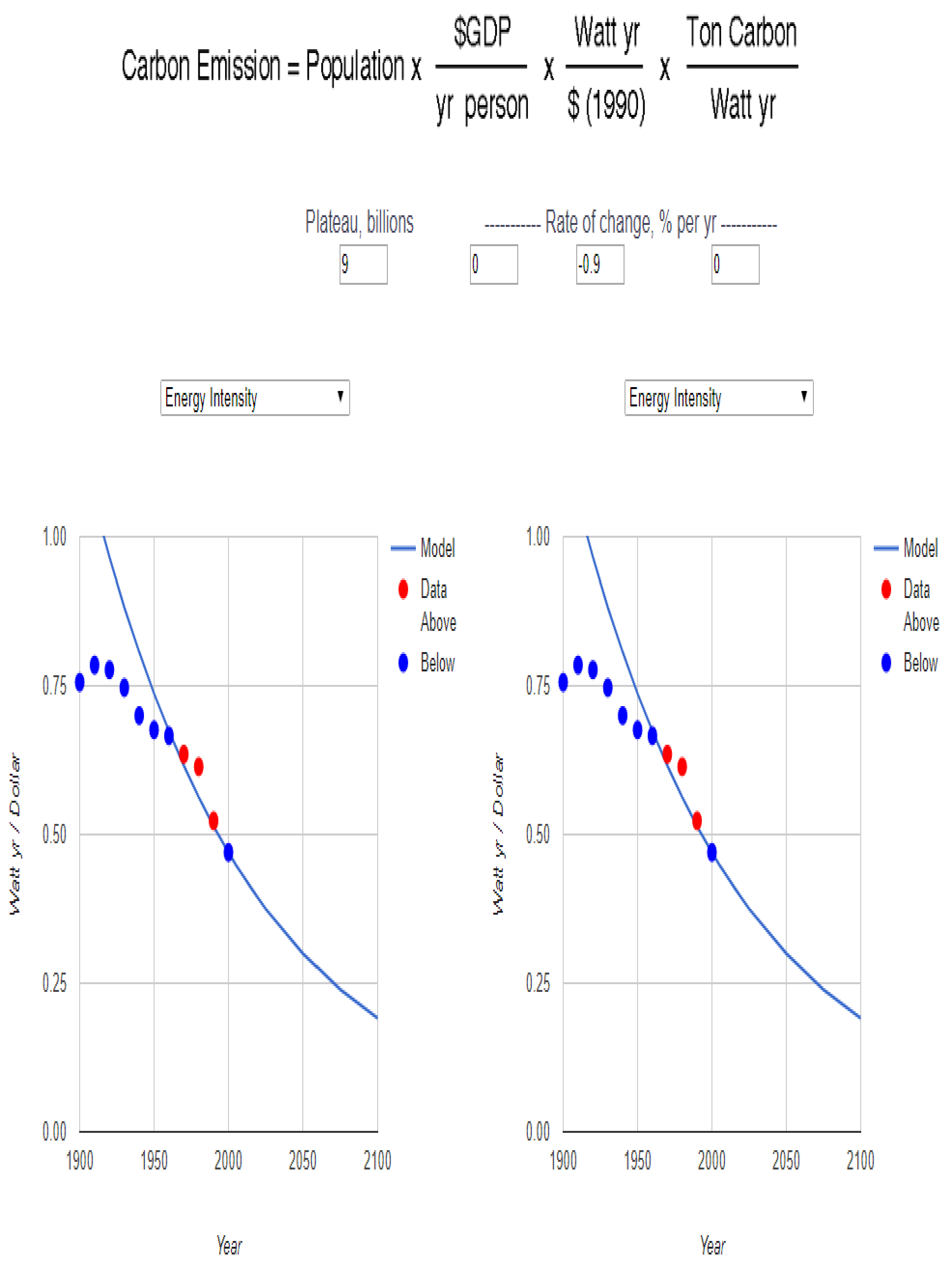

FIGURE 4.12 MODEL CURVE FOR ENERGY INTENSITY VALUE OF -0.9%

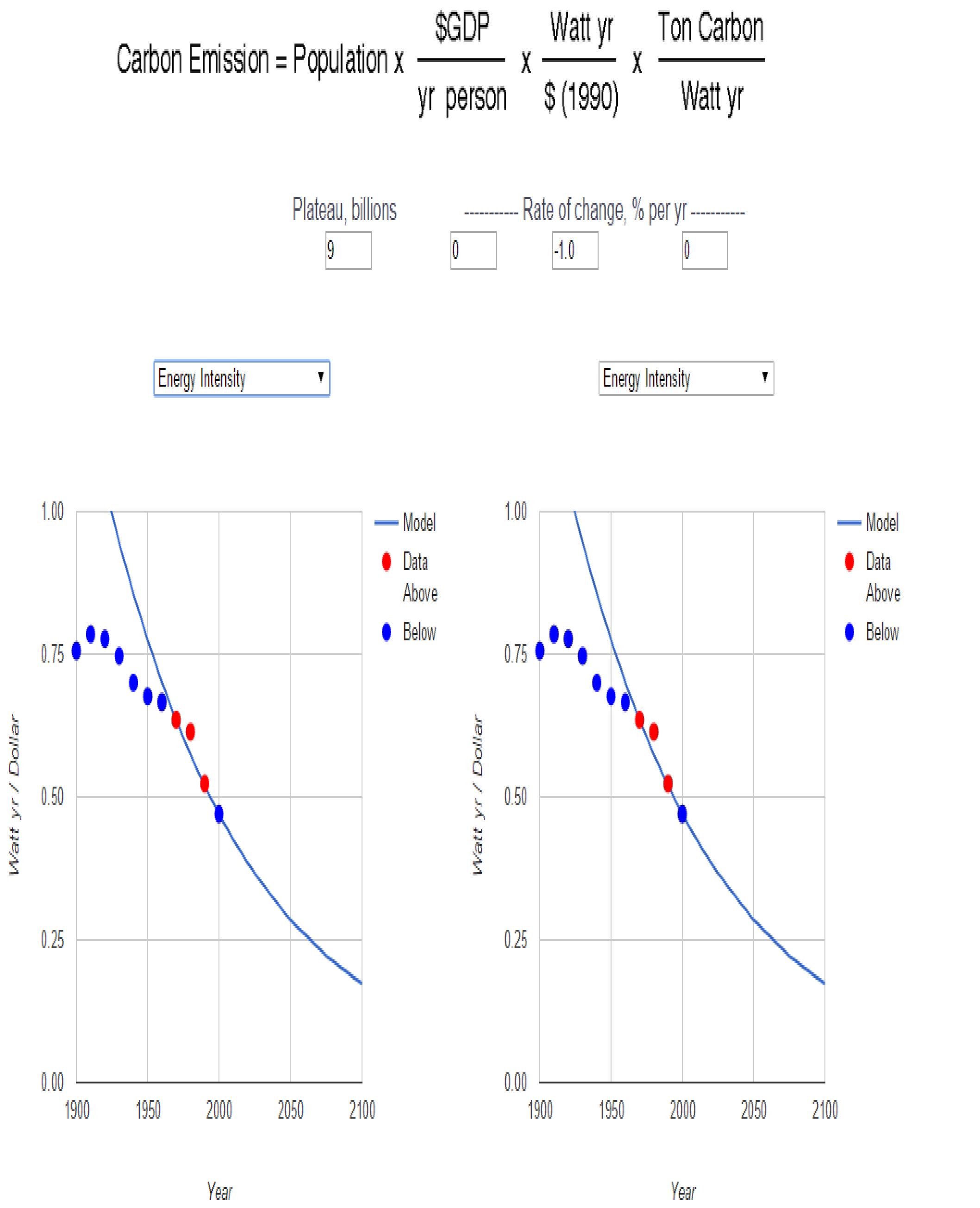

FIGURE 4.13 MODEL CURVE FOR ENERGY INTENSITY VALUE OF -1.0%

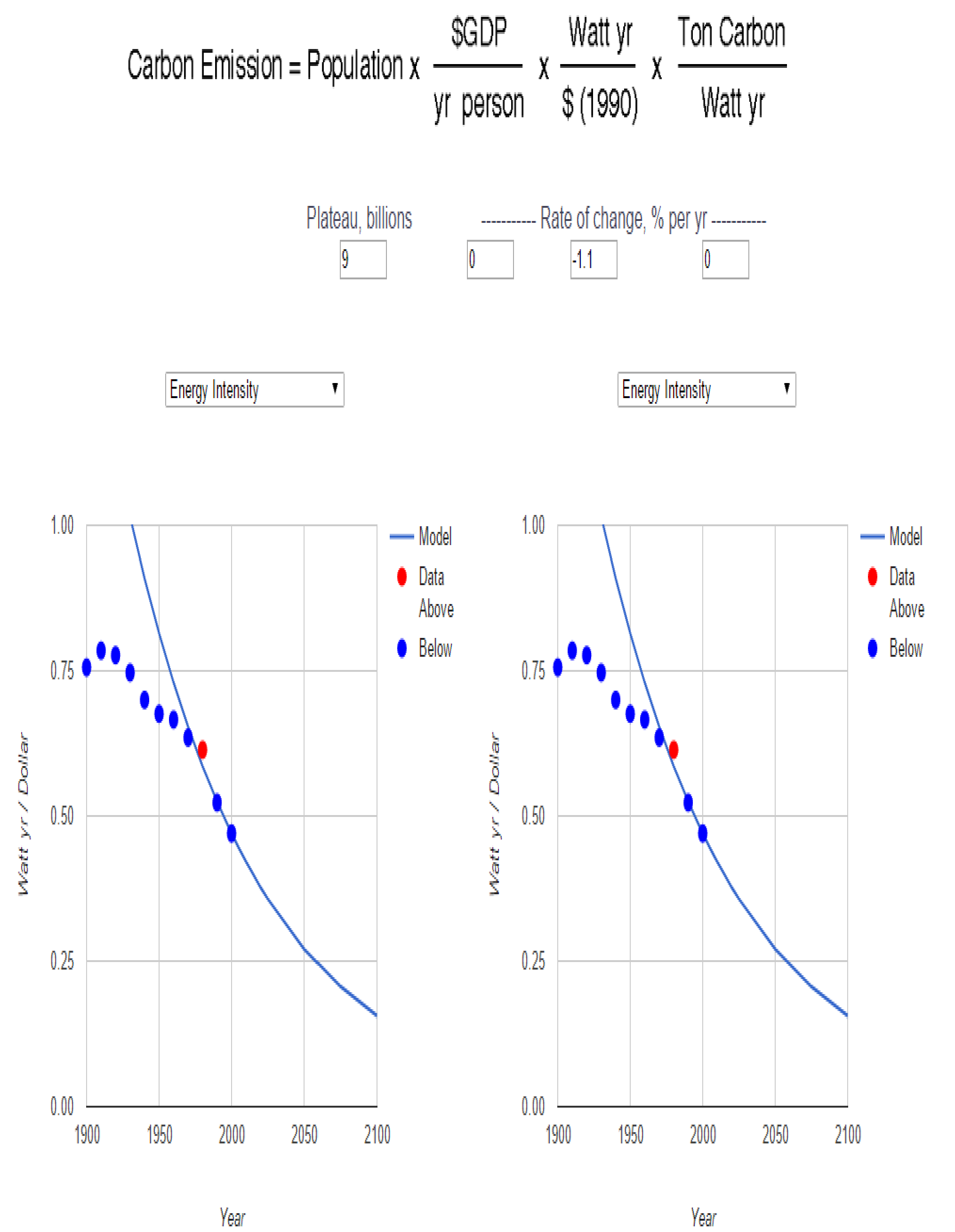

FIGURE 4.14 MODEL CURVE FOR ENERGY INTENSITY VALUE OF -1.1%

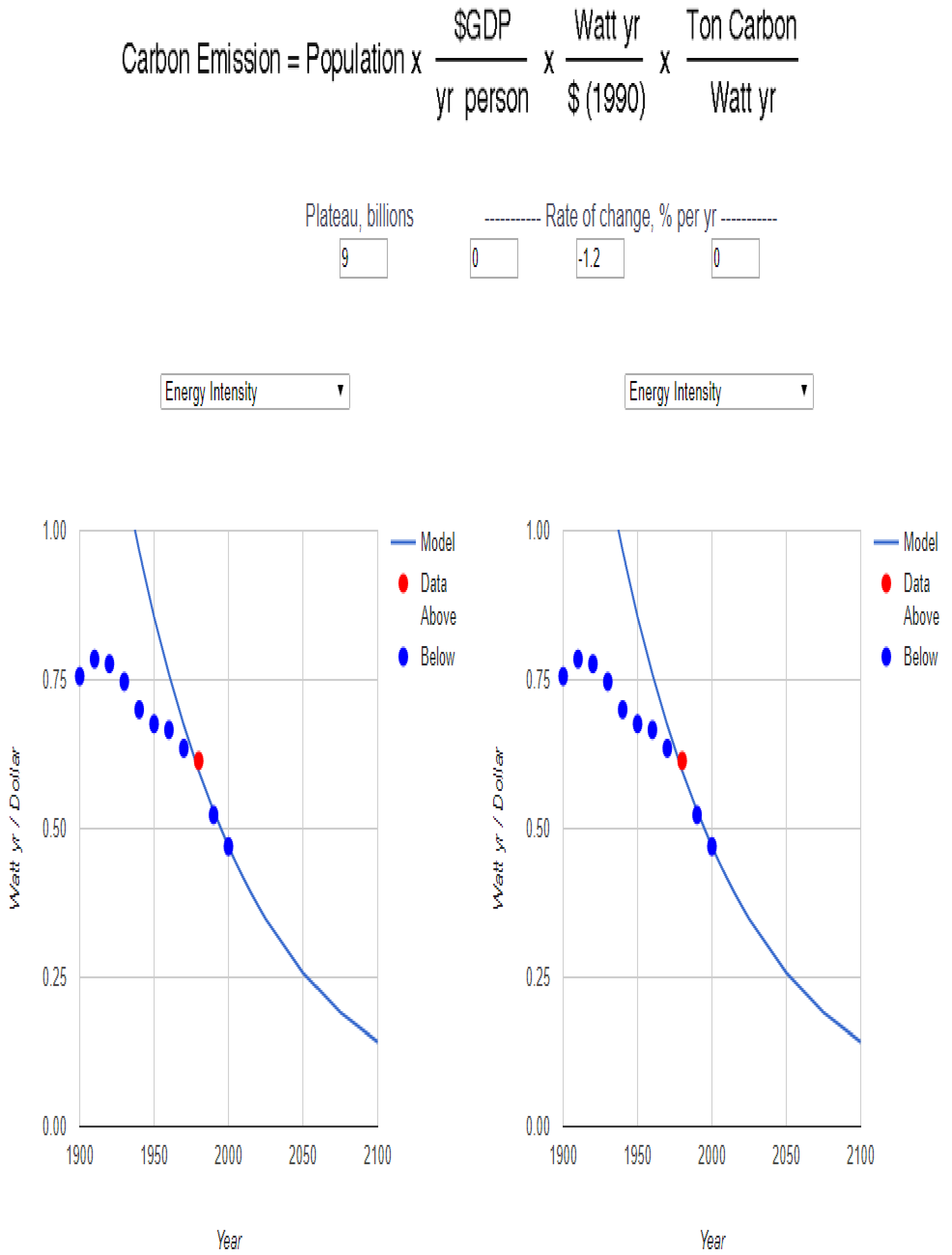

FIGURE 4.15 MODEL CURVE FOR ENERGY INTENSITY VALUE OF -1.2%

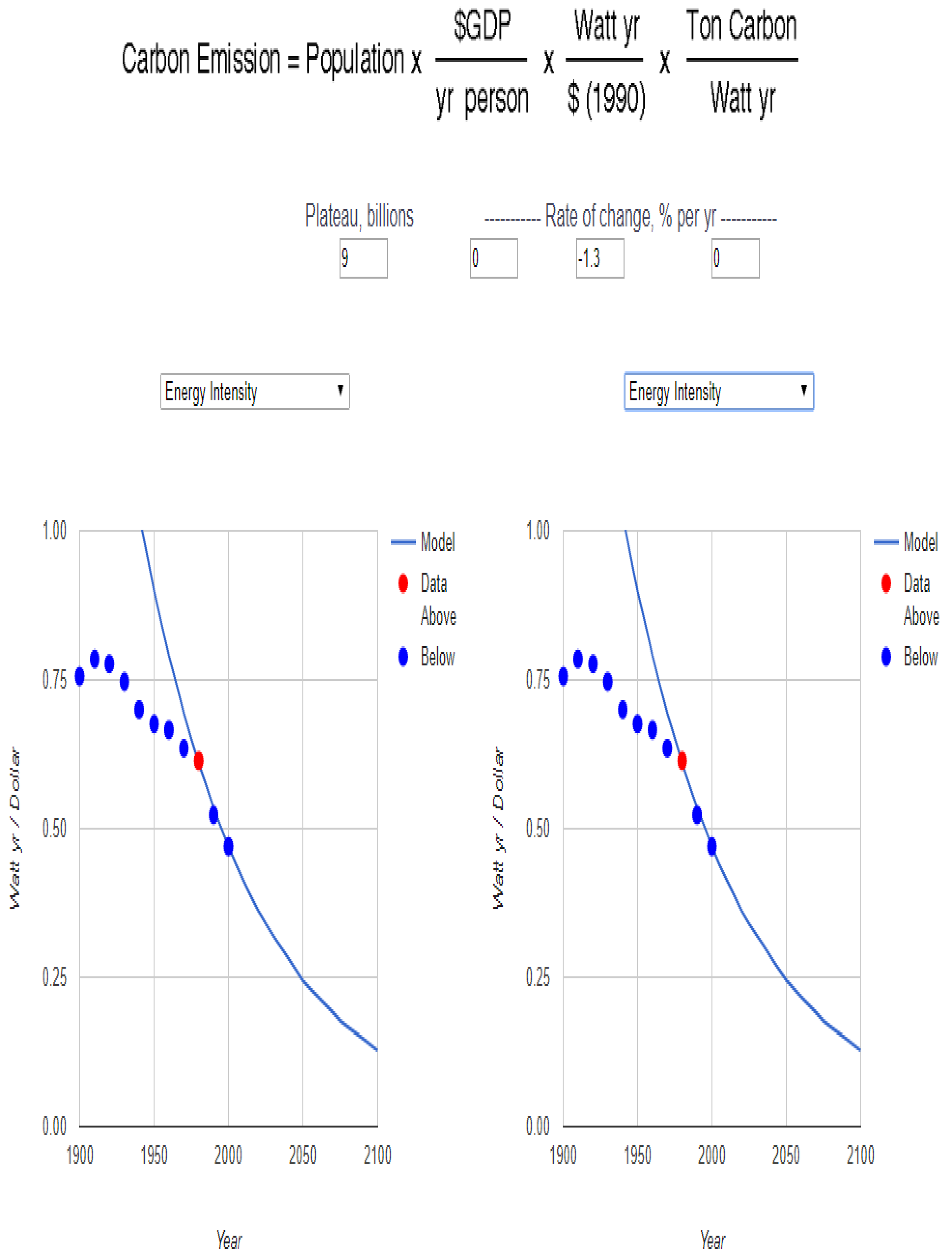

FIGURE 4.16 MODEL CURVE FOR ENERGY INTENSITY VALUE OF -1.3%

4.1.3 CARBON INTENSITY BEST FIT VALUE FIGURES

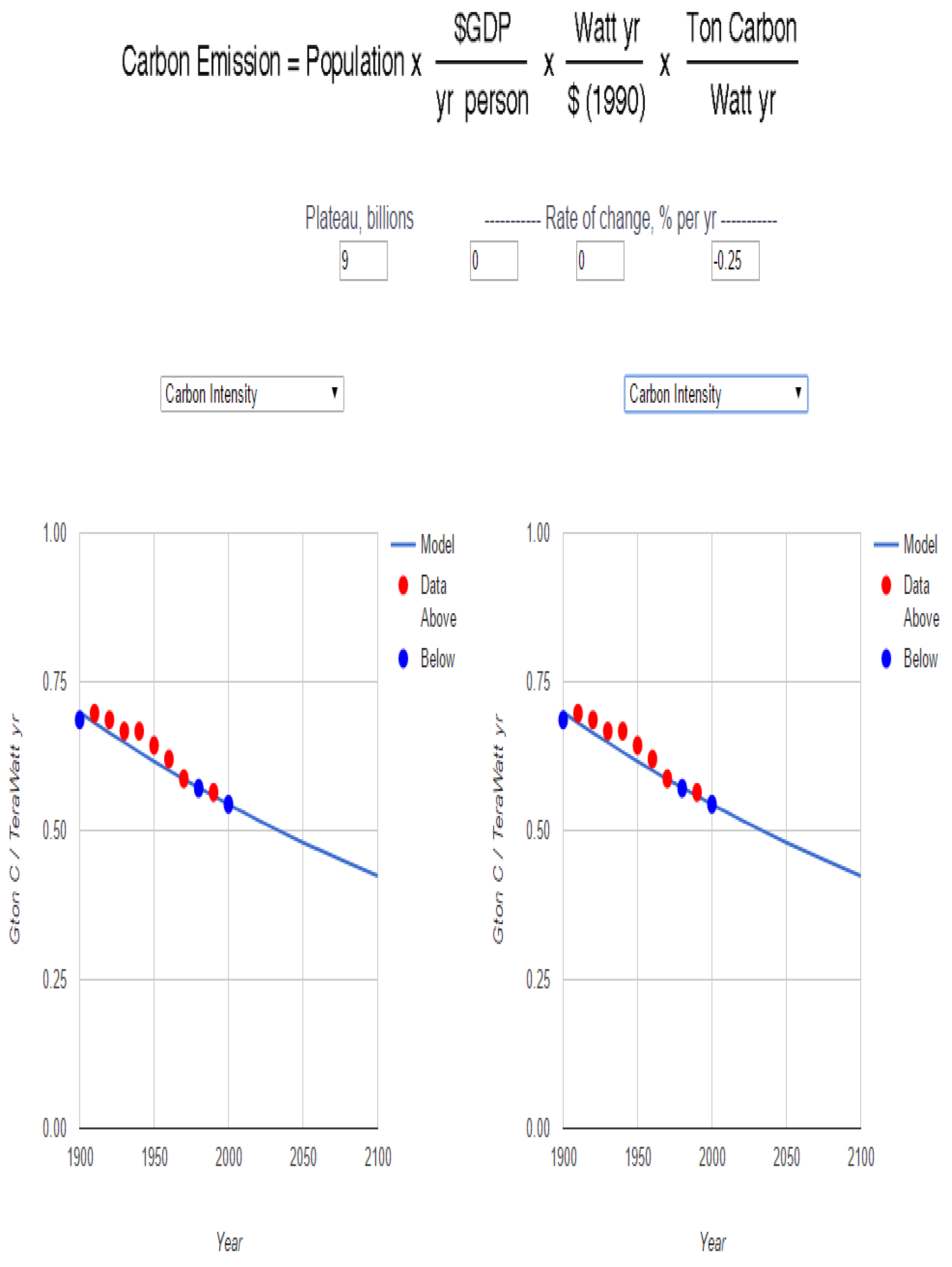

FIGURE 4.17 MODEL CURVE FOR CARBON INTENSITY VALUE OF -0.25%

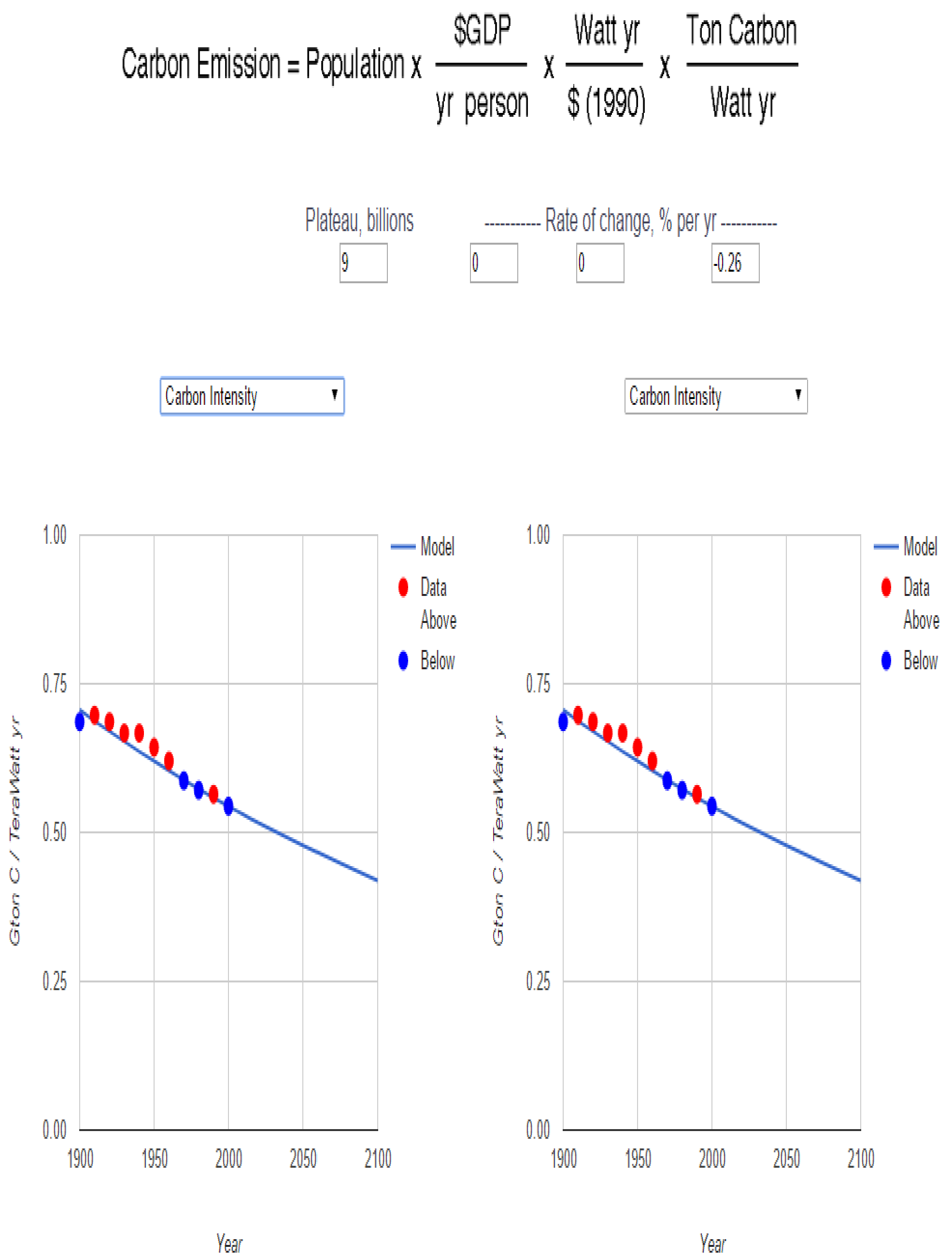

FIGURE 4.18 MODEL CURVE FOR CARBON INTENSITY VALUE OF -0.26%

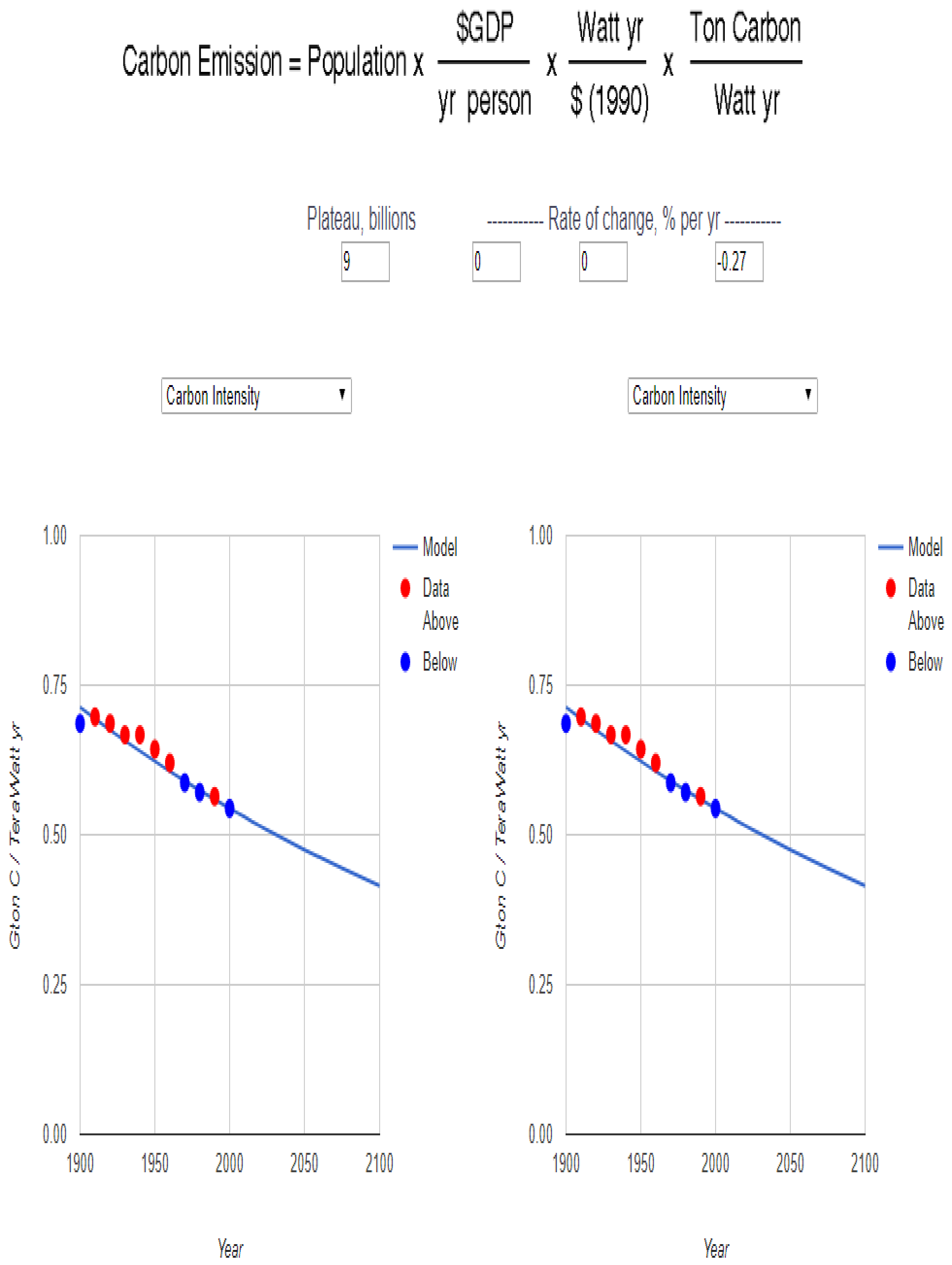

FIGURE 4.19 MODEL CURVE FOR CARBON INTENSITY VALUE OF -0.27%

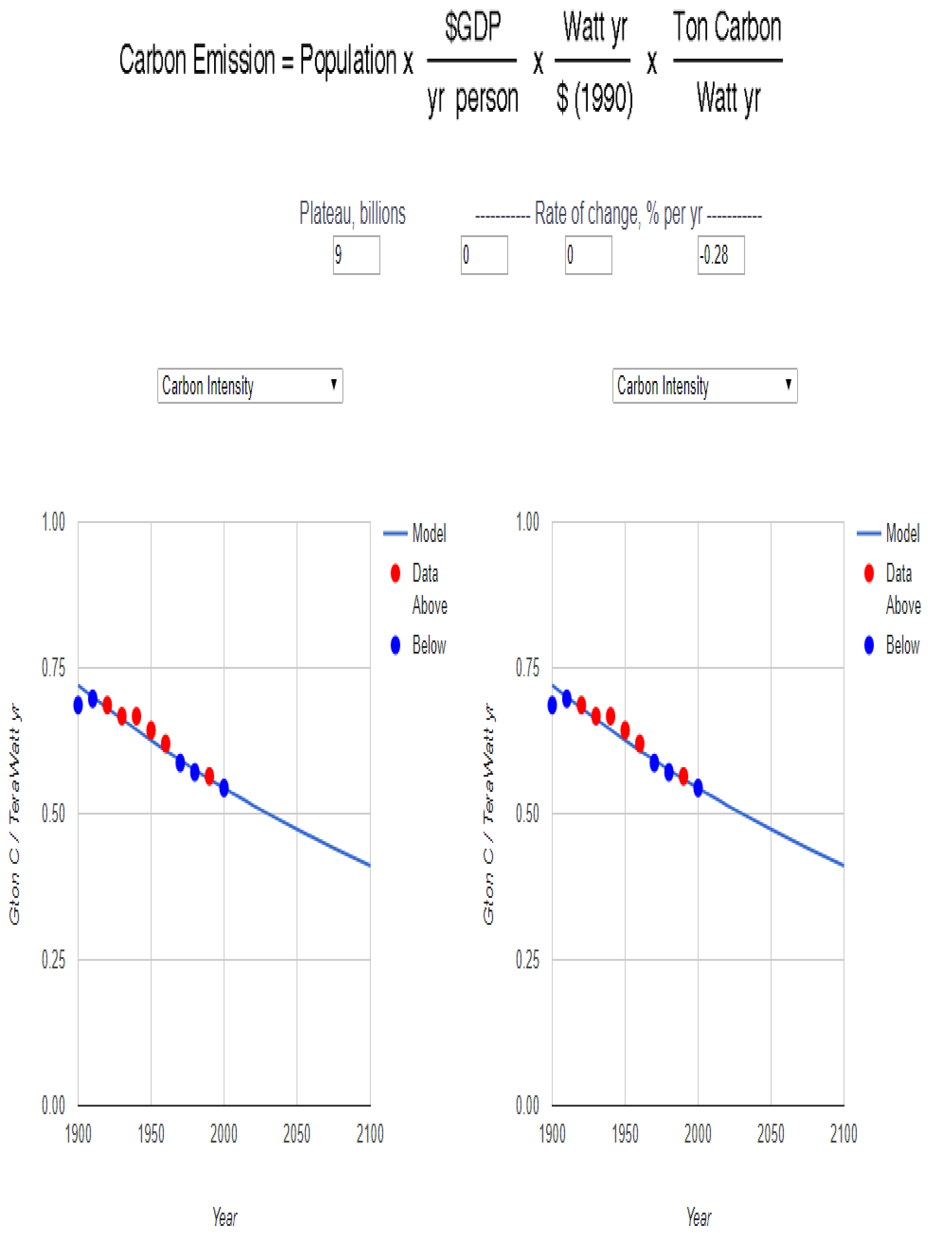

FIGURE 4.20 MODEL CURVE FOR CARBON INTENSITY VALUE OF -0.28%

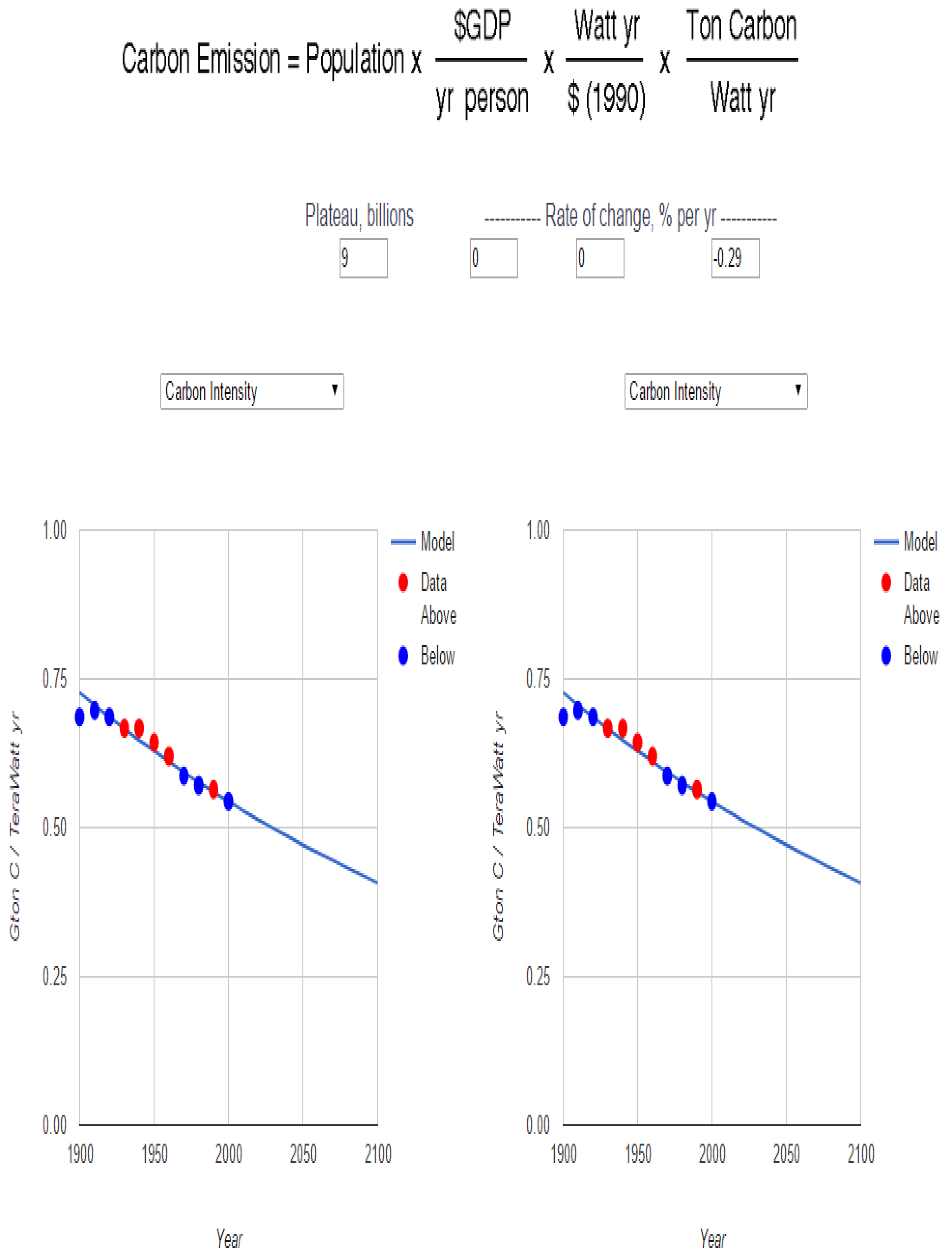

FIGURE 4.21 MODEL CURVE FOR CARBON INTENSITY VALUE OF -0.29%

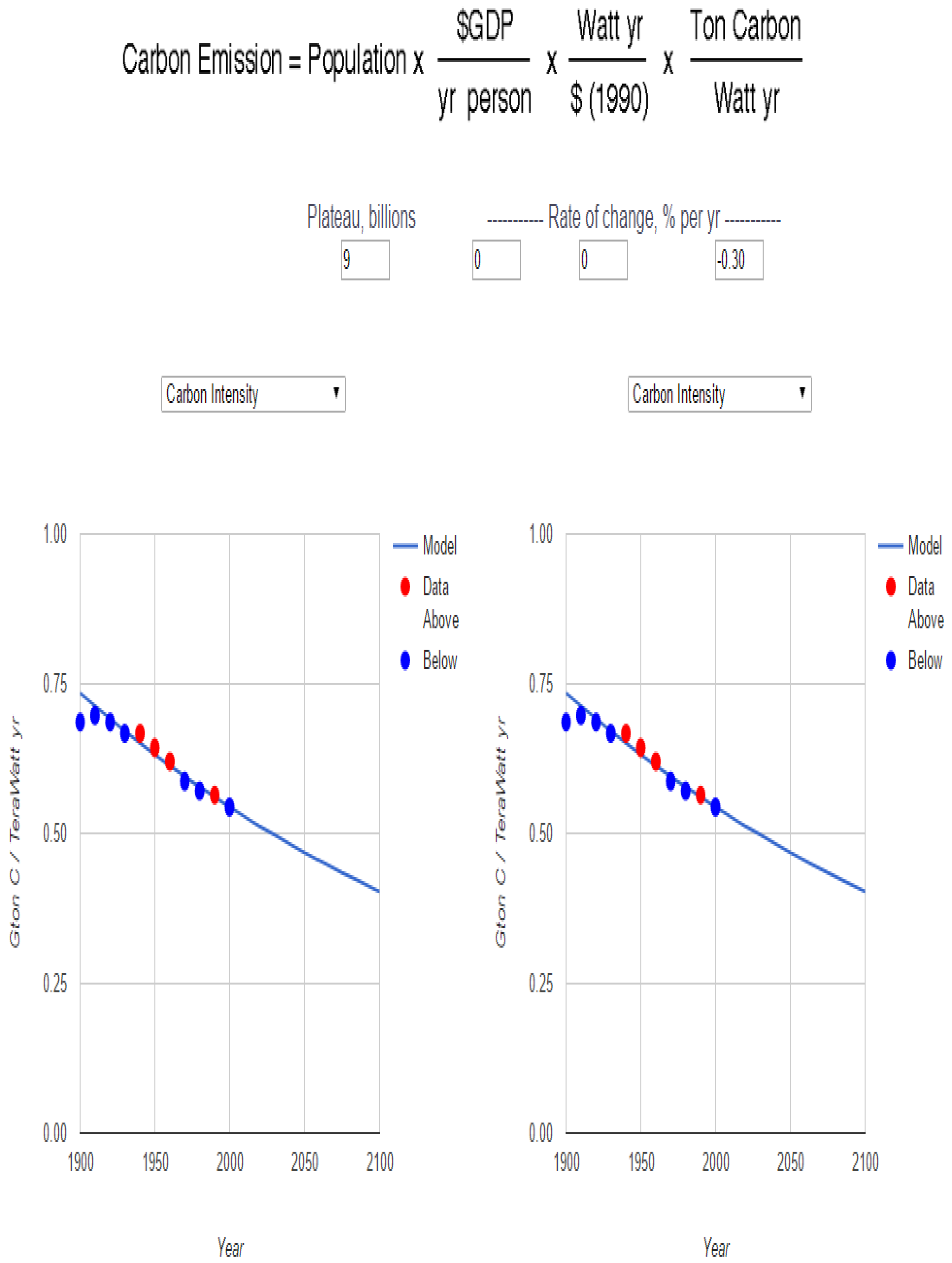

FIGURE 4.22 MODEL CURVE FOR CARBON INTENSITY VALUE OF -0.30%

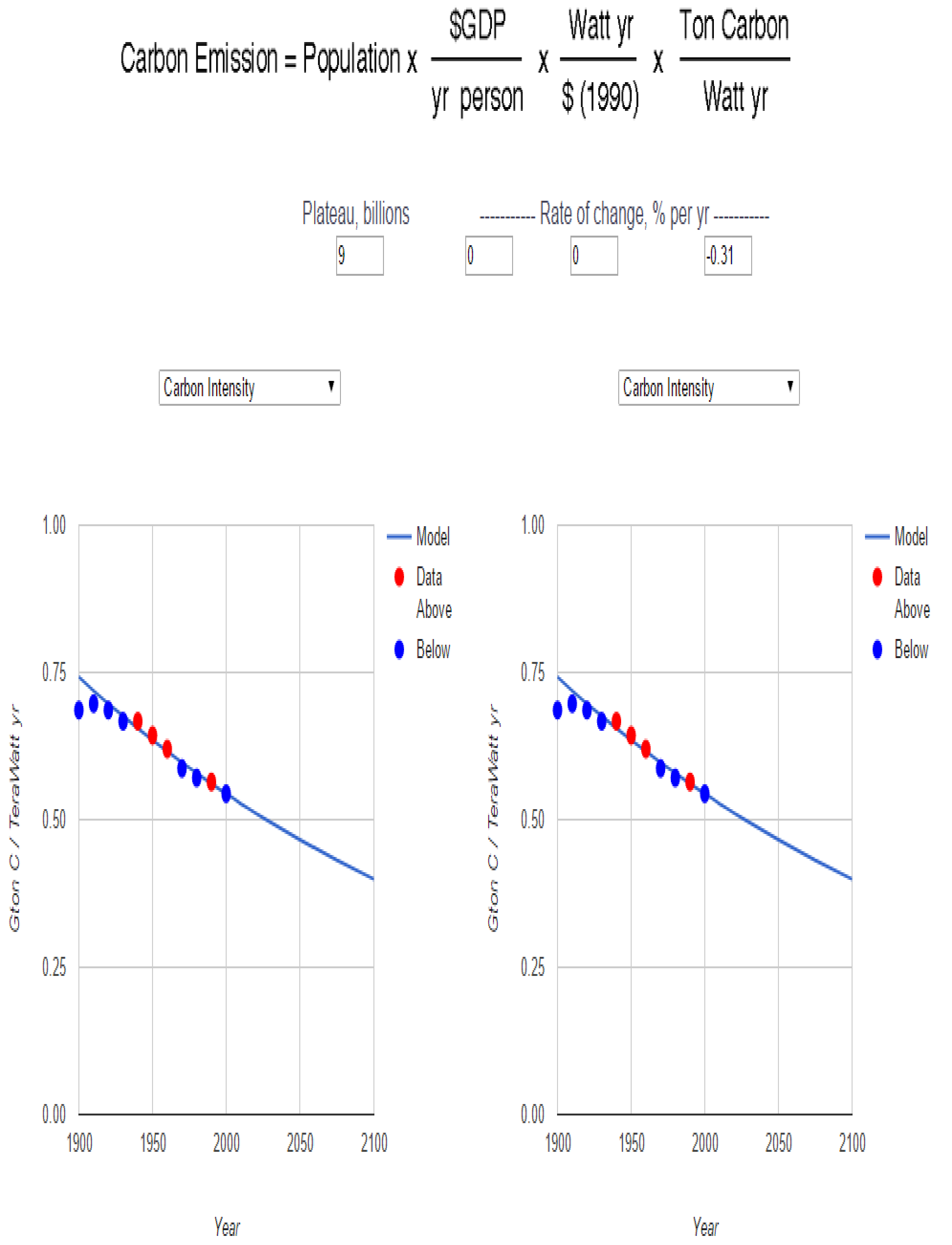

FIGURE 4.23 MODEL CURVE FOR CARBON INTENSITY VALUE OF -0.31%

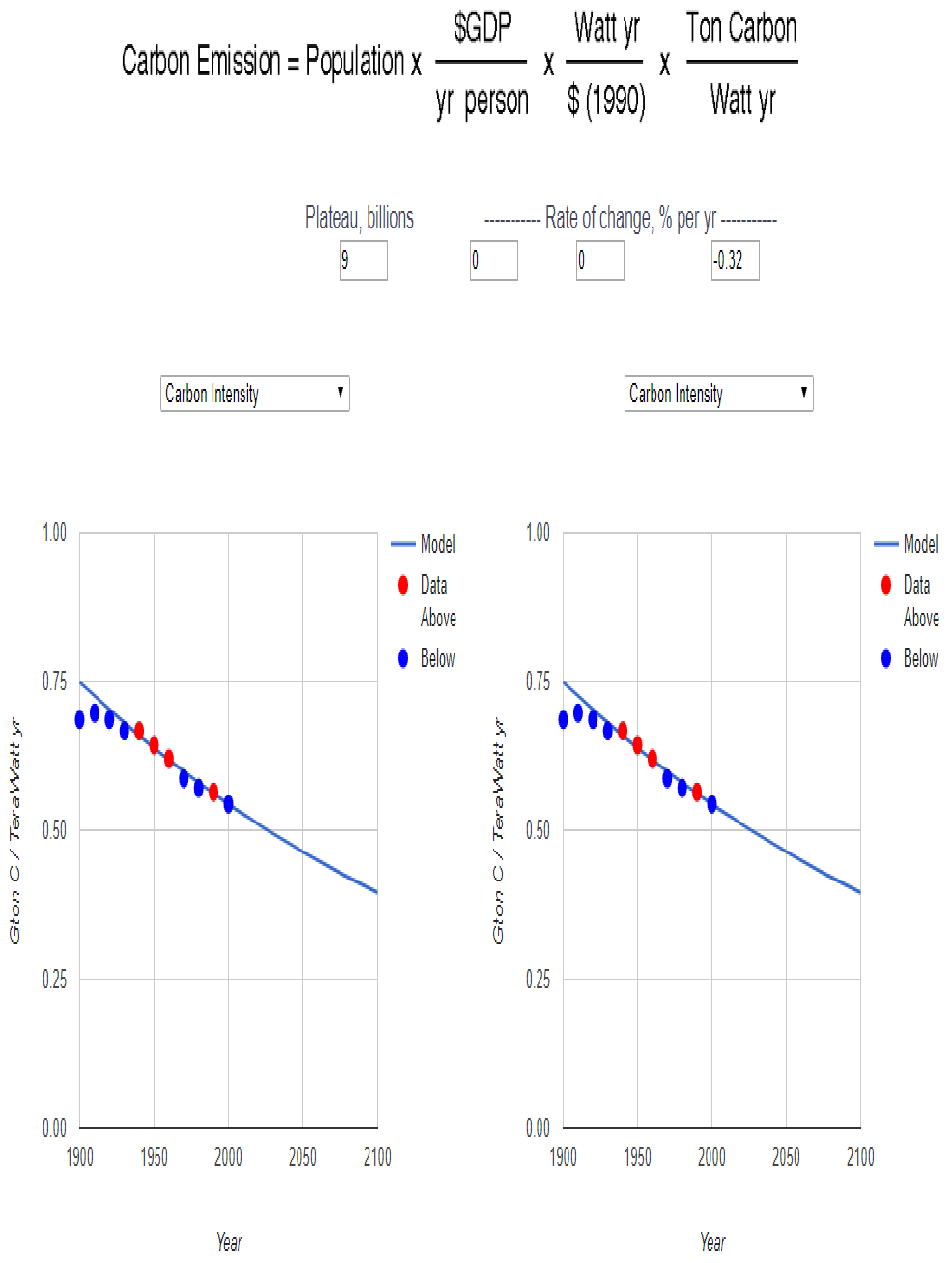

FIGURE 4.24 MODEL CURVE FOR CARBON INTENSITY VALUE OF -0.32%

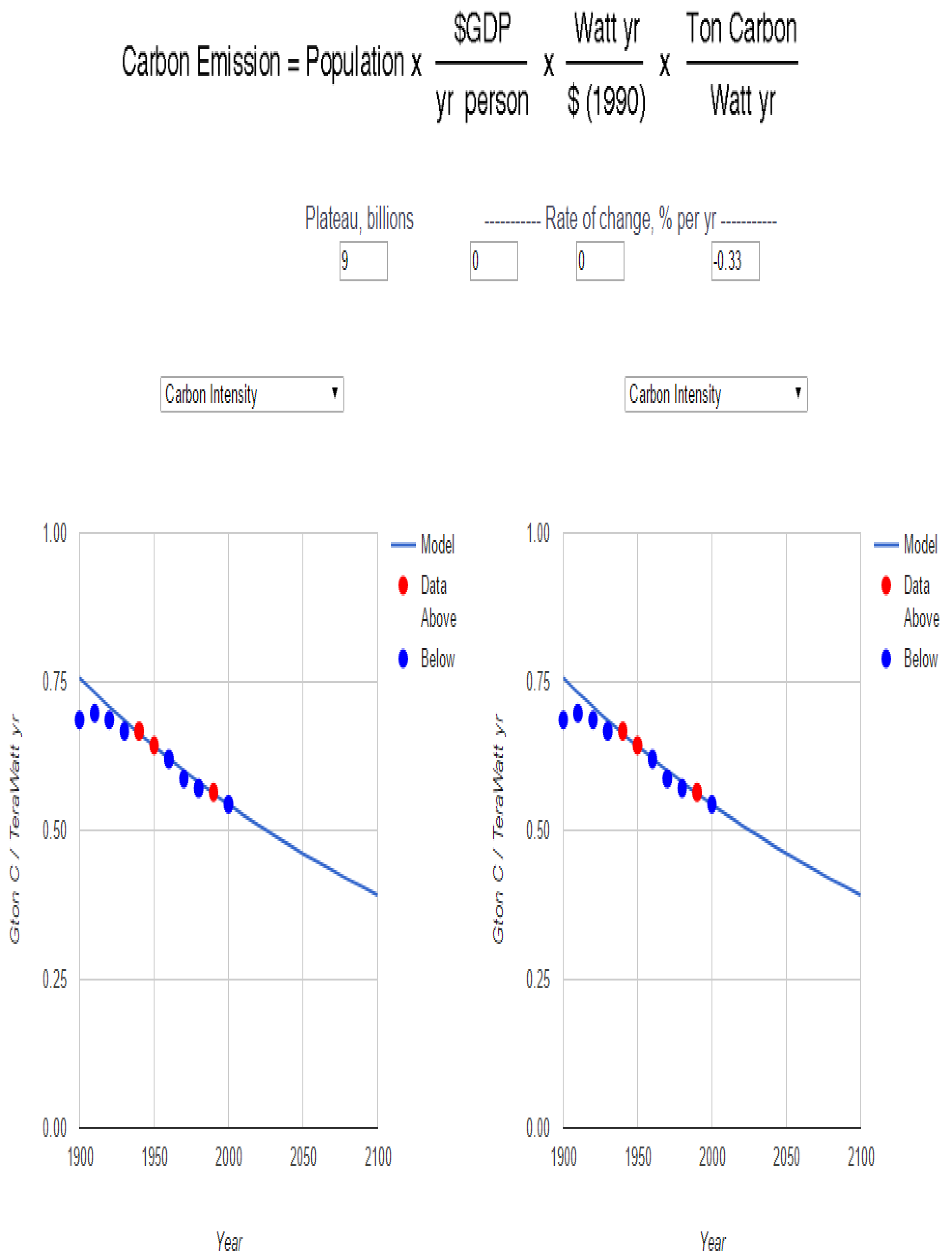

FIGURE 4.25 MODEL CURVE FOR CARBON INTENSITY VALUE OF -0.33%

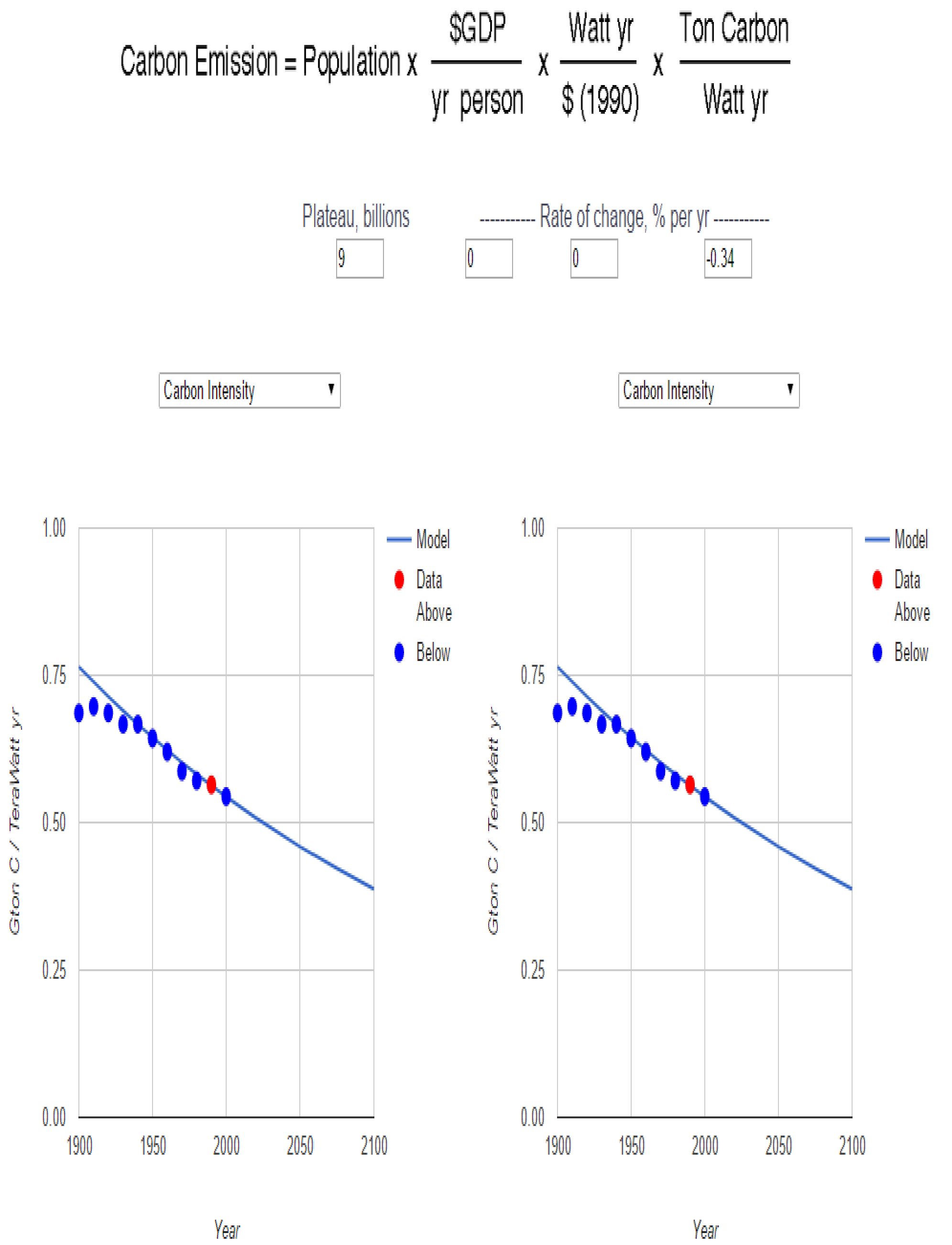

FIGURE 4.26 MODEL CURVE FOR CARBON INTENSITY VALUE OF -0.34%

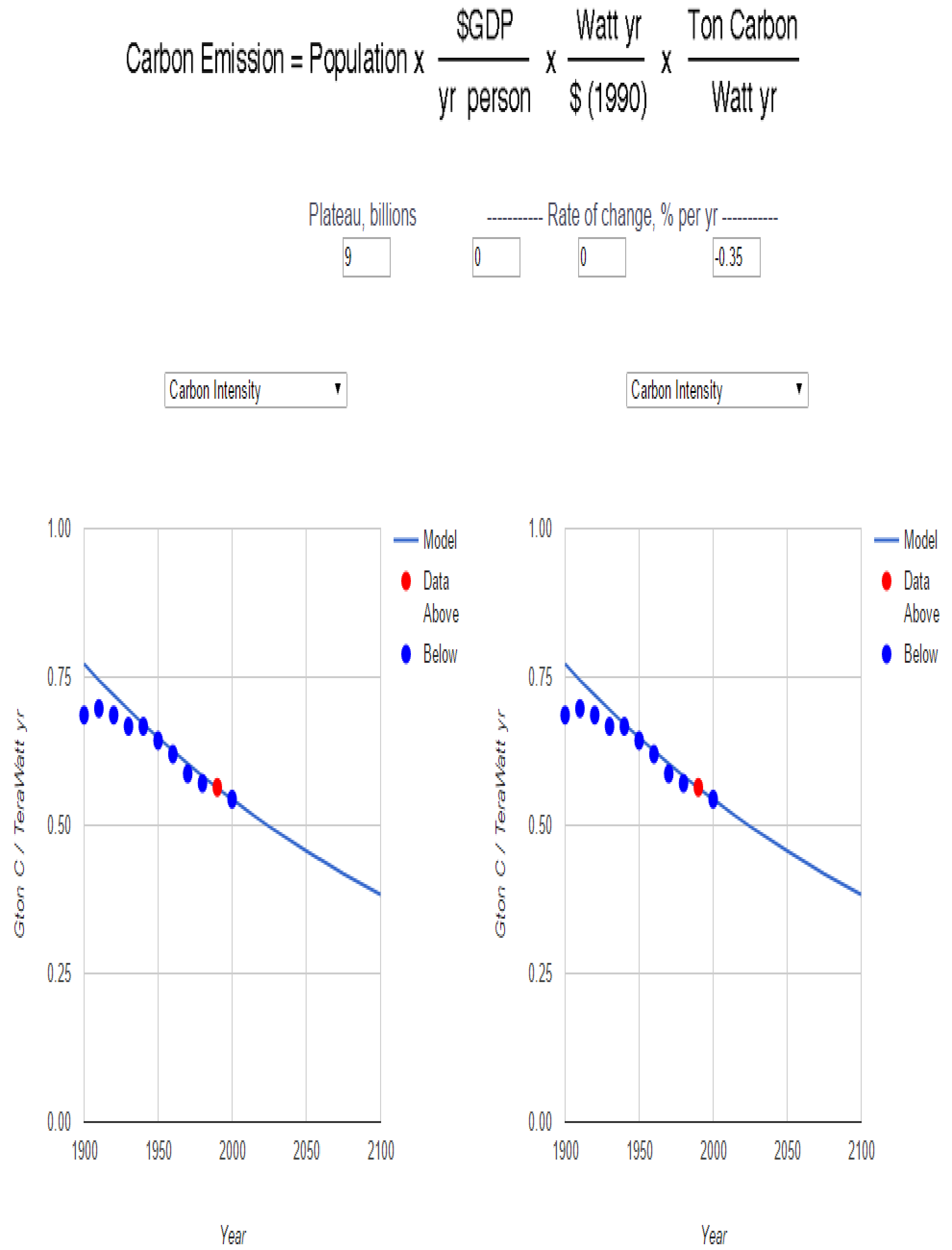

FIGURE 4.27 MODEL CURVE FOR CARBON INTENSITY VALUE OF -0.35%

4.2 WORST CASE SCENARIO OF CARBON EMISSIONS

1) Population = 13 billion

2) GDP Per Capita = 2%

3) Energy Intensity = [-0.55,-0.45]

4) Carbon Intensity = [-0.25,-0.20]

5) Carbon Emission by the end of 21st century = (45, 60) Gton C/year

The population and GDP Per Capita values taken for this particular scenario has been discussed earlier. For the energy intensity values, we can see from the model figures that any value beyond -0.55 or -0.45% would either get too close or too far from the historical data set. The values which are too close would not count as worst case values and the values which are too far would give unrealistic predictions. Same applies for the carbon intensity values as well.

4.2.1 ENERGY INTENSITY WORST CASE VALUES

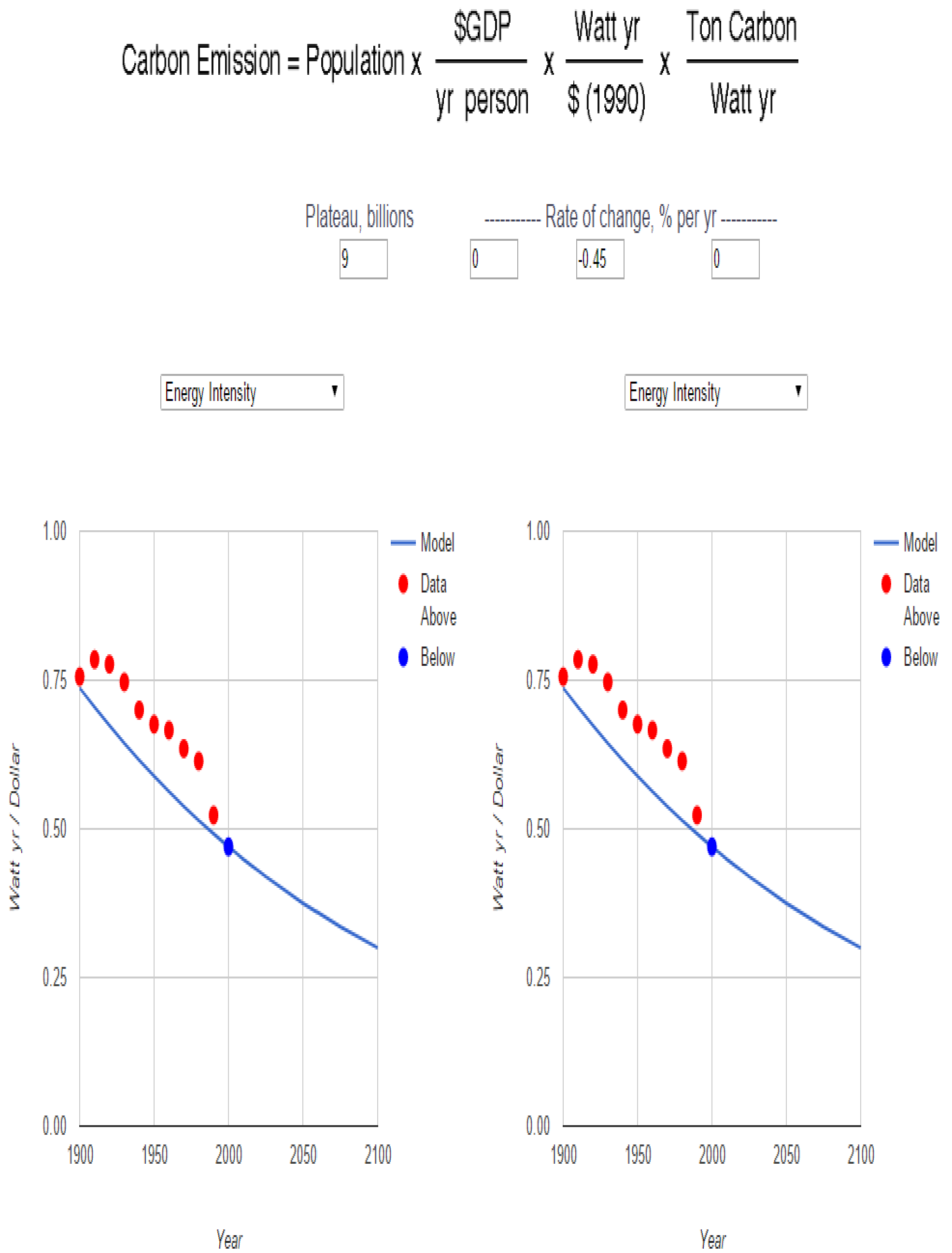

FIGURE 4.28 MODEL CURVE FOR ENERGY INTENSITY VALUE OF -0.45%

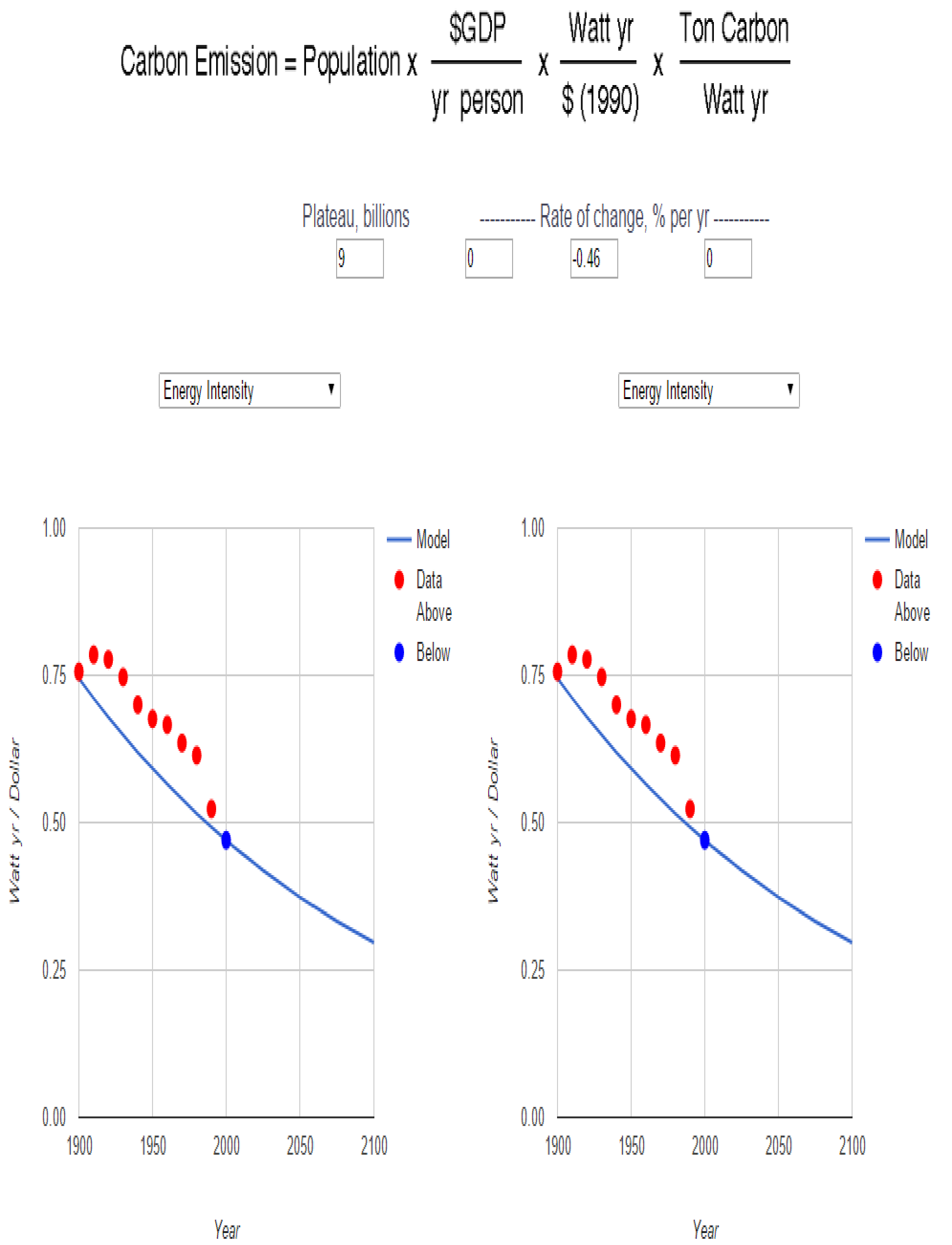

FIGURE 4.29 MODEL CURVE FOR ENERGY INTENSITY VALUE OF -0.46%

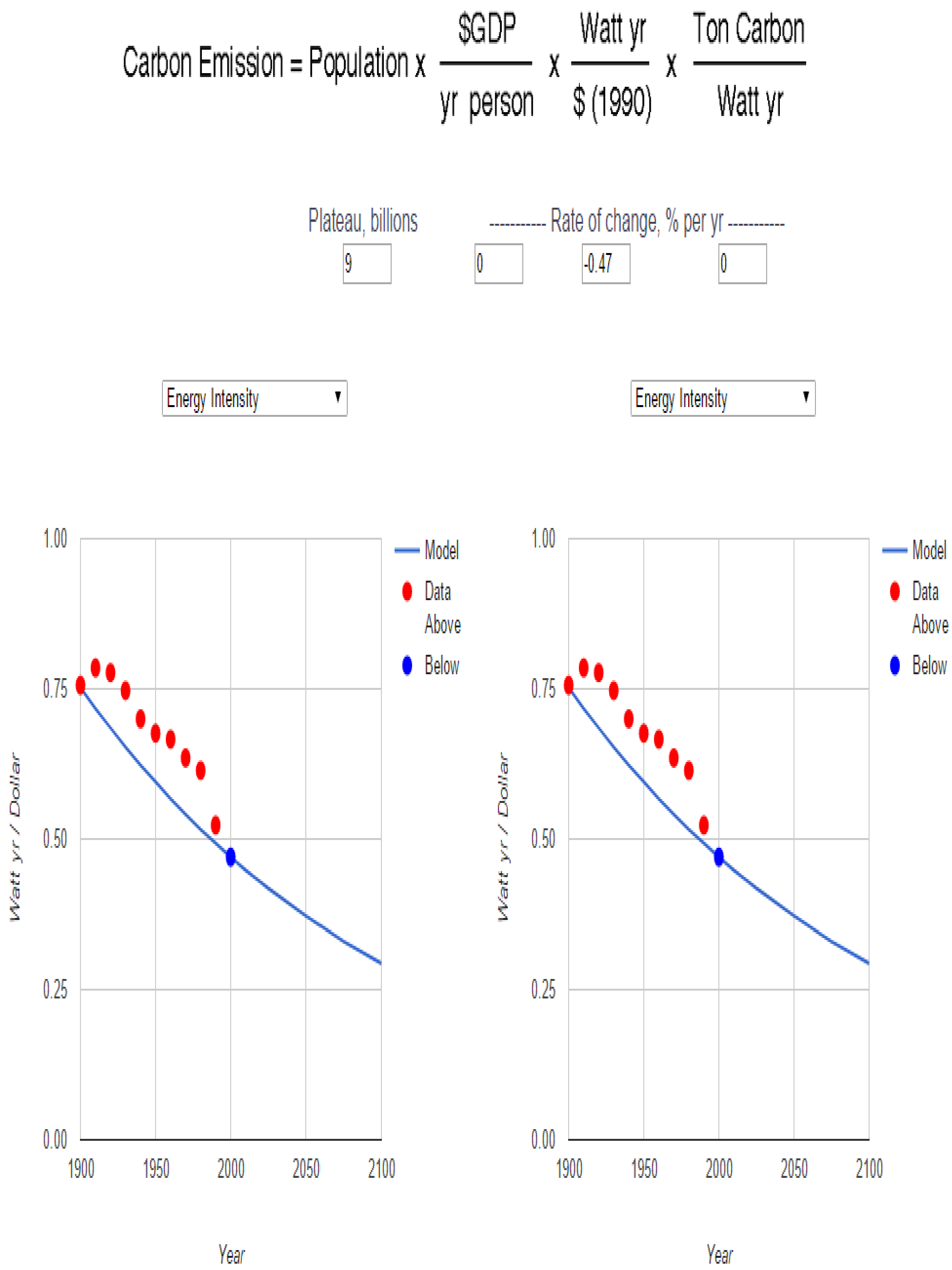

FIGURE 4.30 MODEL CURVE FOR ENERGY INTENSITY VALUE OF -0.47%

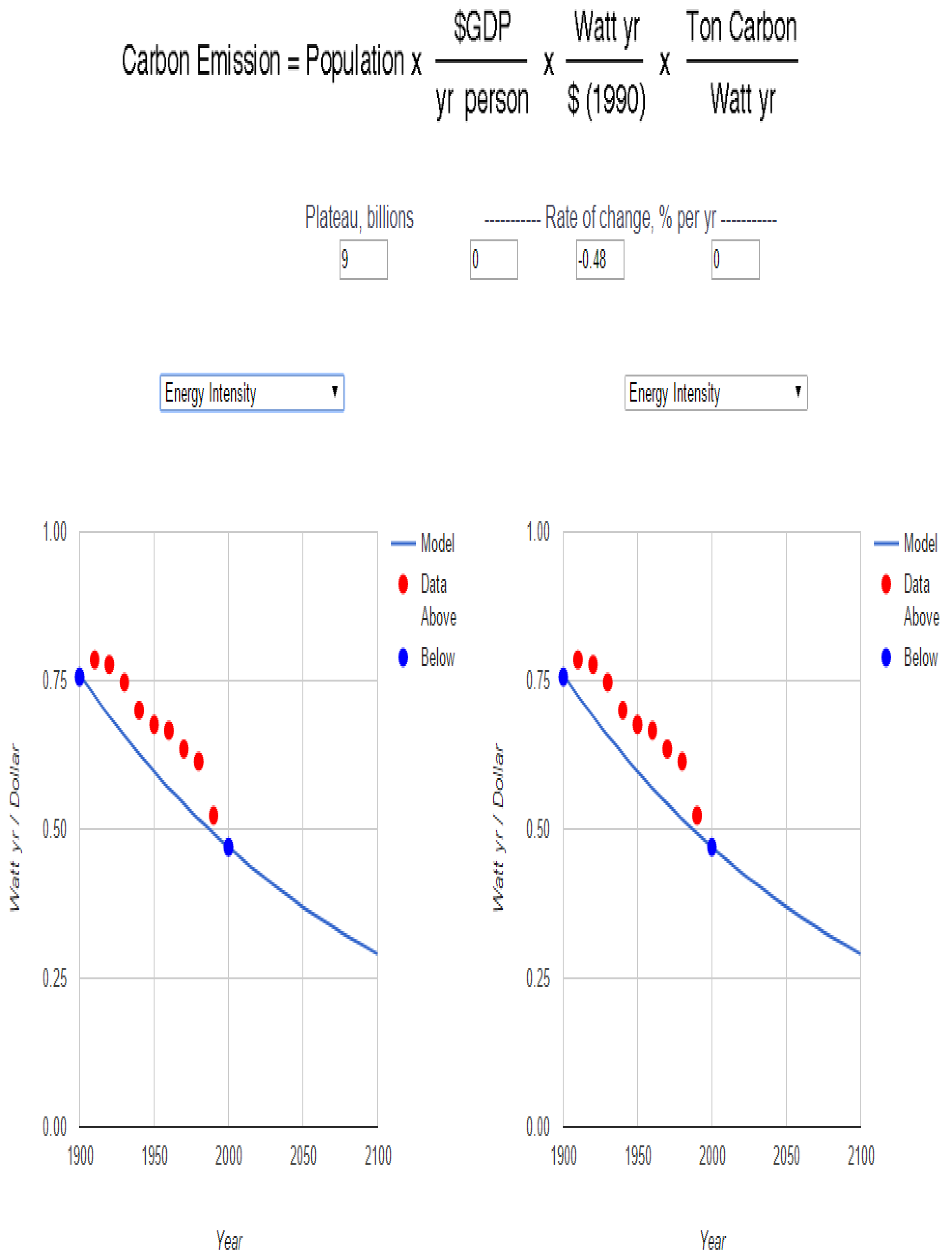

FIGURE 4.31 MODEL CURVE FOR ENERGY INTENSITY VALUE OF -0.48%

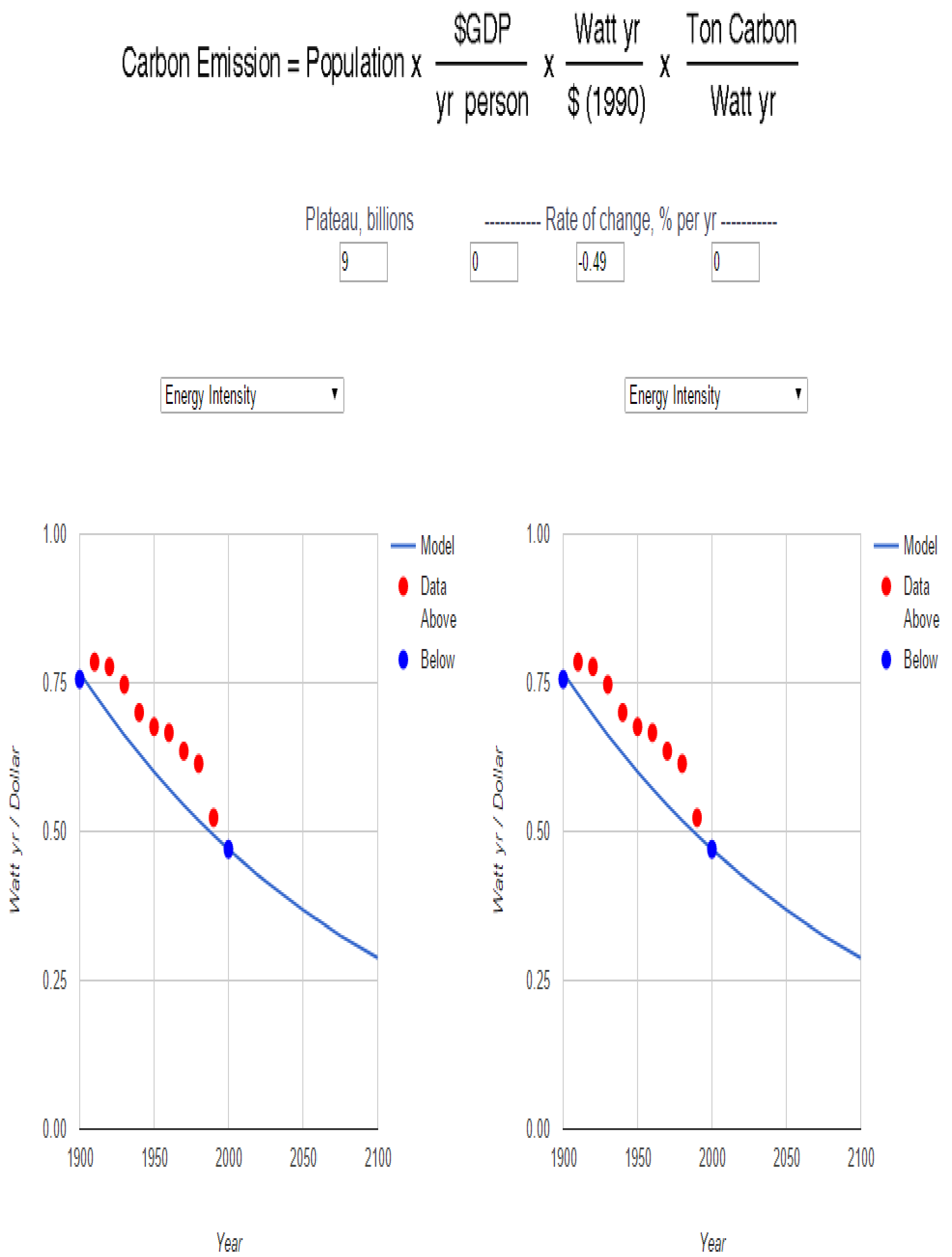

FIGURE 4.32 MODEL CURVE FOR ENERGY INTENSITY VALUE OF -0.49%

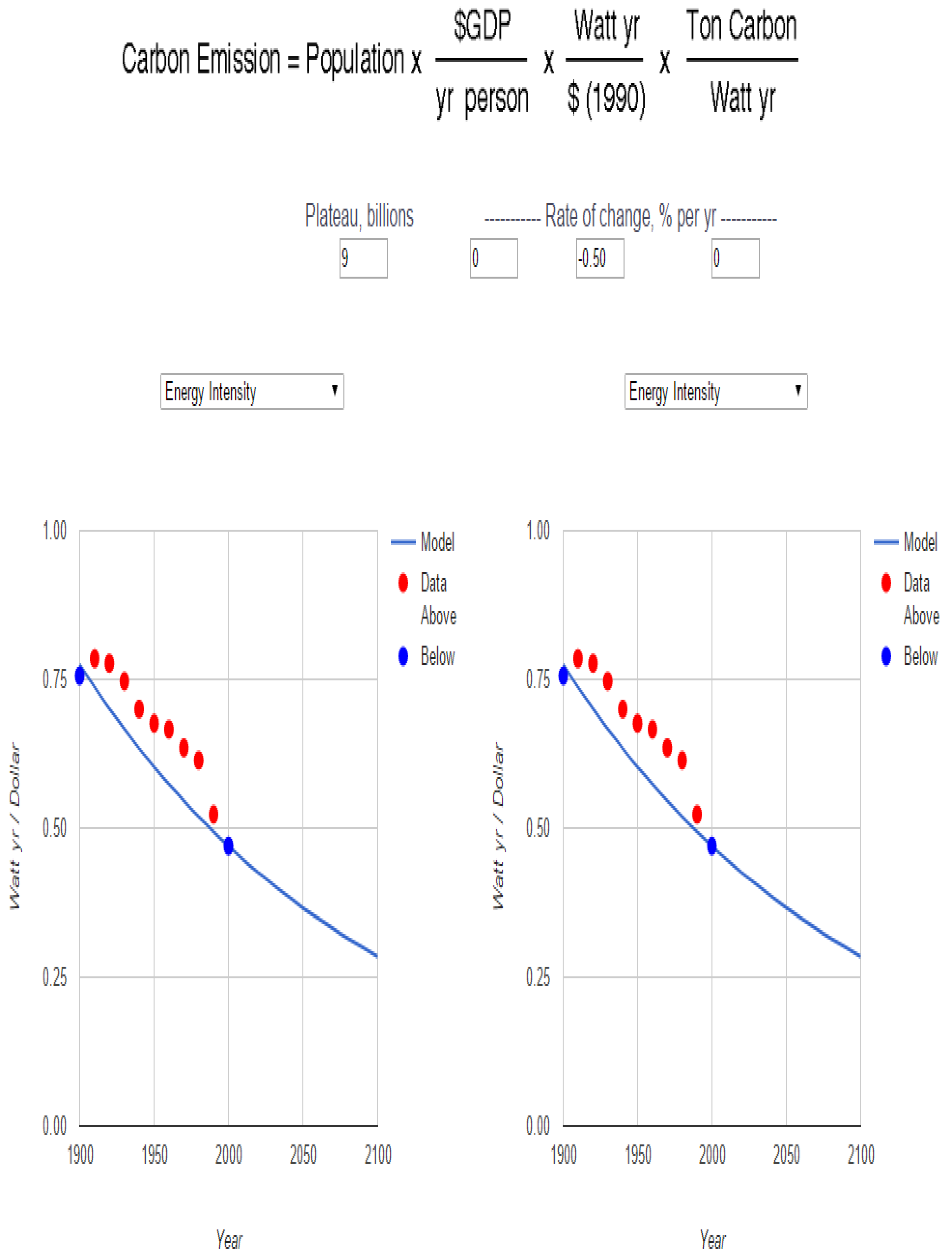

FIGURE 4.33 MODEL CURVE FOR ENERGY INTENSITY VALUE OF -0.50%

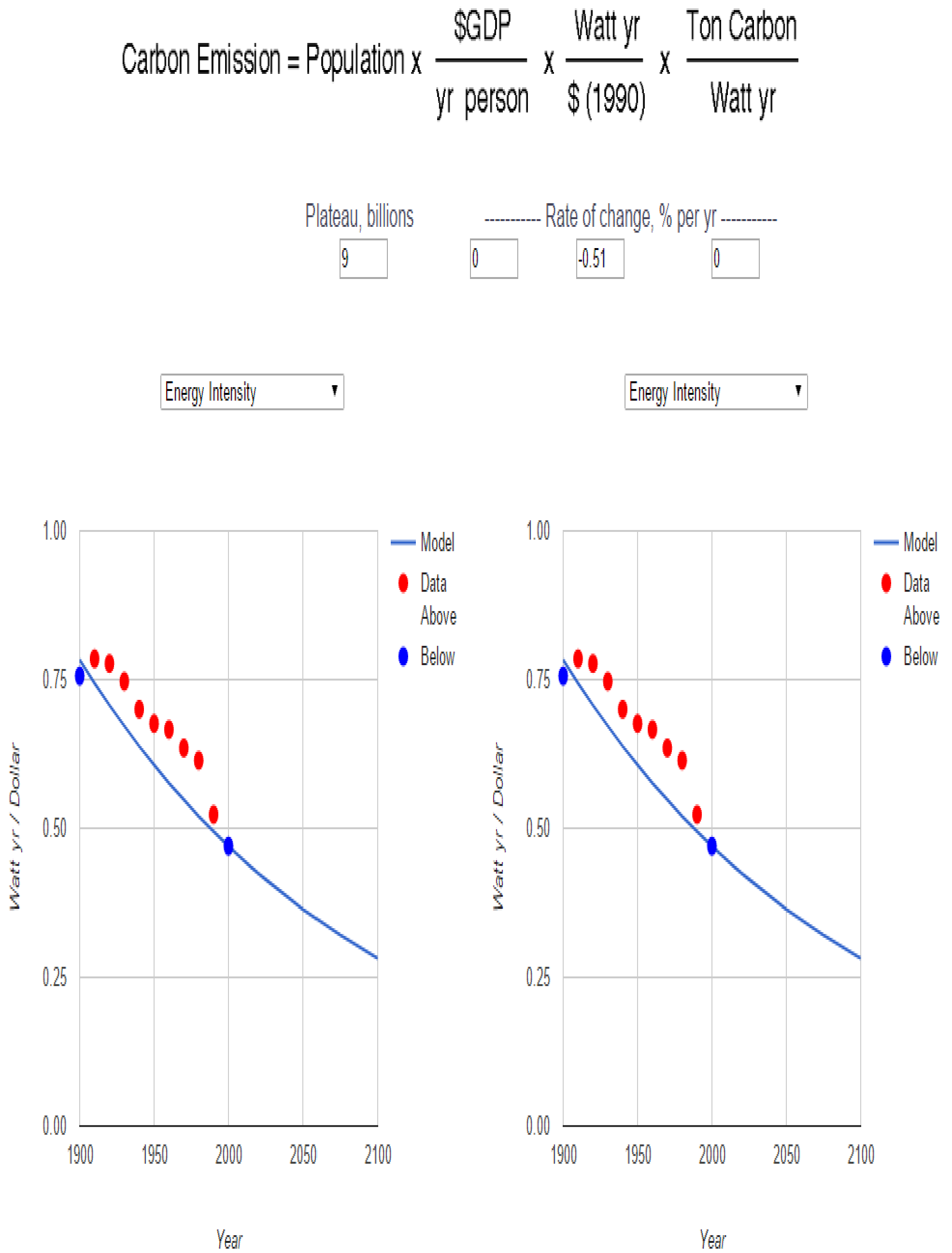

FIGURE 4.34 MODEL CURVE FOR ENERGY INTENSITY VALUE OF -0.51%

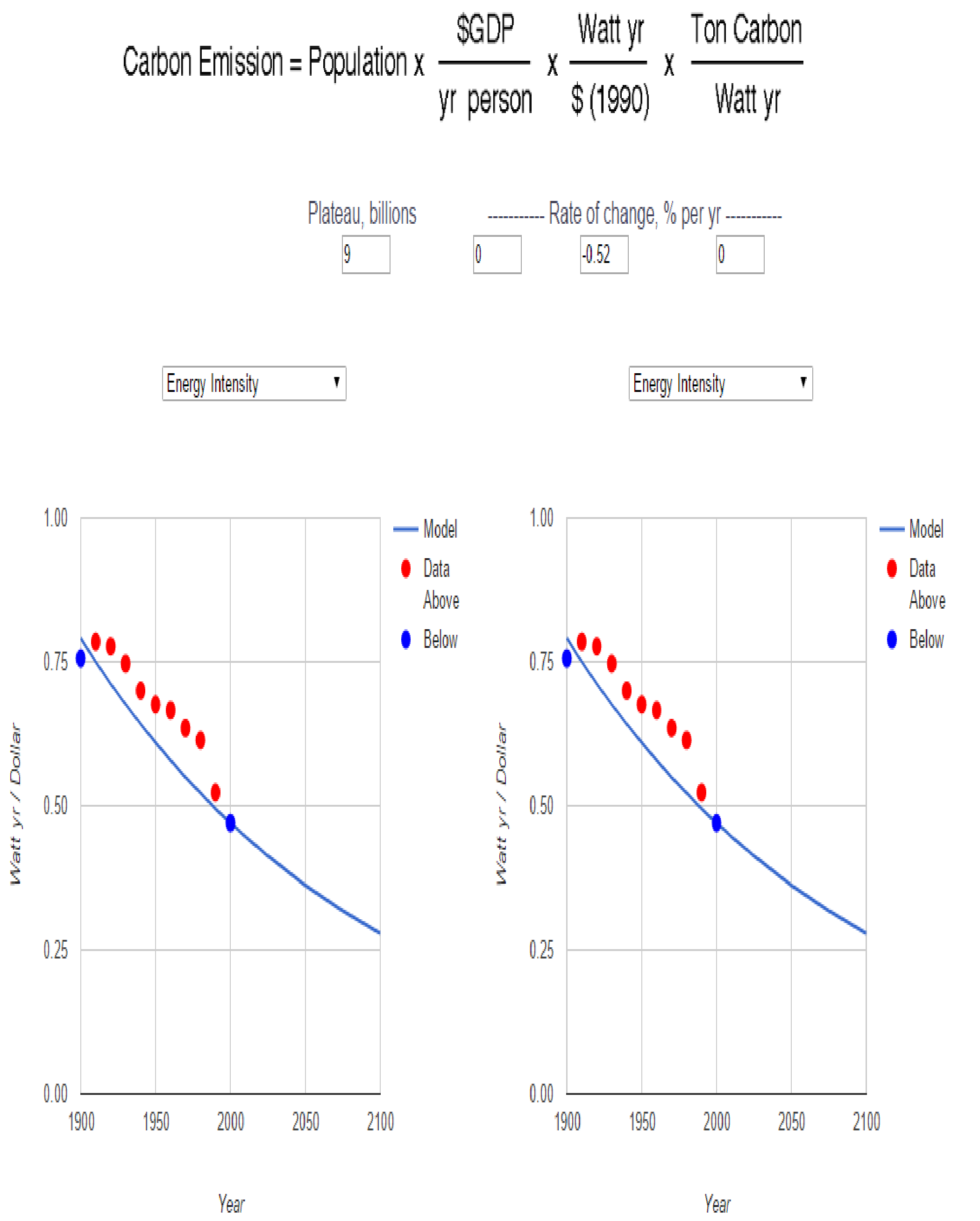

FIGURE 4.35 MODEL CURVE FOR ENERGY INTENSITY VALUE OF -0.52%

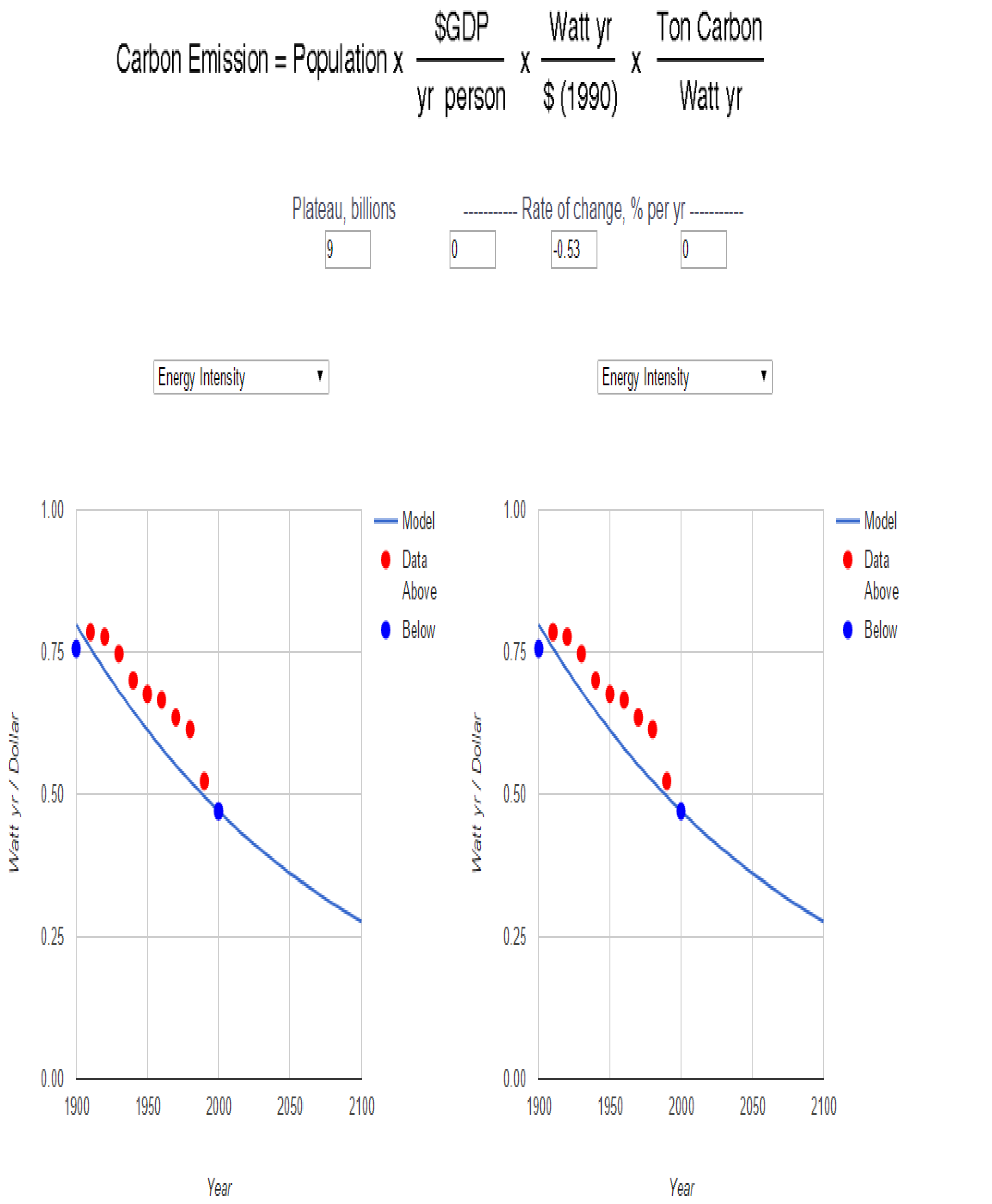

FIGURE 4.36 MODEL CURVE FOR ENERGY INTENSITY VALUE OF -0.53%

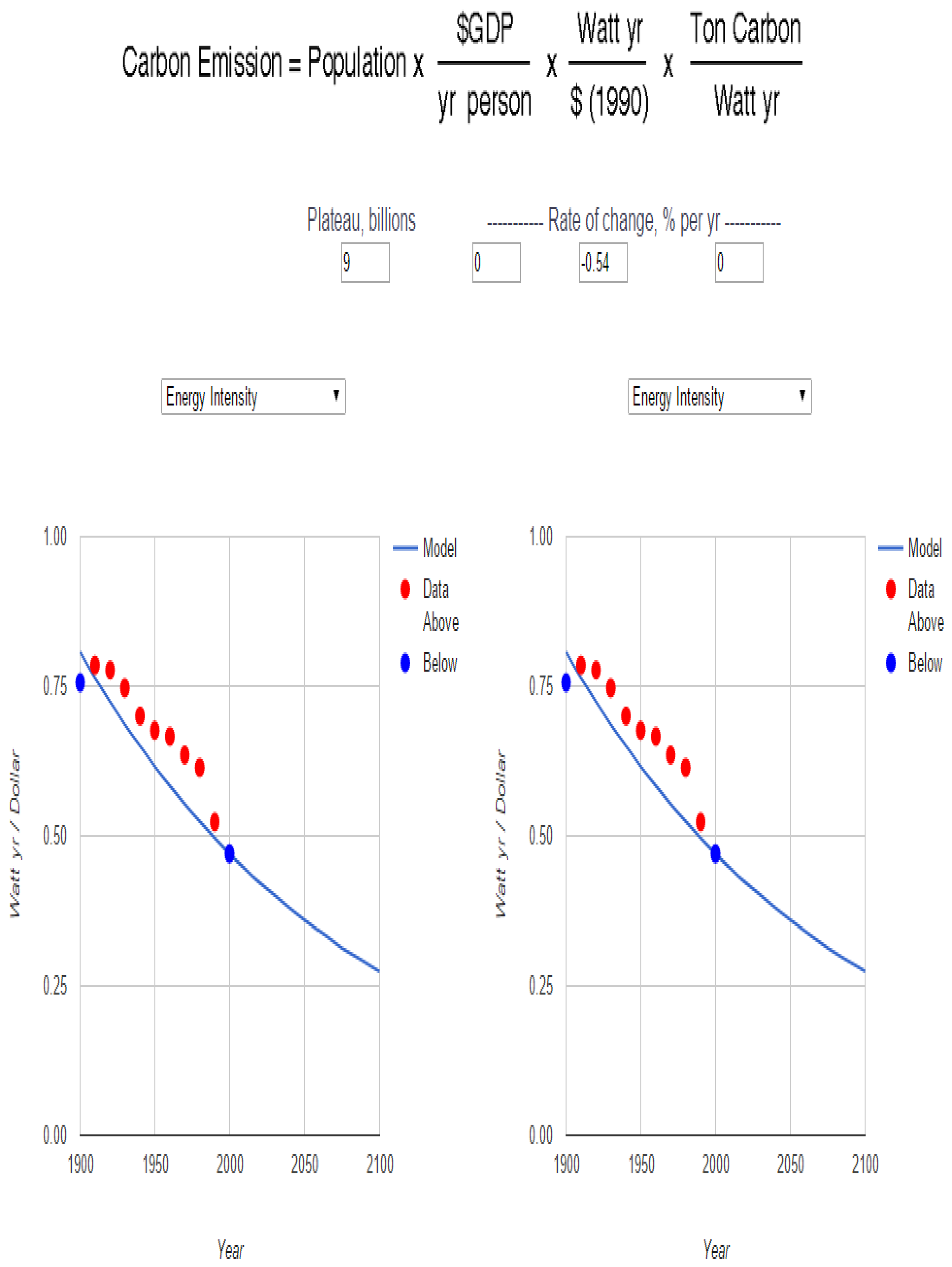

FIGURE 4.37 MODEL CURVE FOR ENERGY INTENSITY VALUE OF -0.54%

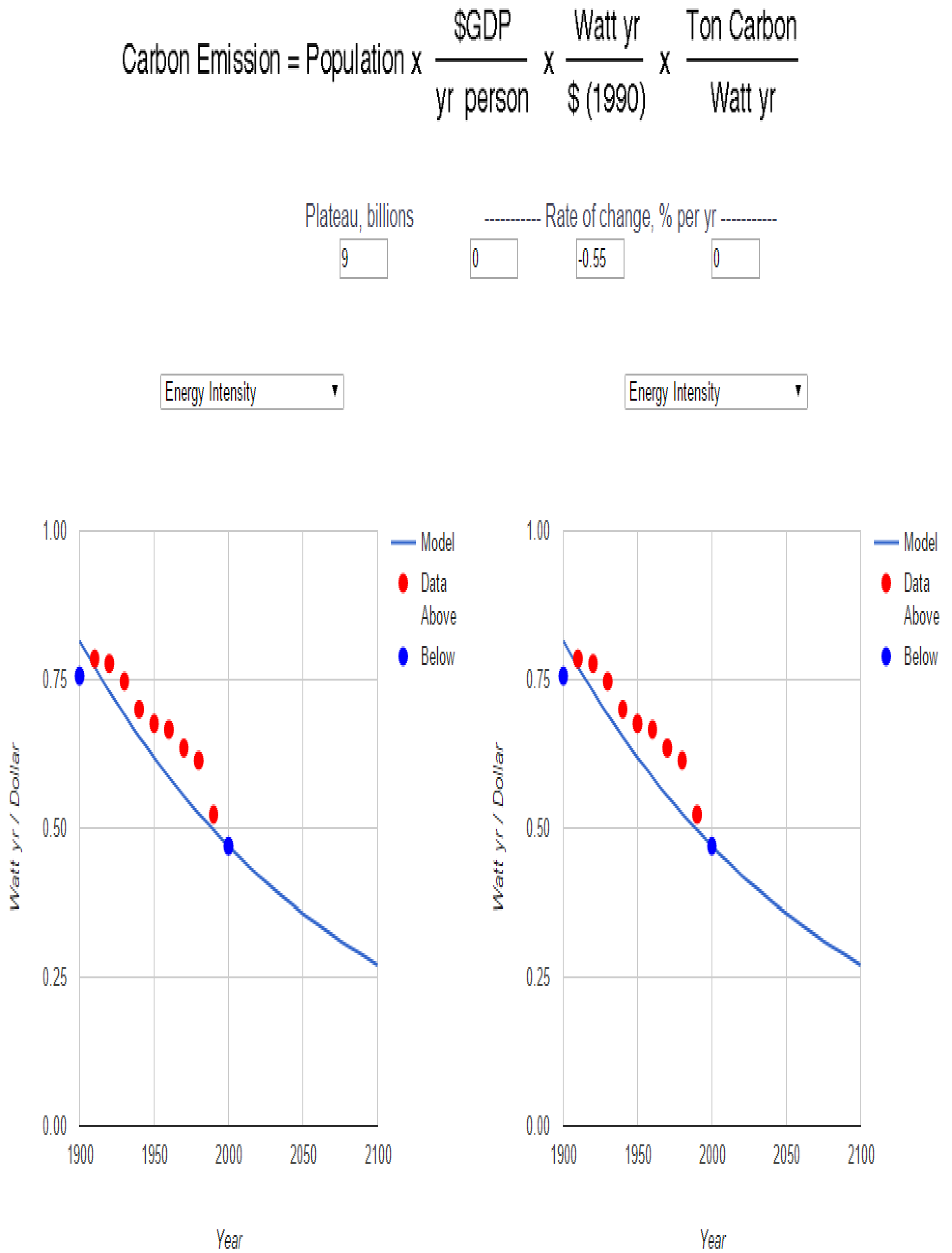

FIGURE 4.38 MODEL CURVE FOR ENERGY INTENSITY VALUE OF -0.55%

4.2.2 CARBON INTENSITY WORST CASE VALUE FIGURES

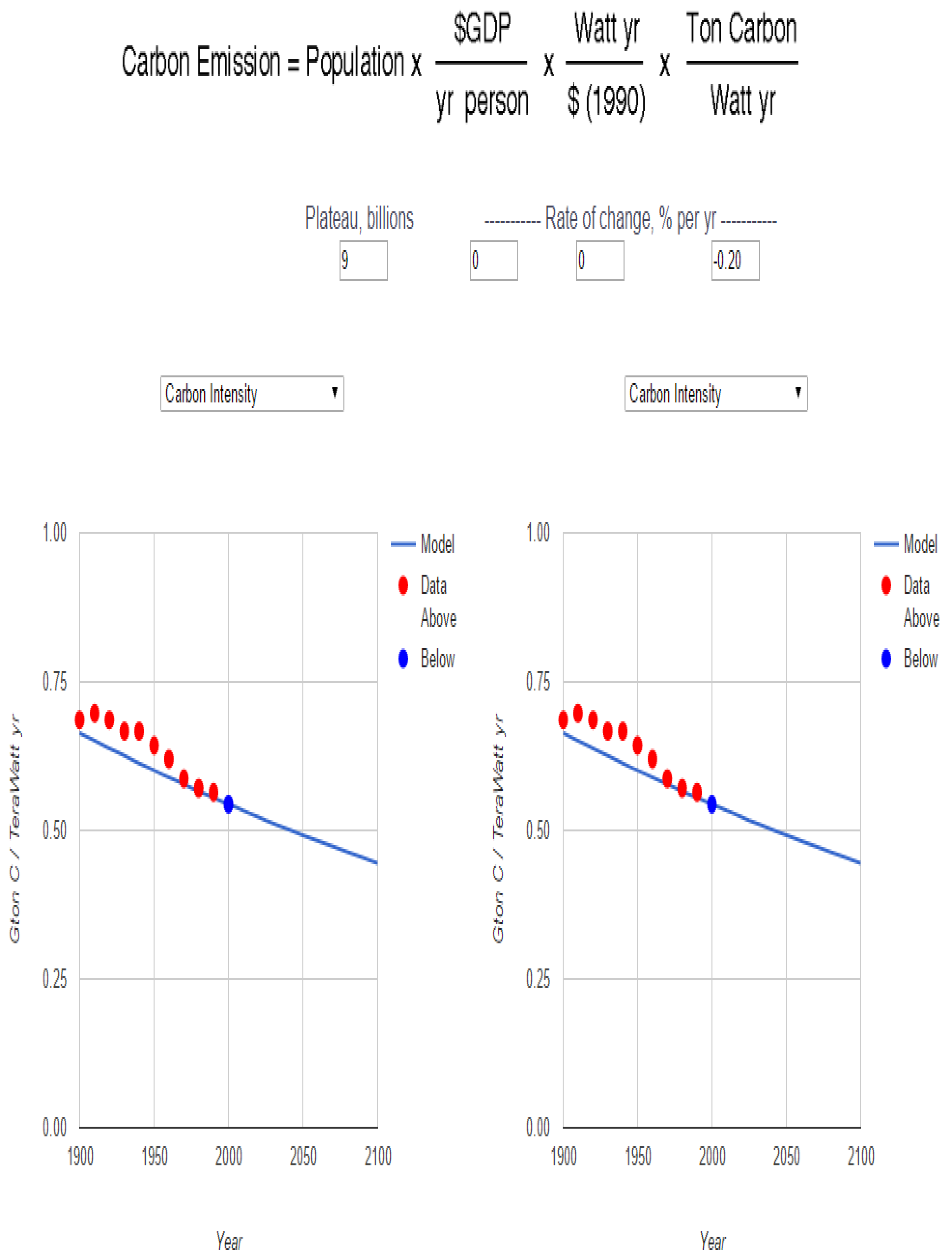

FIGURE 4.39 MODEL CURVE FOR CARBON INTENSITY VALUE OF -0.20%

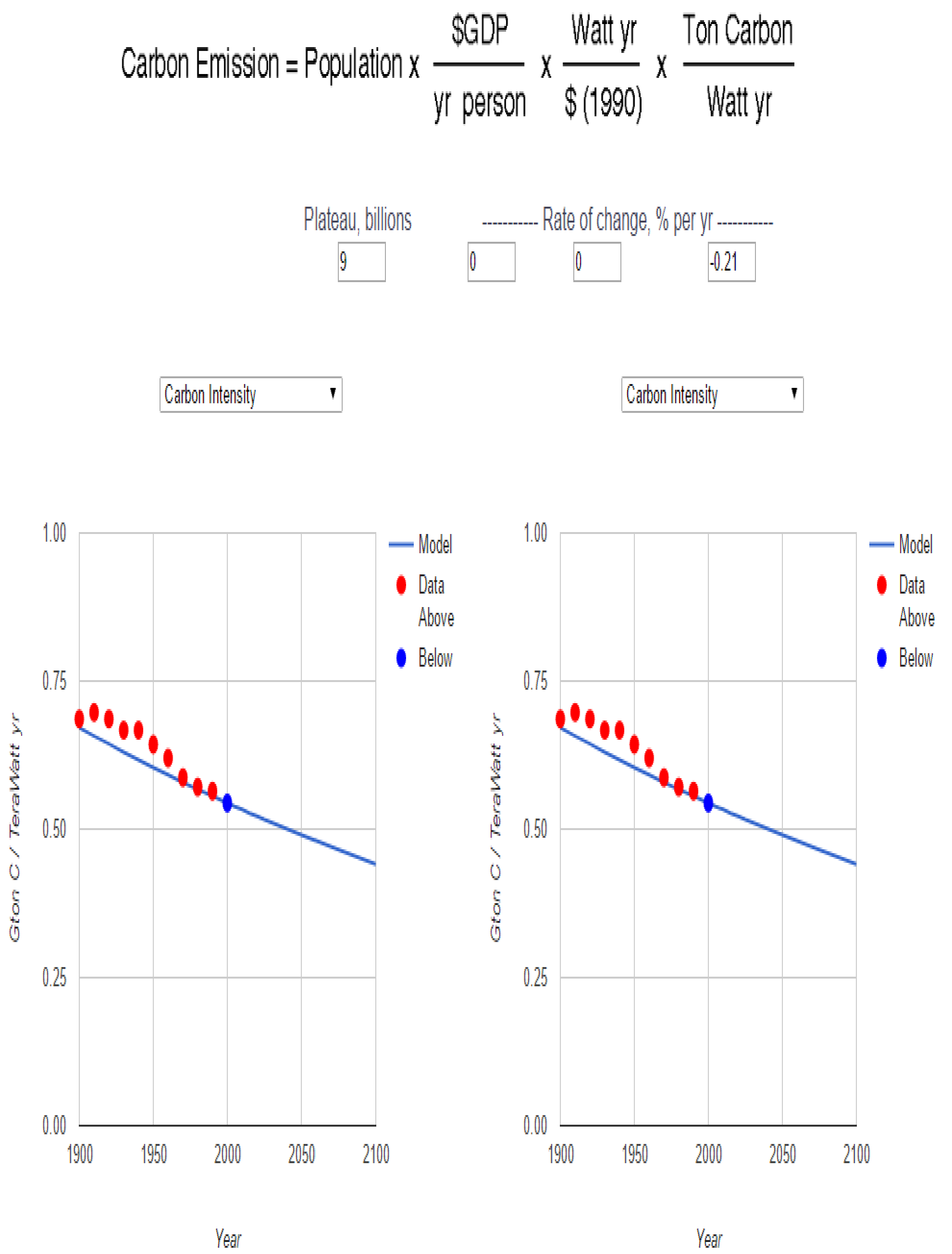

FIGURE 4.40 MODEL CURVE FOR CARBON INTENSITY VALUE OF -0.21%

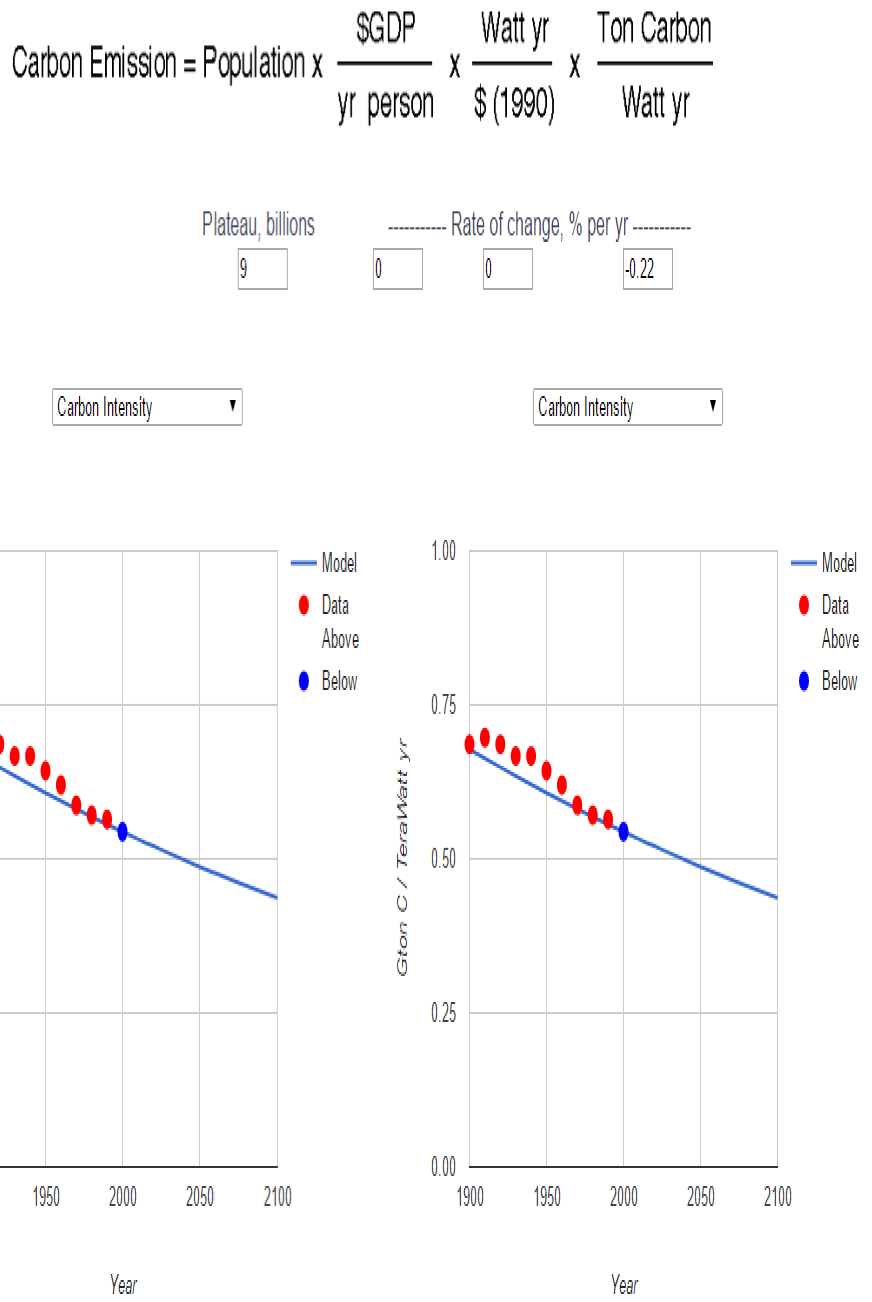

FIGURE 4.41 MODEL CURVE FOR CARBON INTENSITY VALUE OF -0.22%

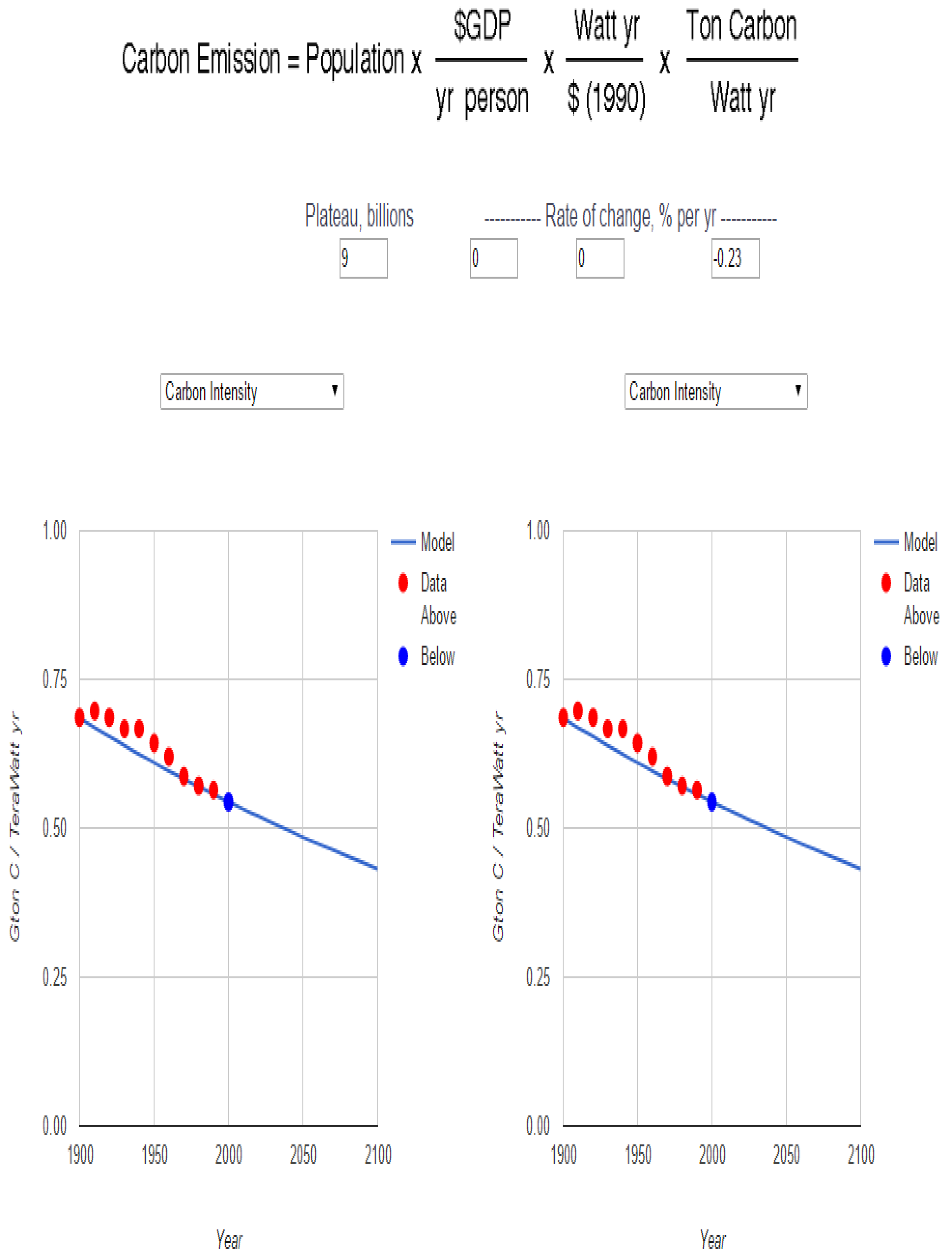

FIGURE 4.42 MODEL CURVE FOR CARBON INTENSITY VALUE OF -0.23%

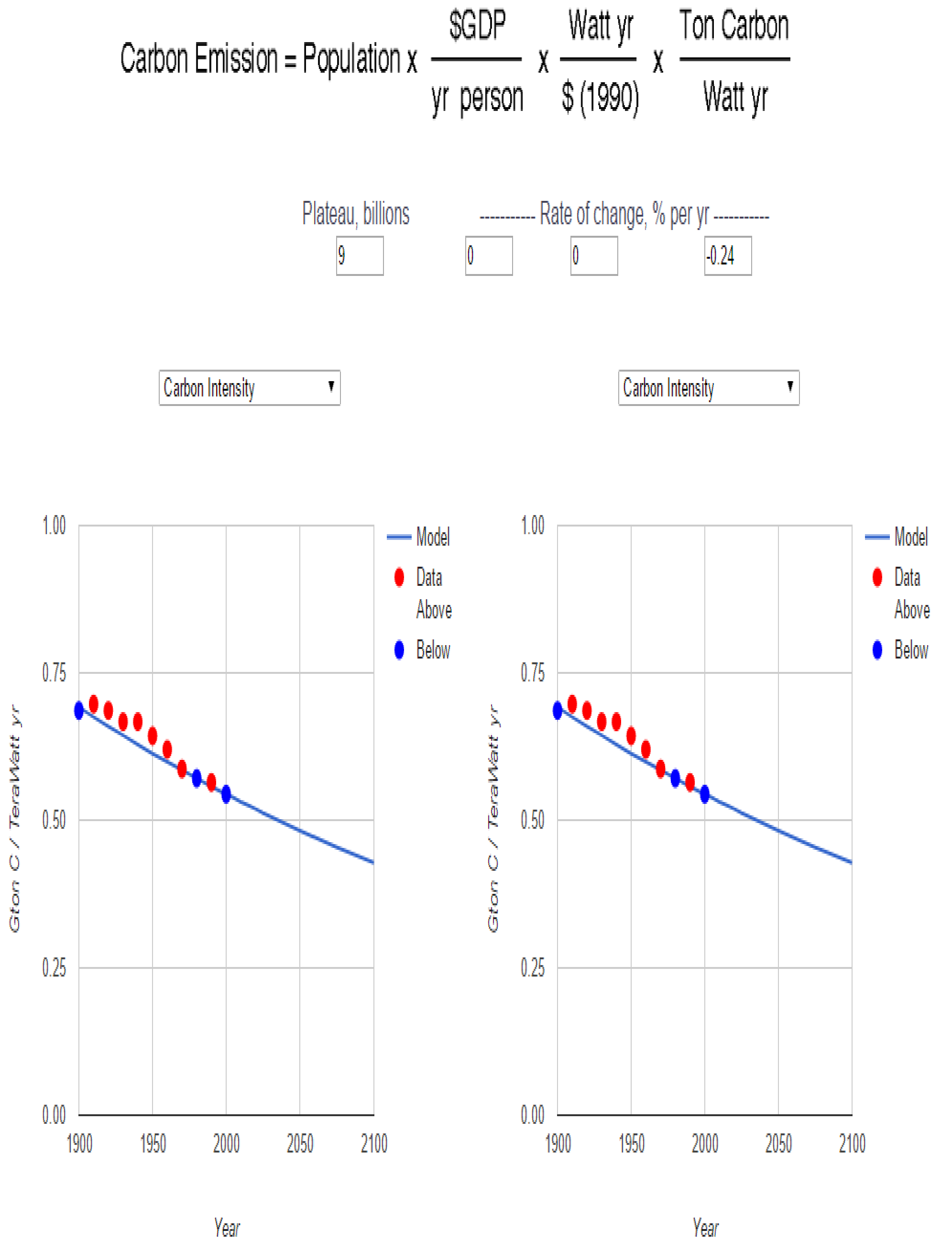

FIGURE 4.43 MODEL CURVE FOR CARBON INTENSITY VALUE OF -0.24%

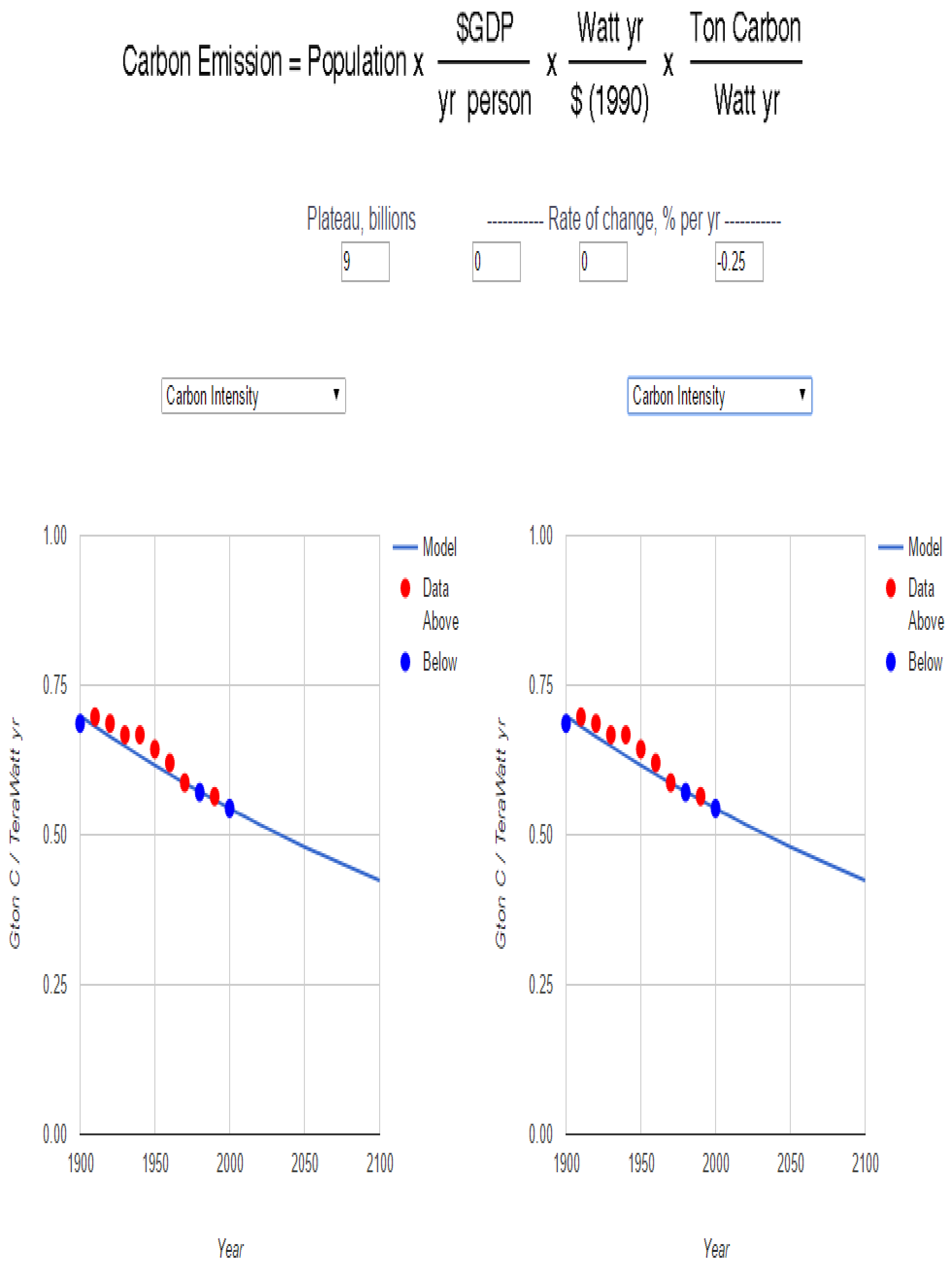

FIGURE 4.44 MODEL CURVE FOR CARBON INTENSITY VALUE OF -0.25%

4.2.3 WORST CASE CARBON EMISSION VALUES AS PER THE MODEL

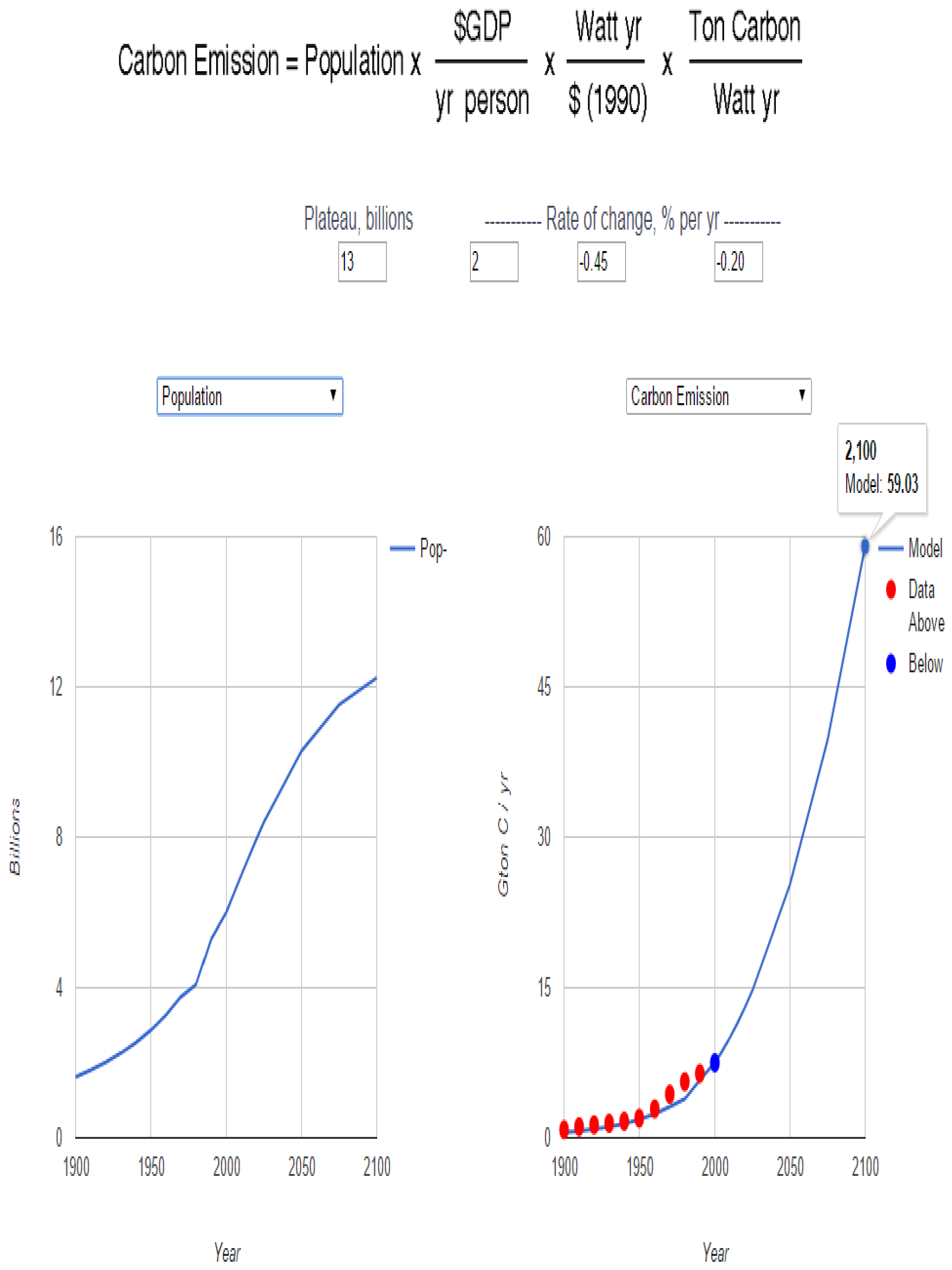

FIGURE 4.45 CARBON EMISSION CURVE FOR ENERGY INTENSITY = -0.45% AND CARBON INTENSITY = -0.20%

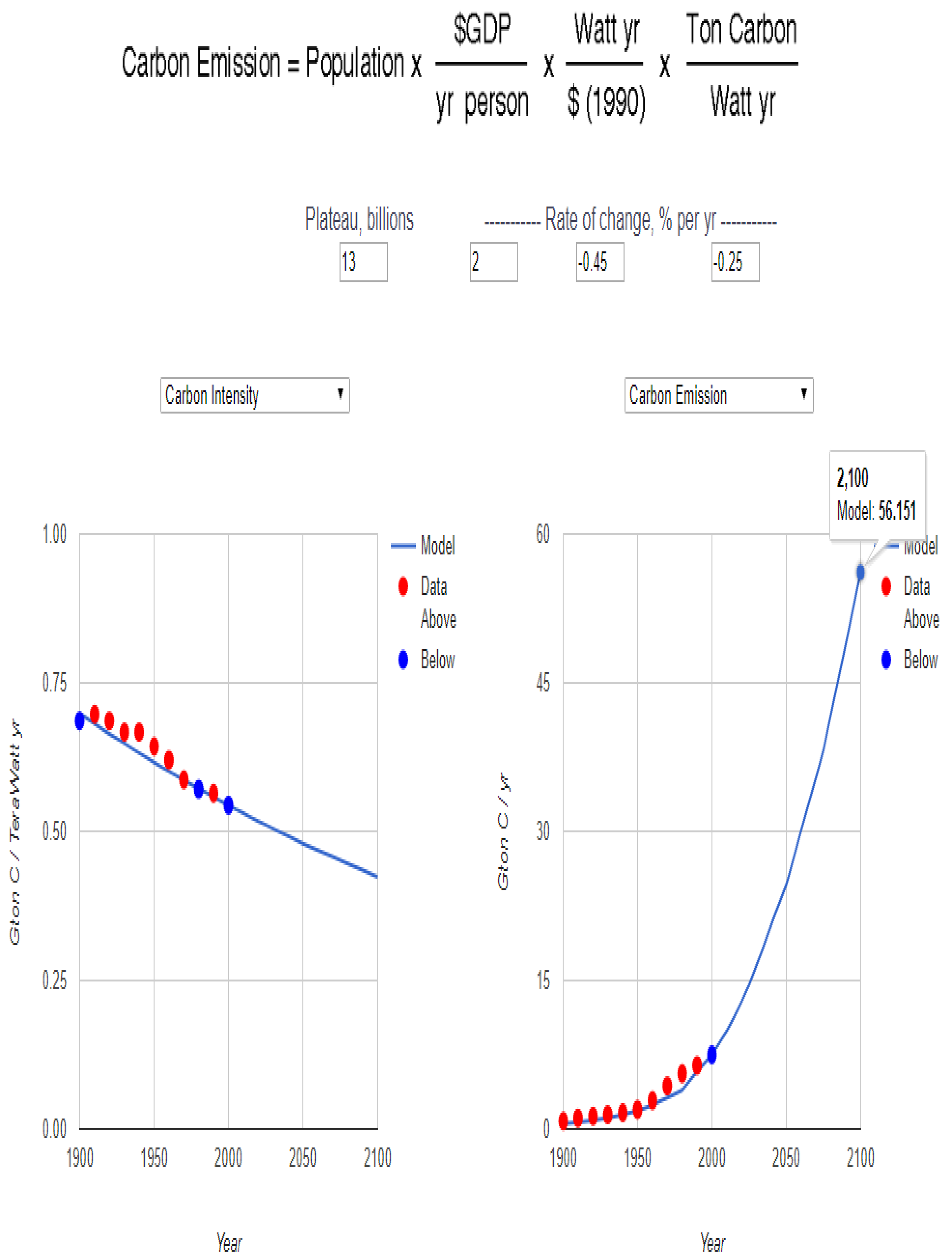

FIGURE 4.55 CARBON EMISSION CURVE FOR ENERGY INTENSITY = -0.45% AND CARBON INTENSITY = -0.25%

$$\text{Carbon Emission} = \text{Population} \times \frac{\$GDP}{\text{yr person}} \times \frac{\text{Watt yr}}{\$\,(1990)} \times \frac{\text{Ton Carbon}}{\text{Watt yr}}$$

Plateau, billions ---------- Rate of change, % per yr ----------

13 2 -0.46 -0.20

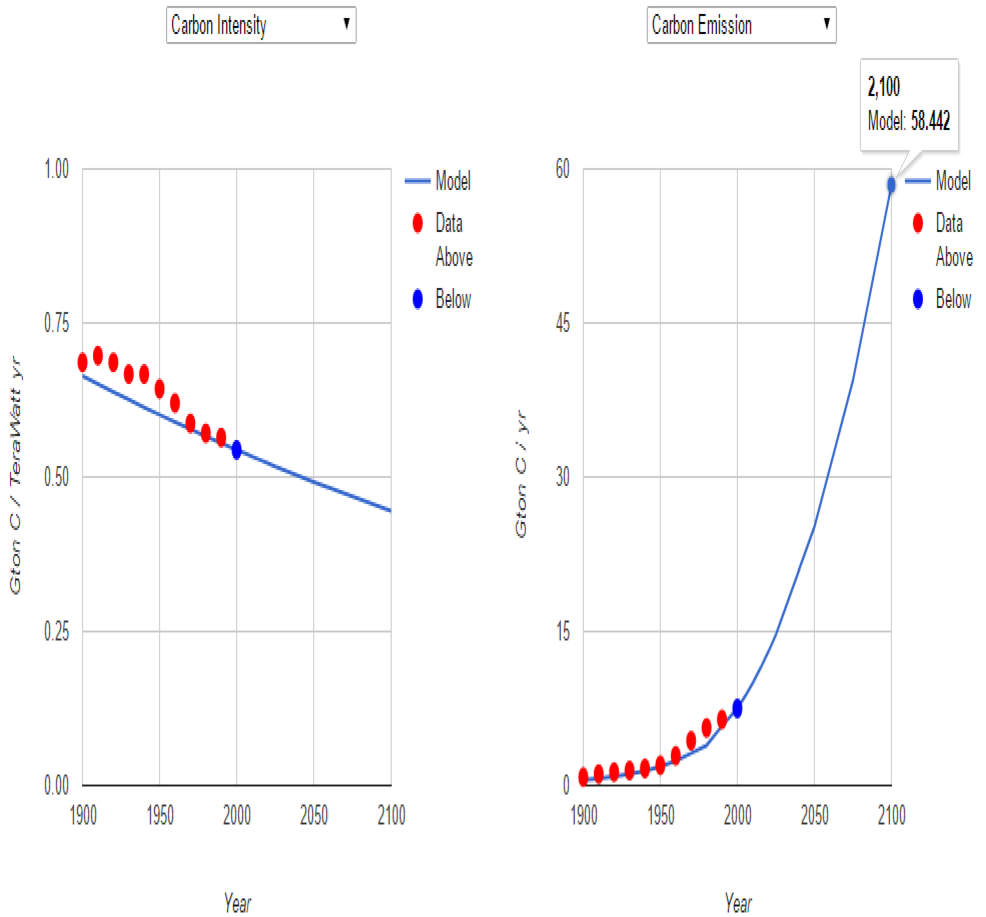

FIGURE 4.46 CARBON EMISSION CURVE FOR ENERGY INTENSITY = -0.46% AND CARBON INTENSITY = -0.20%

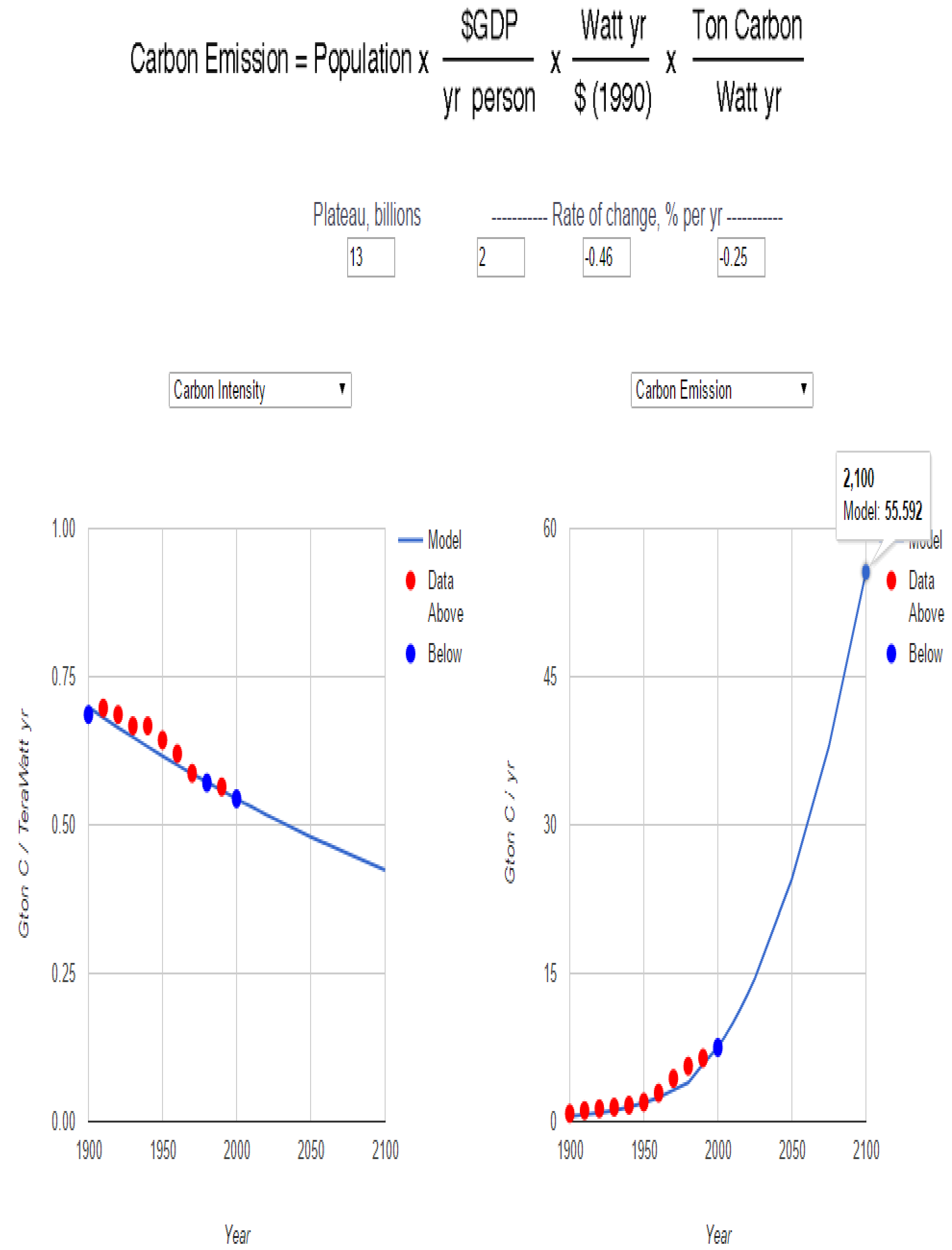

FIGURE 4.47 CARBON EMISSION CURVE FOR ENERGY INTENSITY = -0.46% AND CARBON INTENSITY = 0.25%

$$\text{Carbon Emission} = \text{Population} \times \frac{\$GDP}{\text{yr person}} \times \frac{\text{Watt yr}}{\$\,(1990)} \times \frac{\text{Ton Carbon}}{\text{Watt yr}}$$

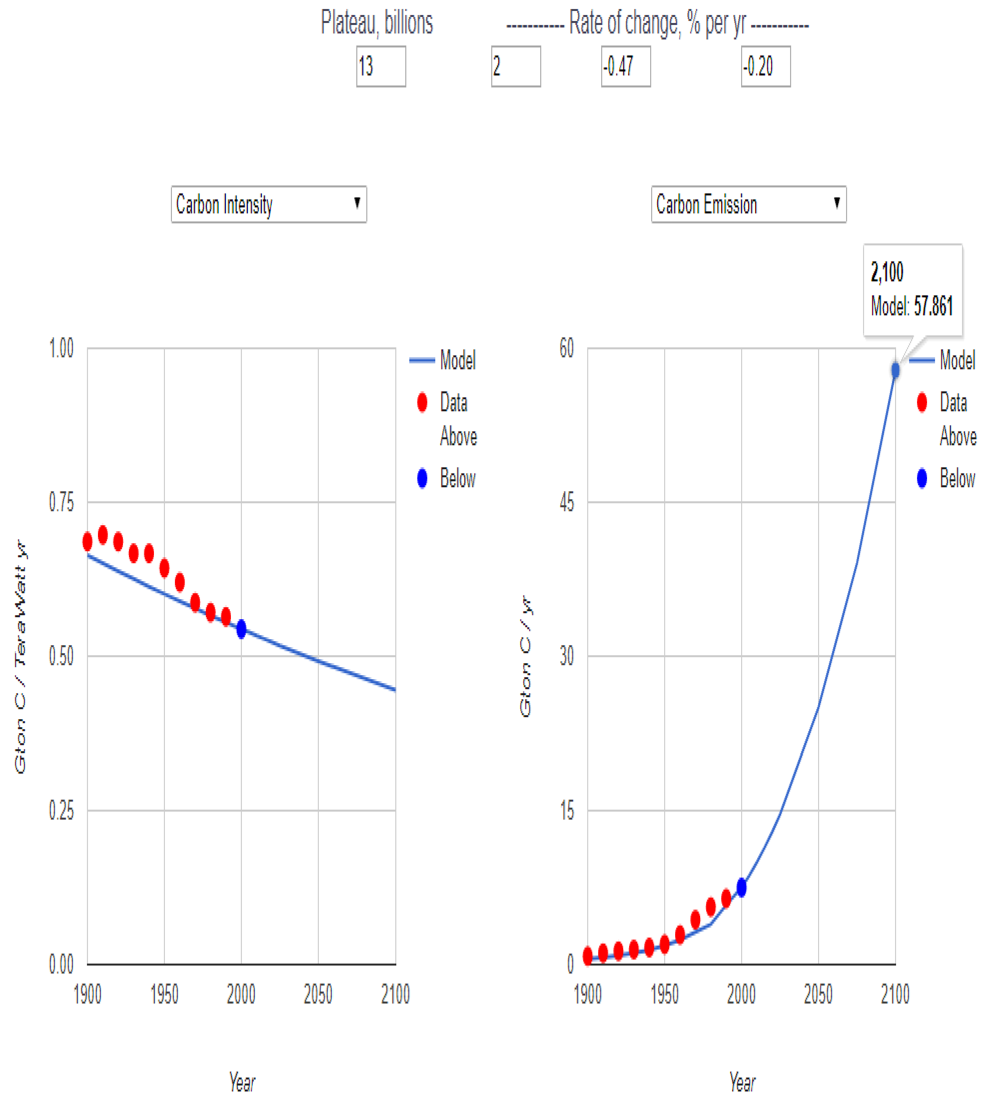

FIGURE 4.48 CARBON EMISSION CURVE FOR ENERGY INTENSITY = -0.47% AND CARBON INTENSITY = -0.20%

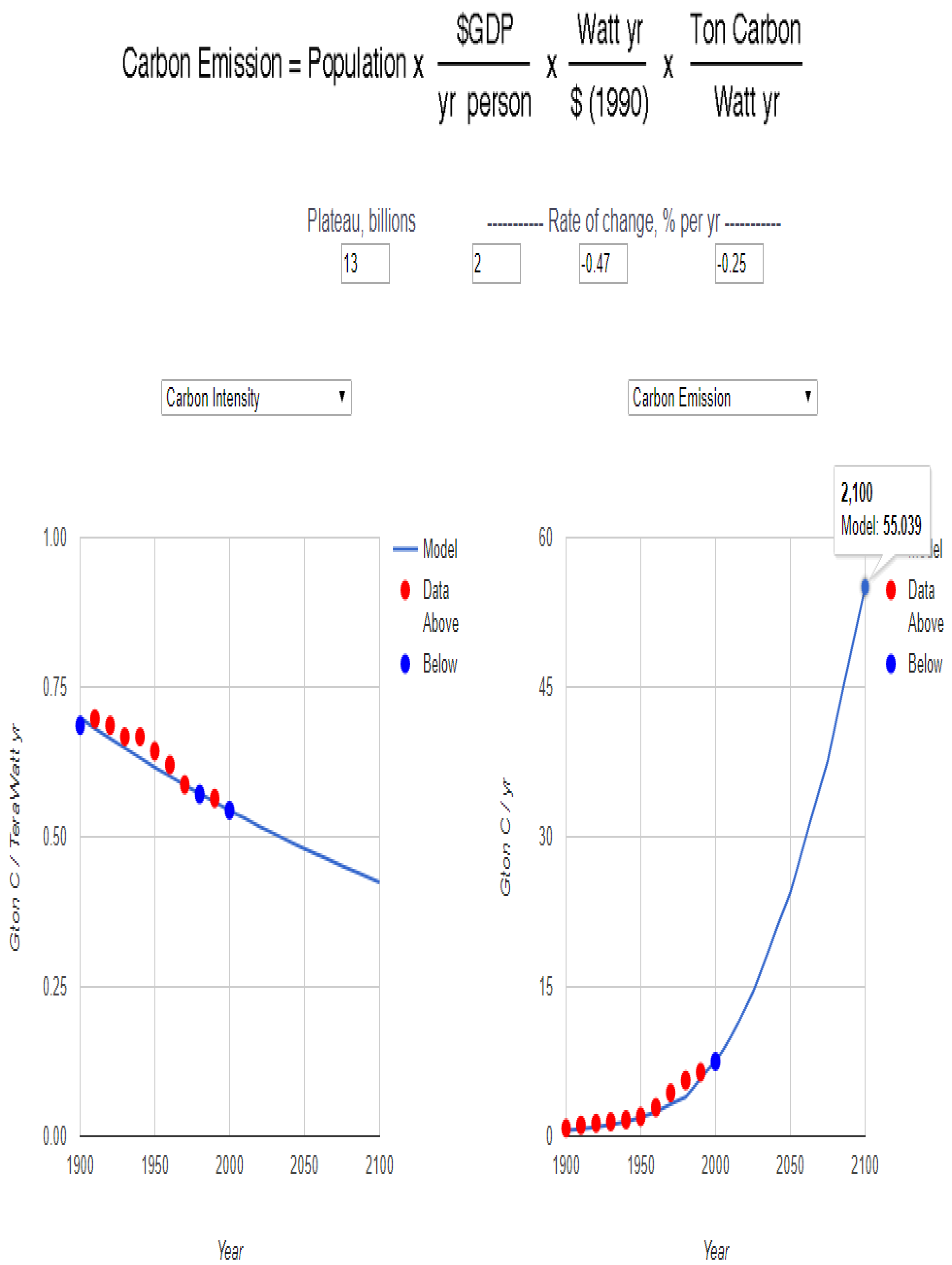

FIGURE 4.49 CARBON EMISSION CURVE FOR ENERGY INTENSITY = -0.47% AND CARBON INTENSITY = -0.25

$$\text{Carbon Emission} = \text{Population} \times \frac{\$GDP}{\text{yr person}} \times \frac{\text{Watt yr}}{\$ (1990)} \times \frac{\text{Ton Carbon}}{\text{Watt yr}}$$

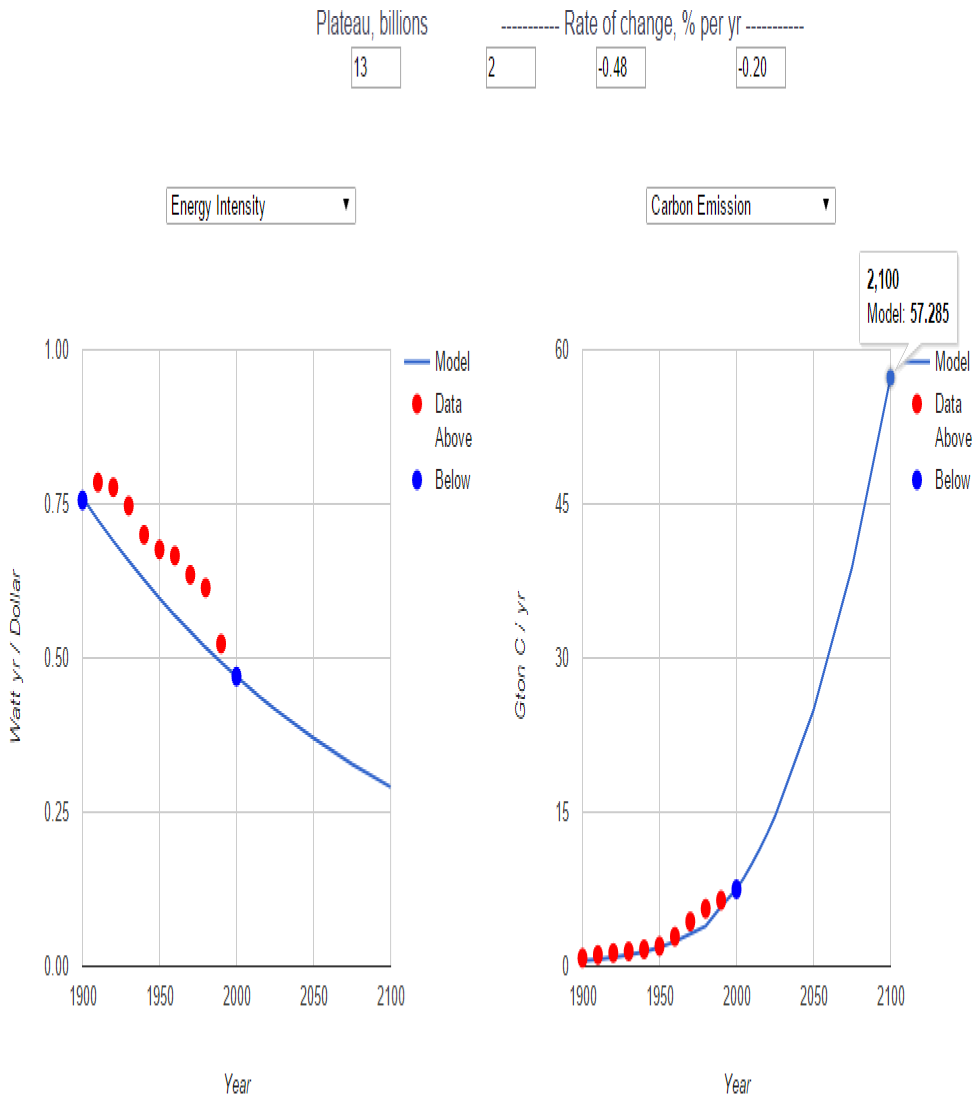

FIGURE 4.50 CARBON EMISSION CURVE FOR ENERGY INTENSITY = -0.48% AND CARBON INTENSITY = -0.20%

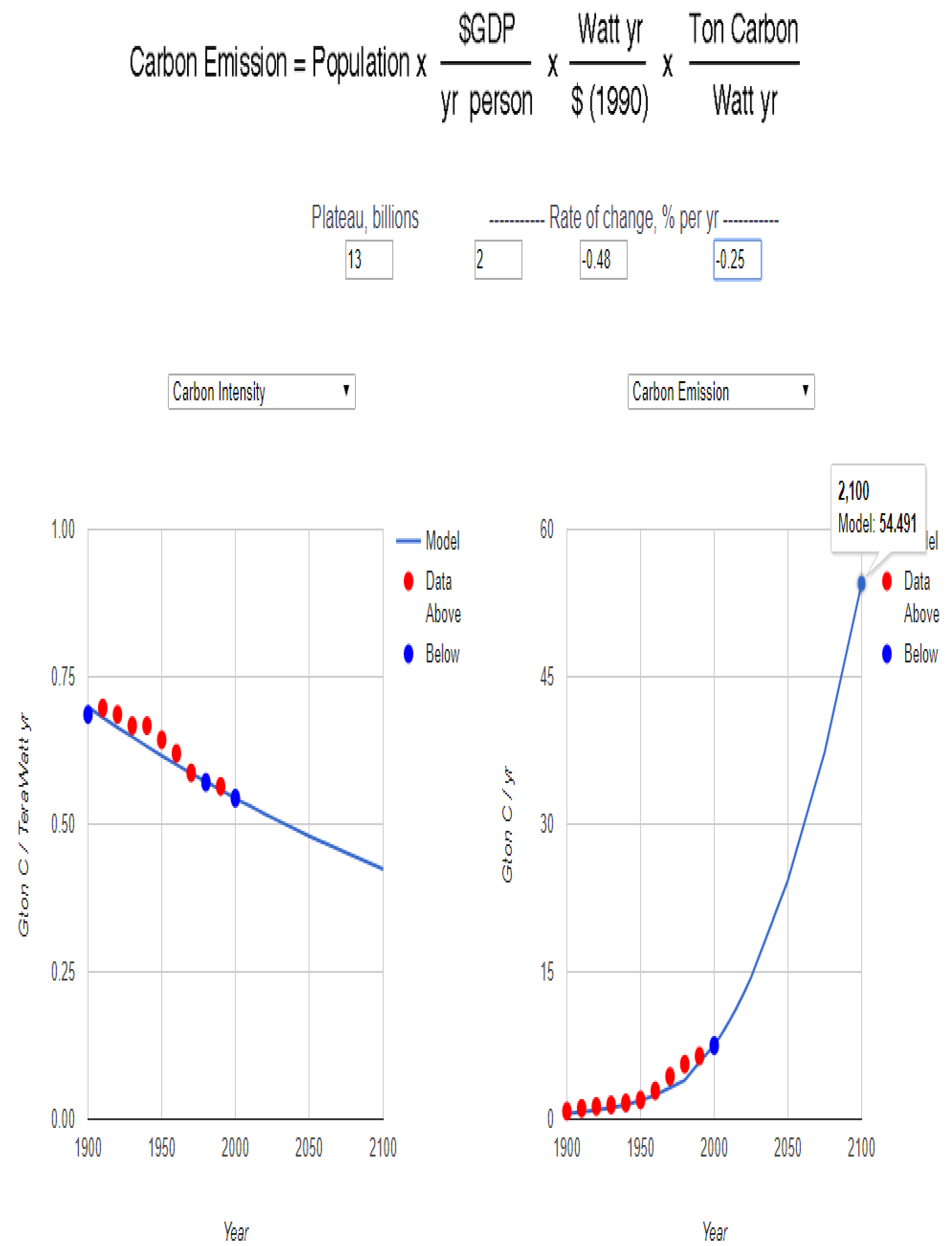

FIGURE 4.51 CARBON EMISSION CURVE FOR ENERGY INTENSITY = -0.48% AND CARBON INTENSITY = -0.25%

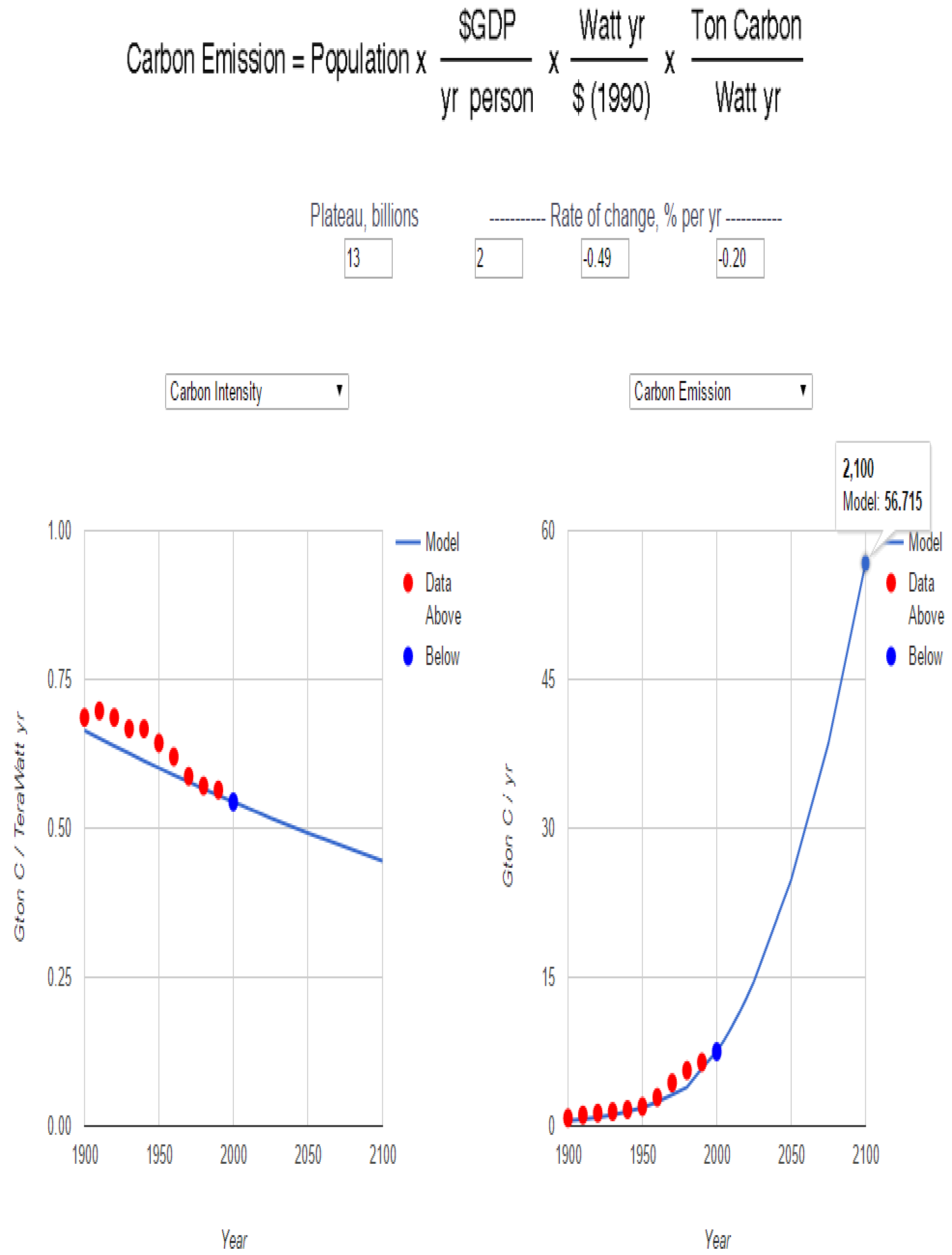

FIGURE 4.52 CARBON EMISSION CURVE FOR ENERGY INTENSITY = -0.49% AND CARBON INTENSITY = -0.20%

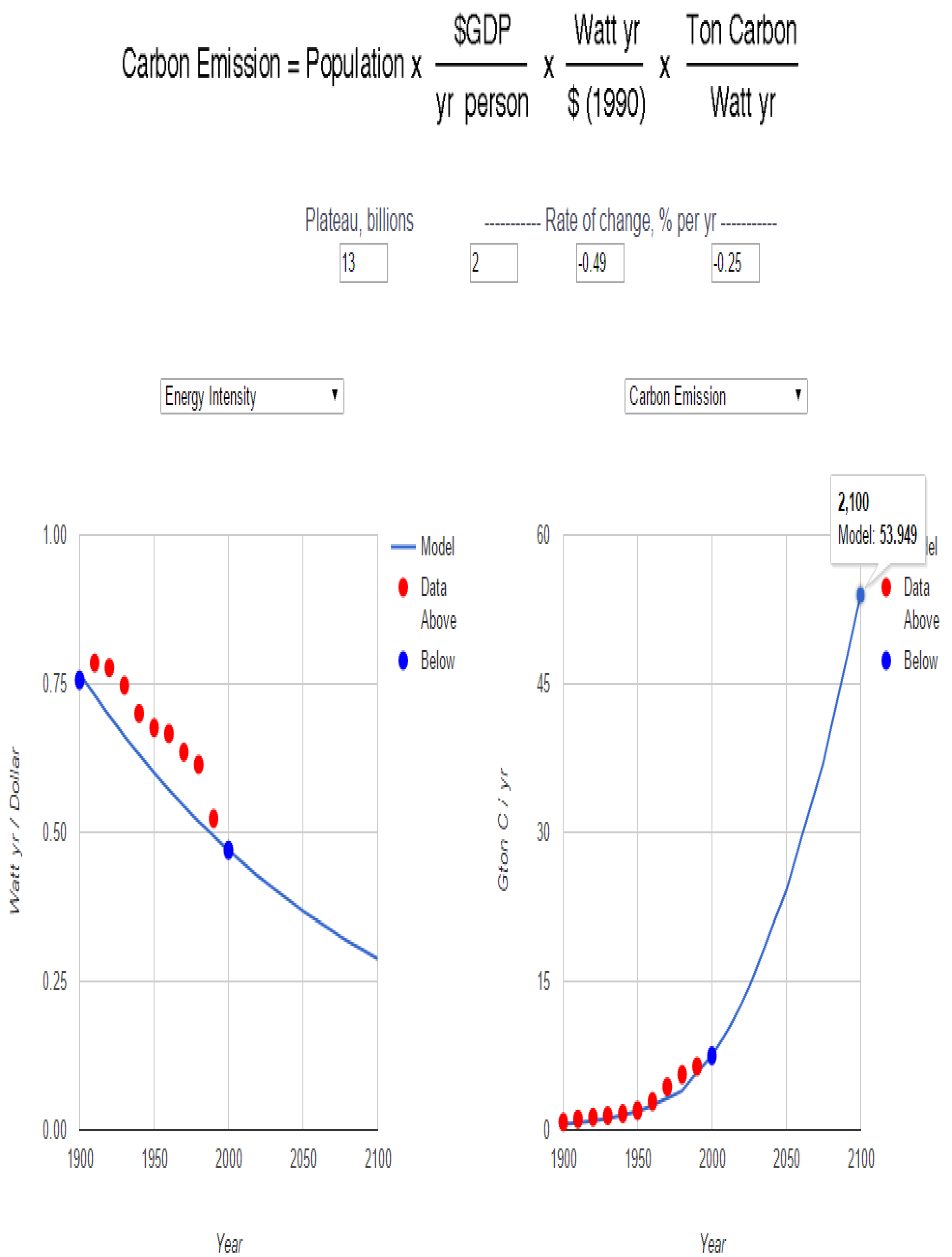

FIGURE 4.53 CARBON EMISSION CURVE FOR ENERGY INTENSITY = -0.49% AND CARBON INTENSITY = -0.25%

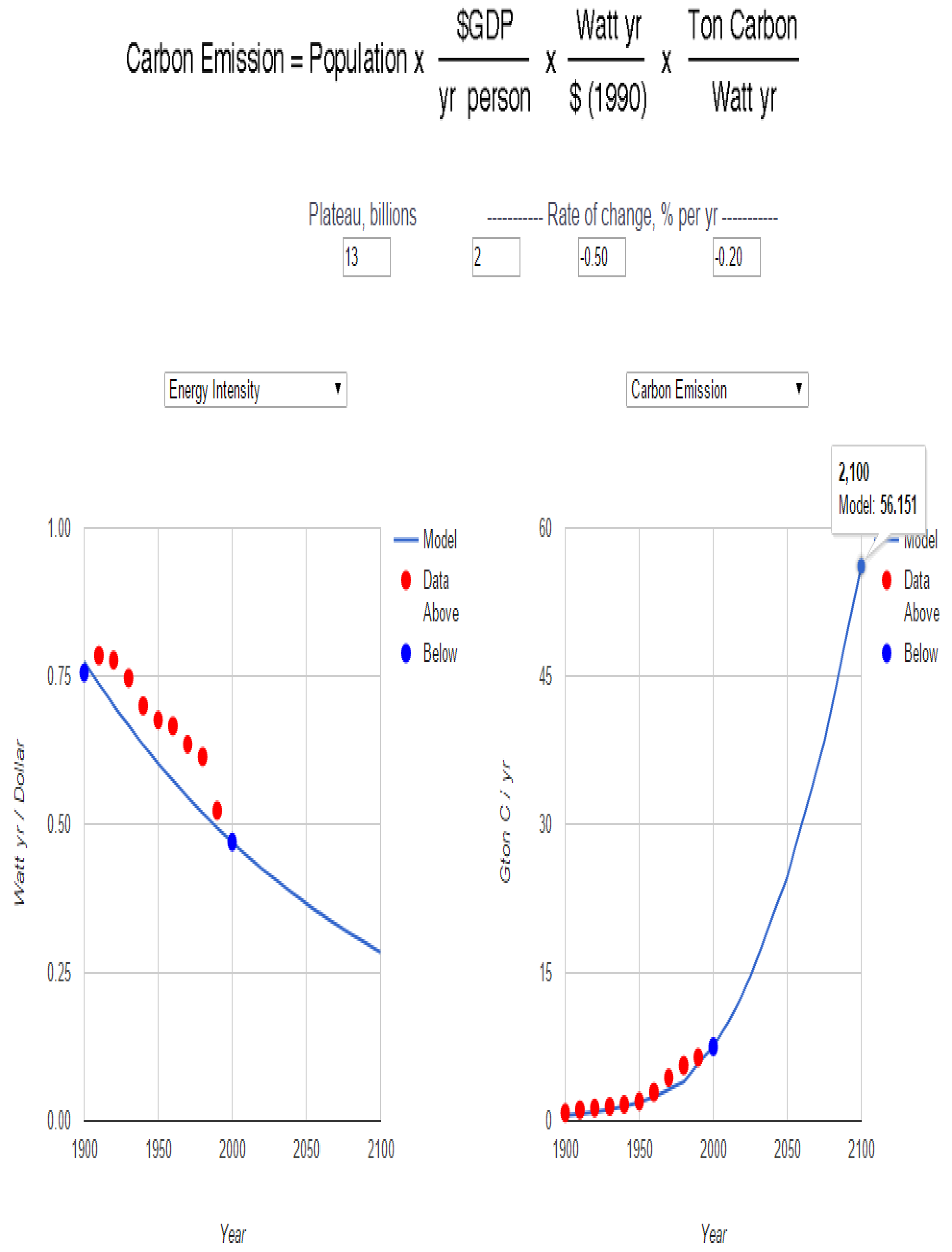

FIGURE 4.54 CARBON EMISSION CURVE FOR ENERGY INTENSITY = -0.50% AND CARBON INTENSITY = -0.20%

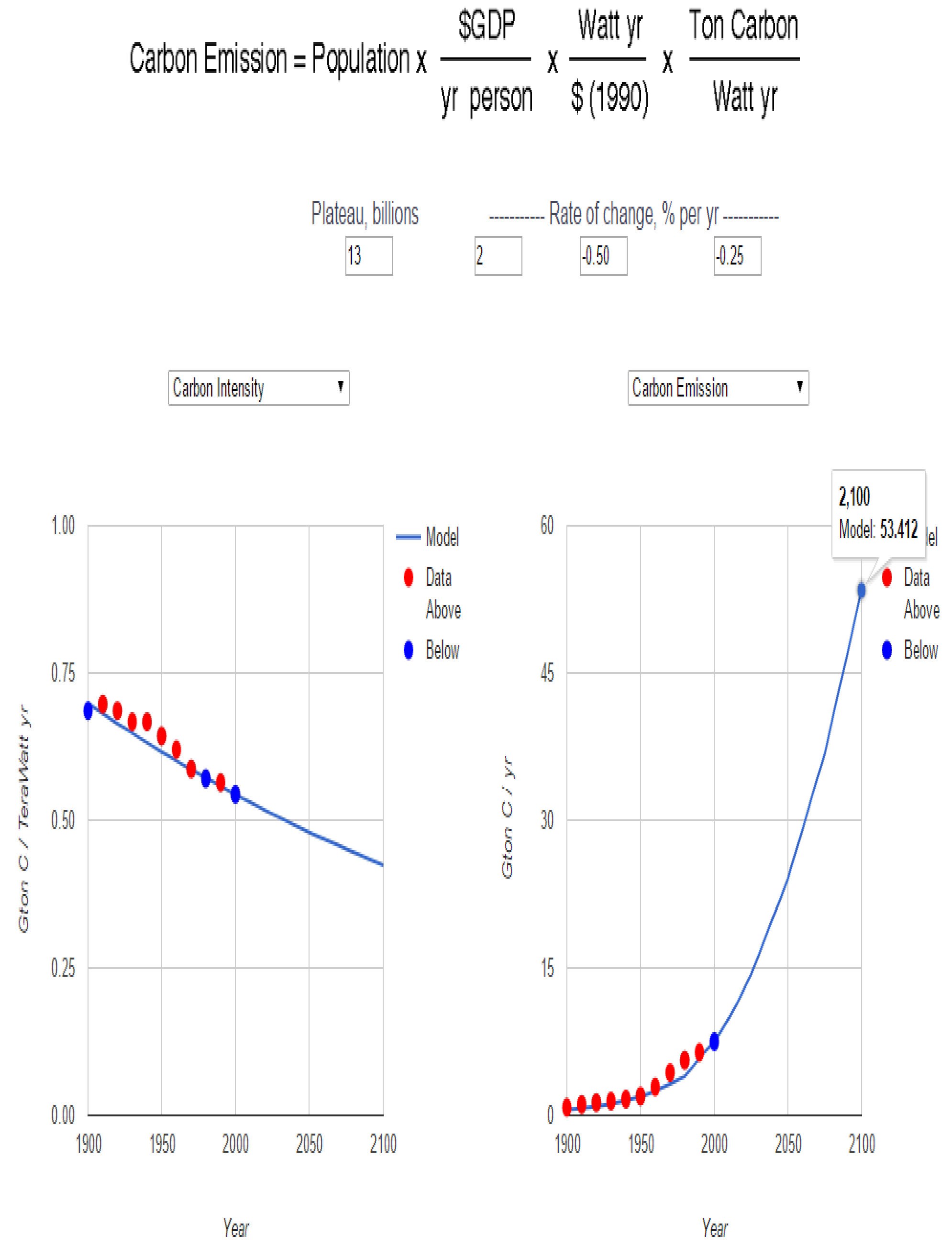

FIGURE 4.55 CARBON EMISSION CURVE FOR ENERGY INTENSITY = -0.50% AND CARBON INTENSITY = -0.25%

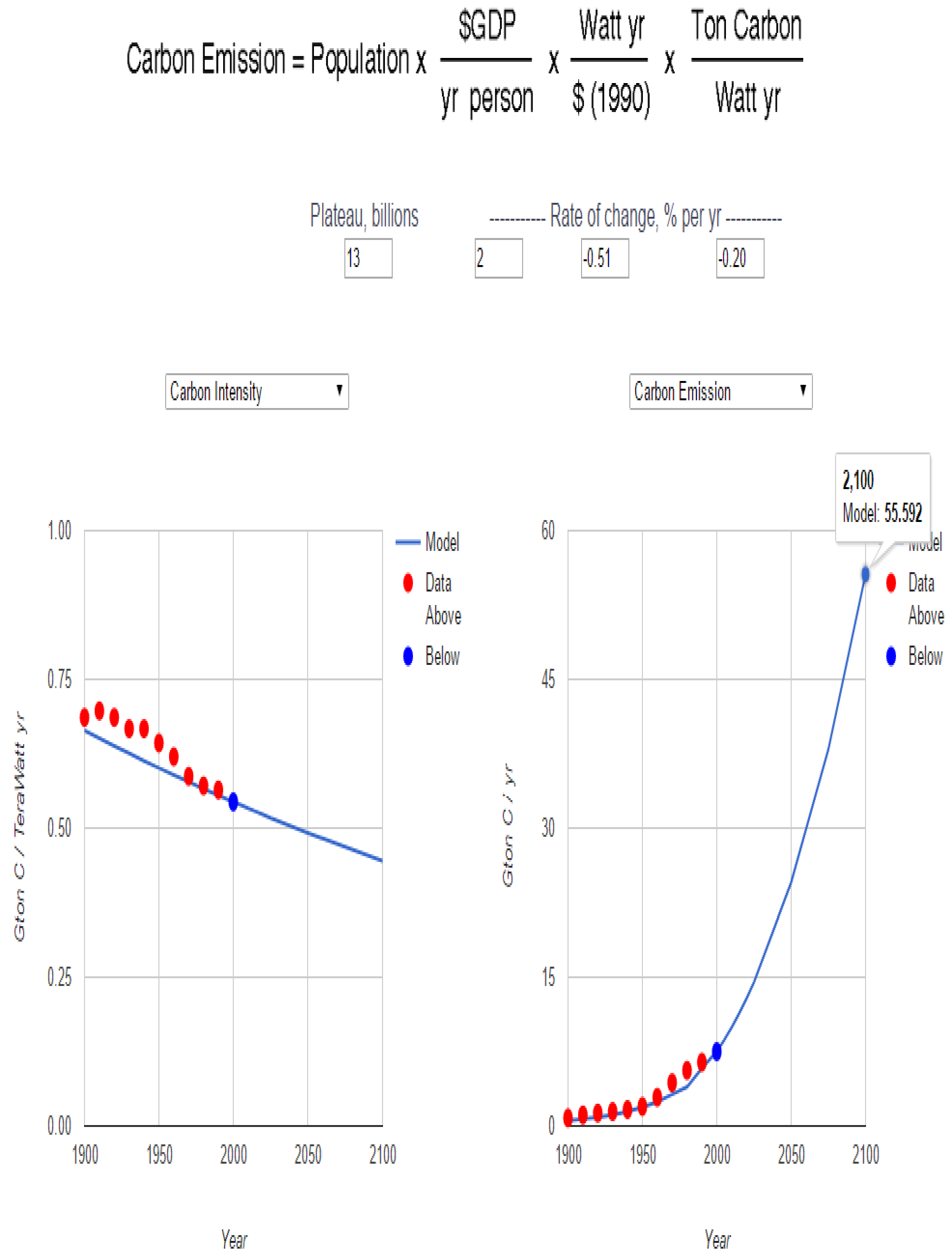

FIGURE 4.56 CARBON EMISSION CURVE FOR ENERGY INTENSITY = -0.51% AND CARBON INTENSITY = -0.20%

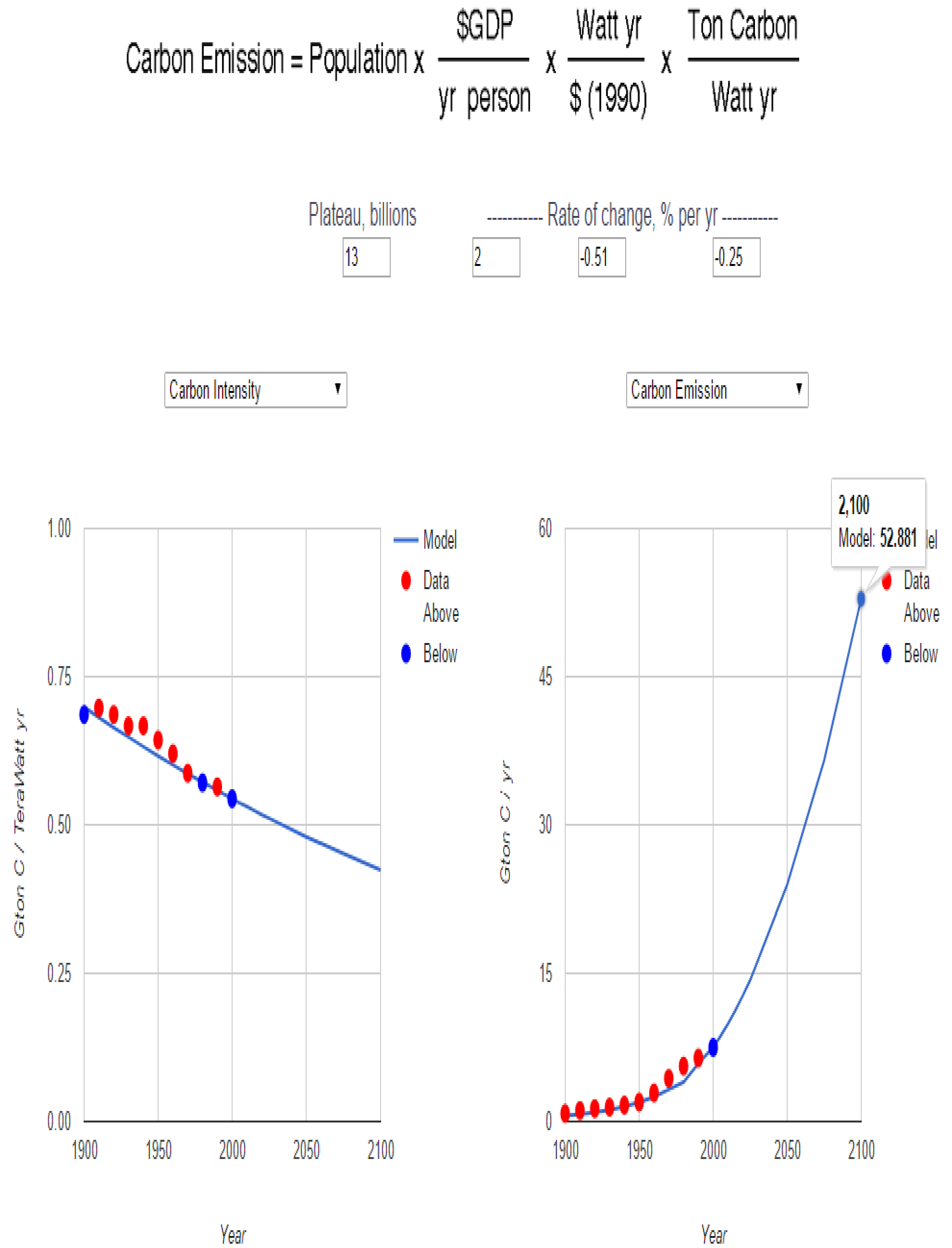

FIGURE 4.57 CARBON EMISSION CURVE FOR ENERGY INTENSITY = -0.51% AND CARBON INTENSITY = -0.25%

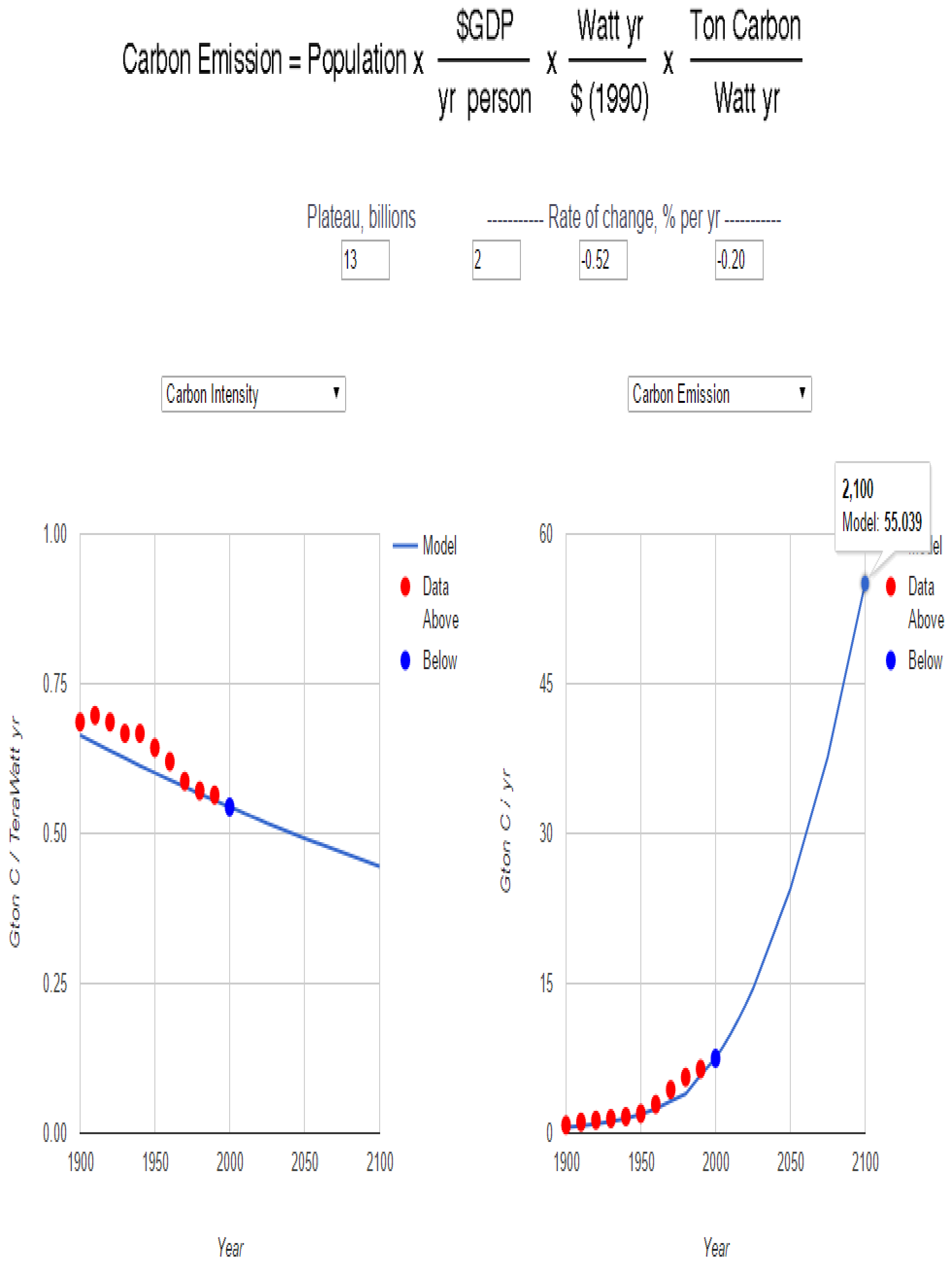

FIGURE 4.58 CARBON EMISSION CURVE FOR ENERGY INTENSITY = -0.52% AND CARBON INTENSITY = -0.20%

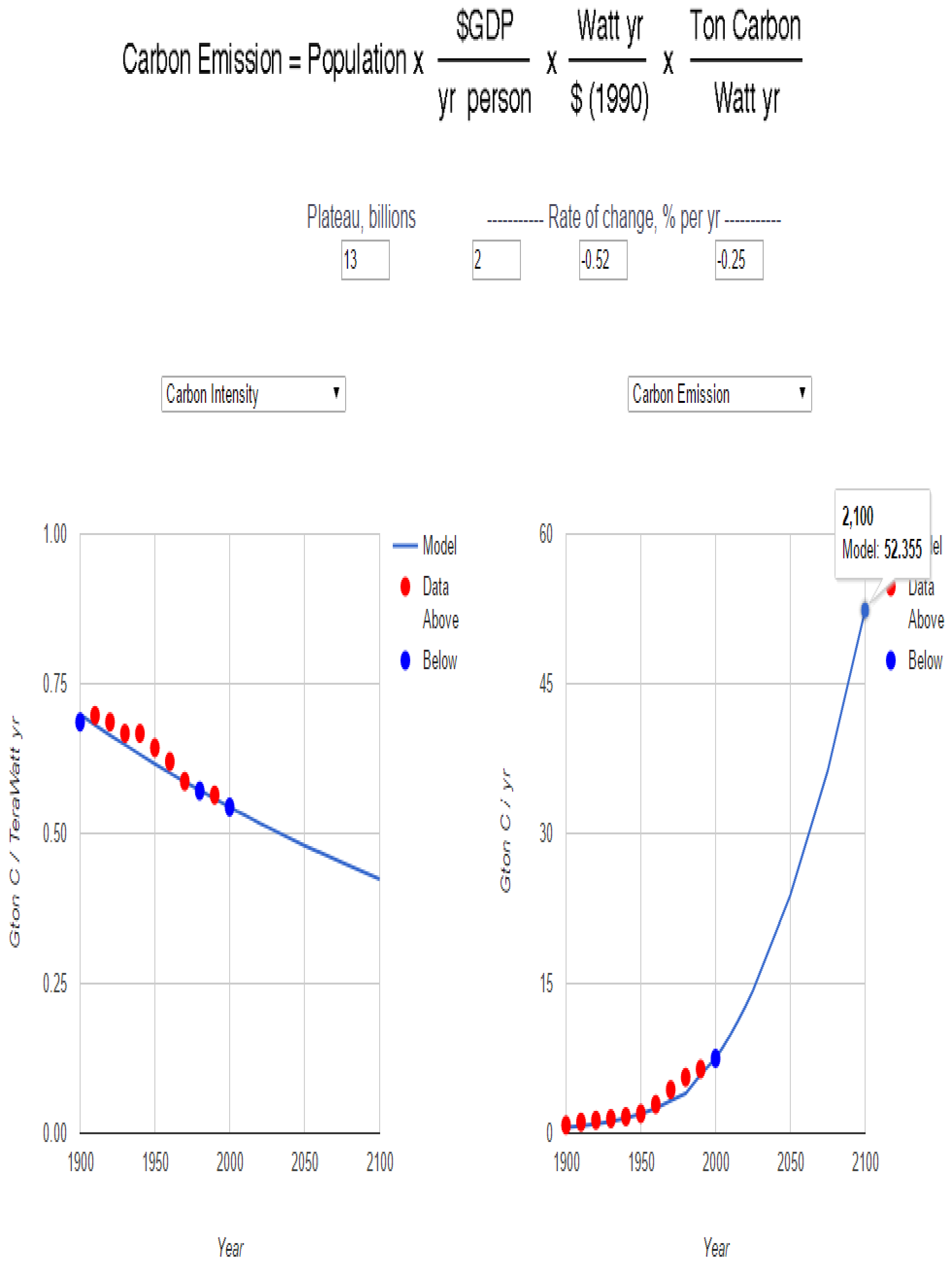

FIGURE 4.59 CARBON EMISSION CURVE FOR ENERGY INTENSITY = -0.52% AND CARBON INTENSITY = -0.25%

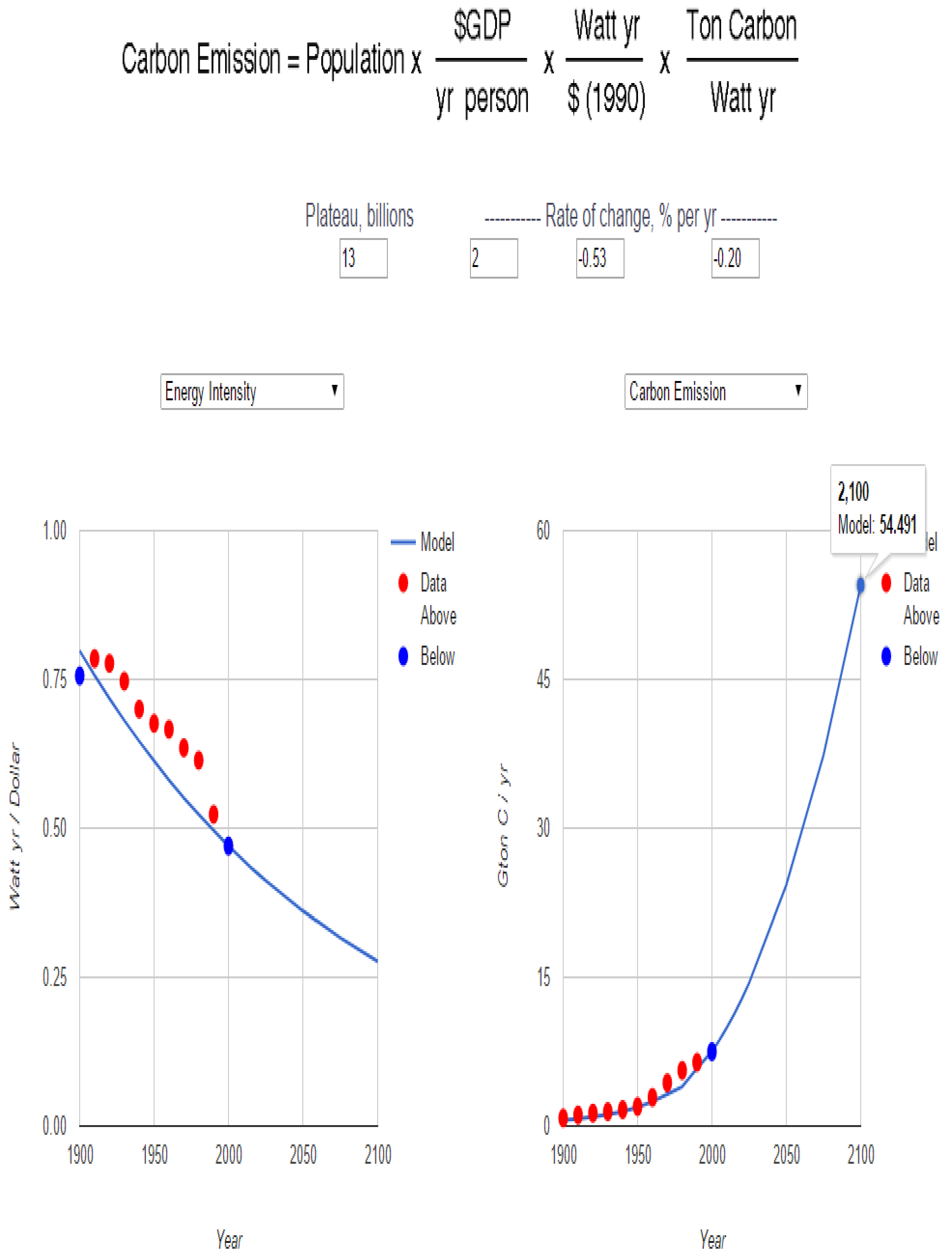

FIGURE 4.60 CARBON EMISSION CURVE FOR ENERGY INTENSITY = -0.53% AND CARBON INTENSITY = -0.20%

$$\text{Carbon Emission} = \text{Population} \times \frac{\$GDP}{\text{yr person}} \times \frac{\text{Watt yr}}{\$\,(1990)} \times \frac{\text{Ton Carbon}}{\text{Watt yr}}$$

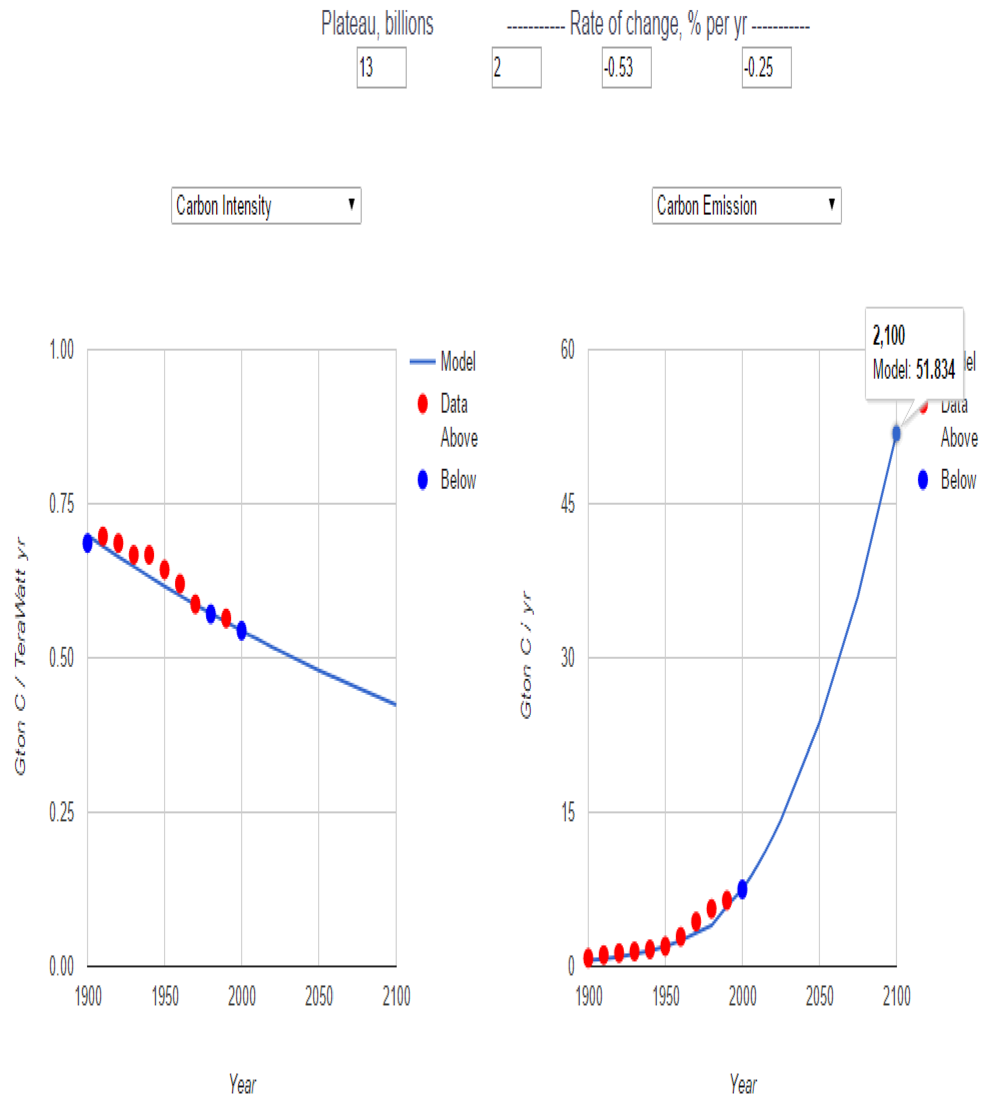

FIGURE 4.61 CARBON EMISSION CURVE FOR ENERGY INTENSITY = -0.53% AND CARBON INTENSITY = -0.25%

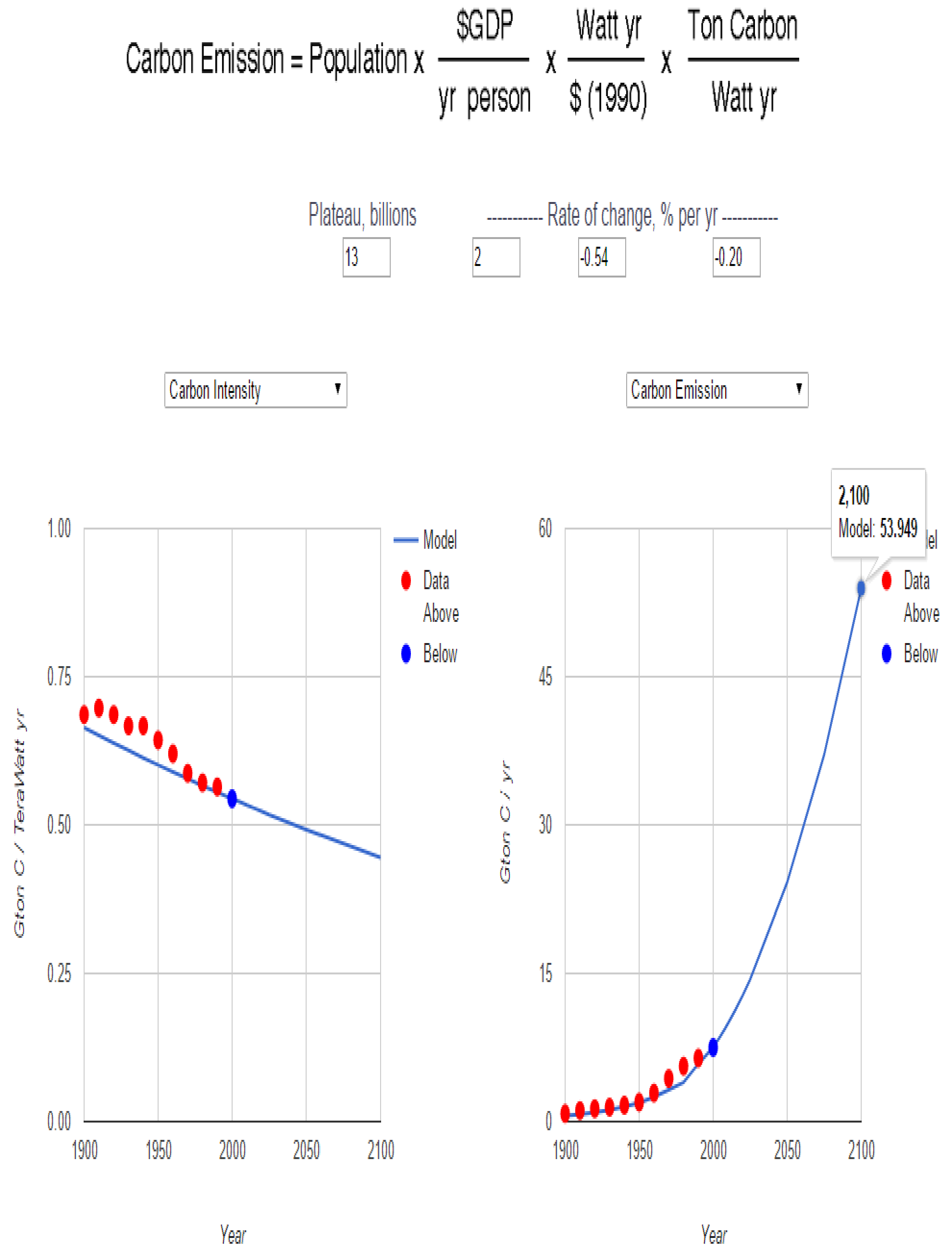

FIGURE 4.62 CARBON EMISSION CURVE FOR ENERGY INTENSITY = -0.54% AND CARBON INTENSITY = -0.20%

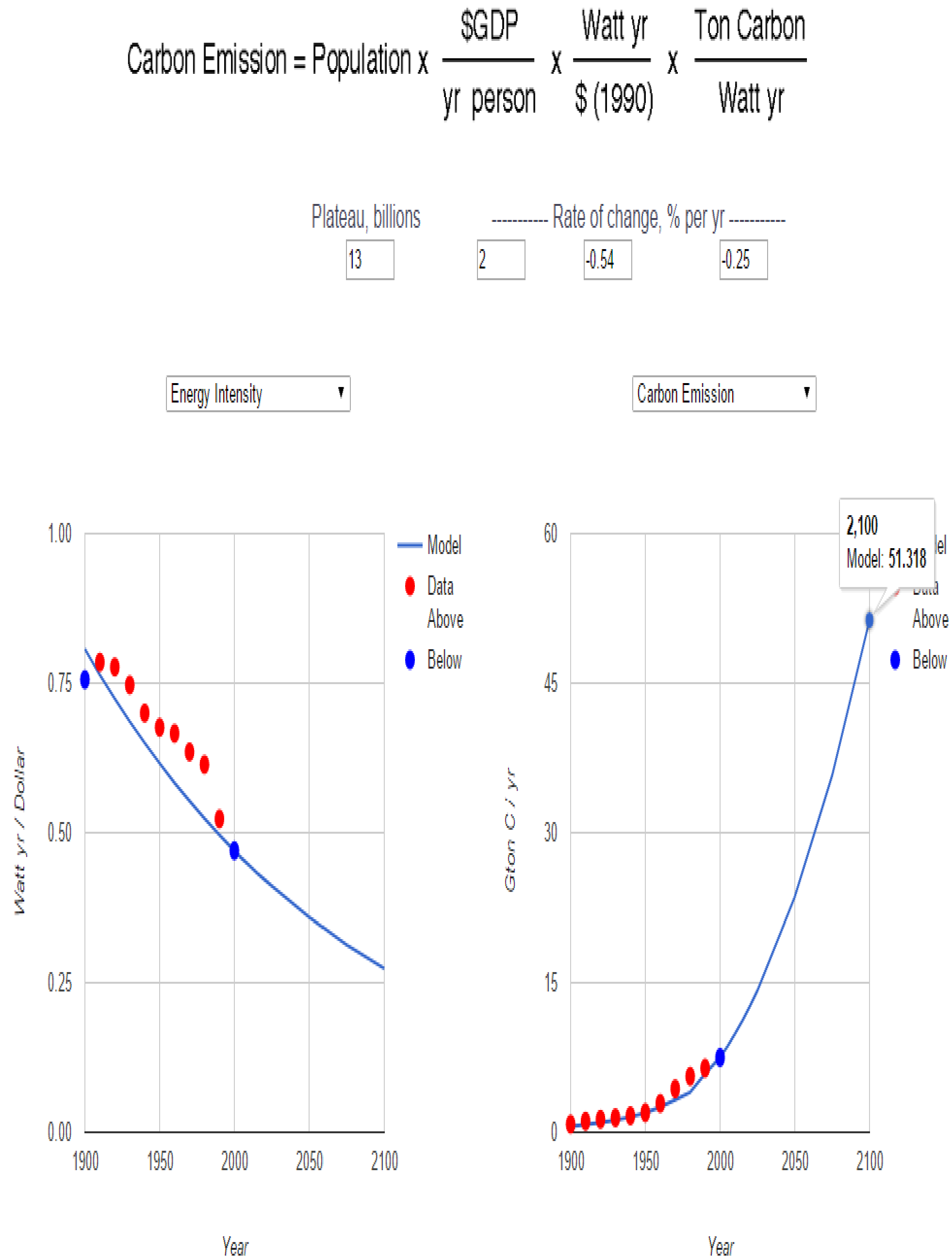

FIGURE 4.63 CARBON EMISSION CURVE FOR ENERGY INTENSITY = -0.54% AND CARBON INTENSITY = -0.25%

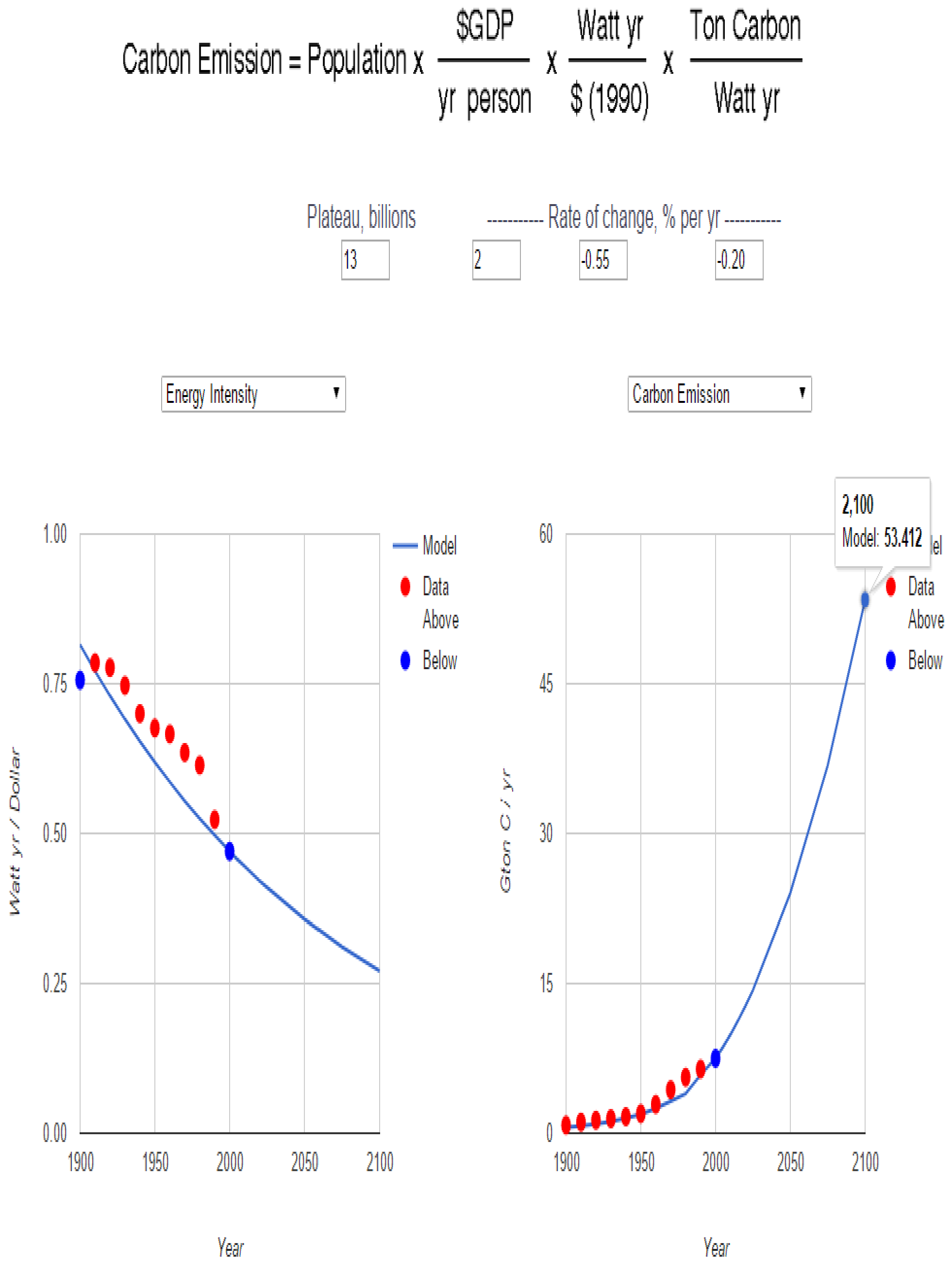

FIGURE 4.64 CARBON EMISSION CURVE FOR ENERGY INTENSITY = -0.55% AND CARBON INTENSITY = -0.20%

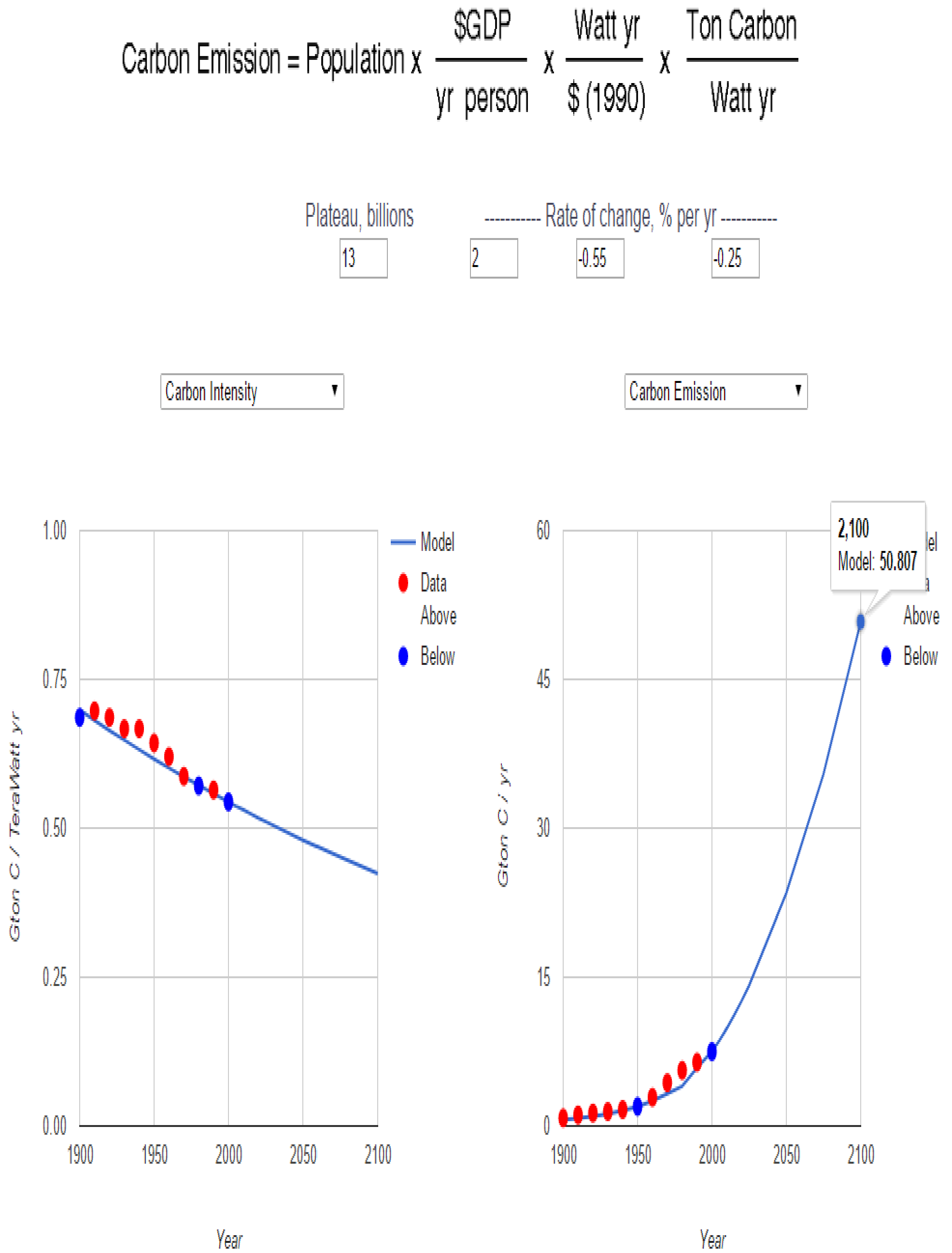

FIGURE 4.65 CARBON EMISSION CURVE FOR ENERGY INTENSITY = -0.55% AND CARBON INTENSITY = -0.25%

TABLE4.1 WORST CASE CARBON EMISSION VALUES FOR VARIOUS MODEL PARAMETERS

POPULATION (Billions)	GDP PER CAPITA (%)	ENERGY INTENSITY (%)	CARBON INTENSITY (%)	CARBON EMISSIONS (GTonC/year)
13	2	-0.45	-0.20	59.03
13	2	-0.45	-0.25	56.151
13	2	-0.46	-0.20	58.442
13	2	-0.46	-0.25	55.592
13	2	-0.47	-0.20	57.861
13	2	-0.47	-0.25	55.039
13	2	-0.48	-0.20	57.285
13	2	-0.48	-0.25	54.491
13	2	-0.49	-0.20	56.715
13	2	-0.49	-0.25	53.949
13	2	-0.50	-0.20	56.151
13	2	-0.50	-0.25	53.412
13	2	-0.51	-0.20	55.592
13	2	-0.51	-0.25	52.881
13	2	-0.52	-0.20	58.039
13	2	-0.52	-0.25	52.355
13	2	-0.53	-0.20	54.491
13	2	-0.53	-0.25	51.834
13	2	-0.54	-0.20	53.949
13	2	-0.54	-0.25	51.318
13	2	-0.55	-0.20	53.412
13	2	-0.55	-0.25	50.807

4.3 PRESENTING A STABILIZATION PATHWAY

1) Population = 11 billion

2) GDP = 1.6%

3) Energy Intensity = [-0.55,-0.45]

4) Carbon Intensity = [-3.5,-3.1]

These are the values obtained to stabilize the carbon dioxide concentrations to 450 ppm.

While presenting the stabilization pathway, the first two values have been discussed already in the methodology section. The third value i.e. the energy intensity one has been kept the same as the previous case. For the carbon intensity range, it is seen in the model that for the values which are beyond -3.1 like -3.0, -2.9, -2.8 etc, the CO2 concentrations are above 450 ppm, so they are automatically discarded. But, for values beyond -3.5 like -3.6,-3.7 etc, the concentration does not go beyond 450 ppm, but, still those values have not been taken as they do not belong to our best fit range and also would be almost impossible to achieve in the future. It is because according to IPCC Fifth Assessment Report, the historical trend for carbon intensity decline has been found as -0.8%. So, even the predicted range is hard to achieve, let alone the values beyond that.

4.3.1 STABILIZATION PATHWAY FIGURES

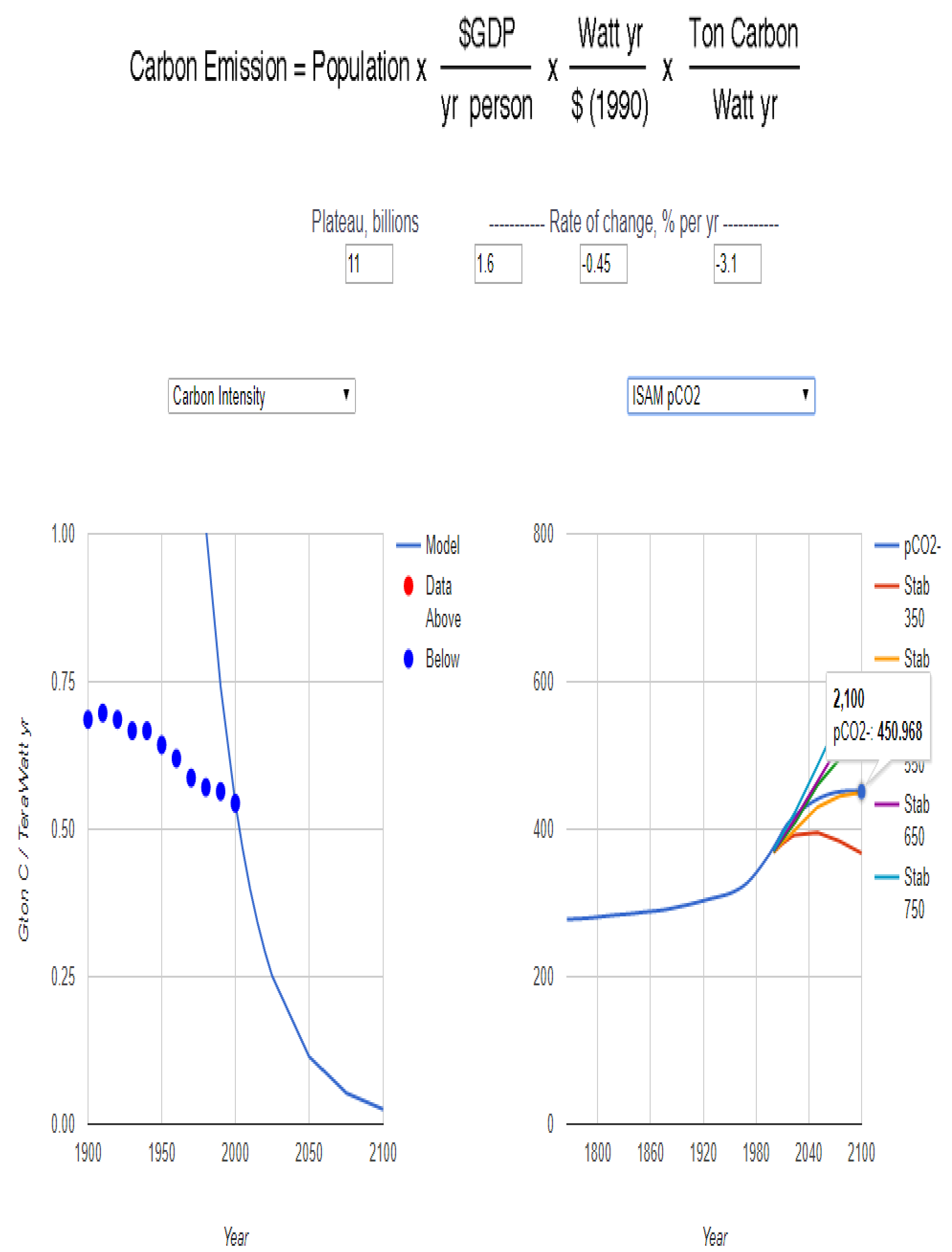

FIGURE 4.66 CARBON DIOXIDE CONCENTRATION CURVE FOR ENERGY INTENSITY = -0.45% AND CARBON INTENSITY = -3.1%

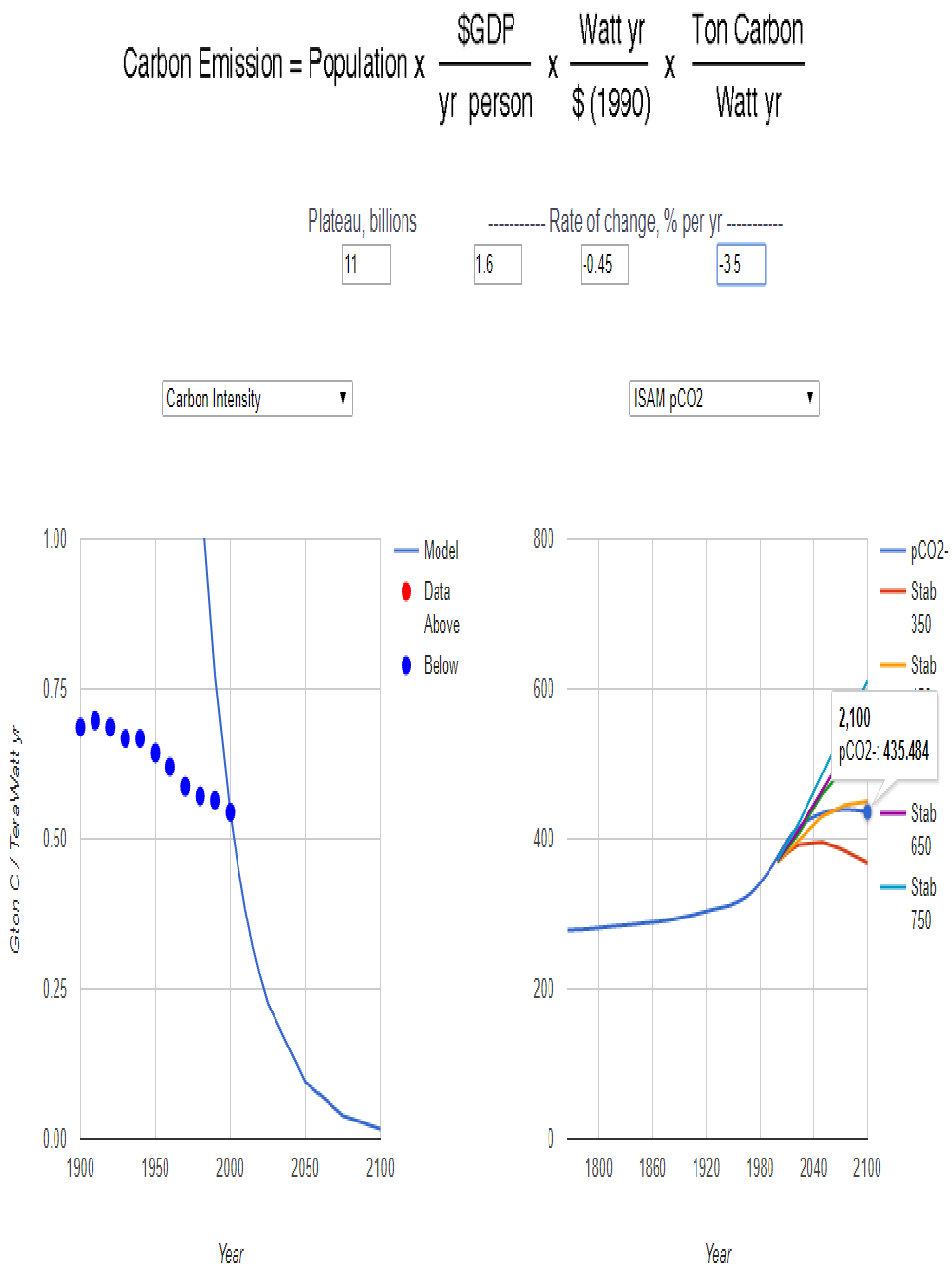

FIGURE 4.67 CARBON DIOXIDE CONCENTRATION CURVE FOR ENERGY INTENSITY = -0.45% AND CARBON INTENSITY = -3.5%

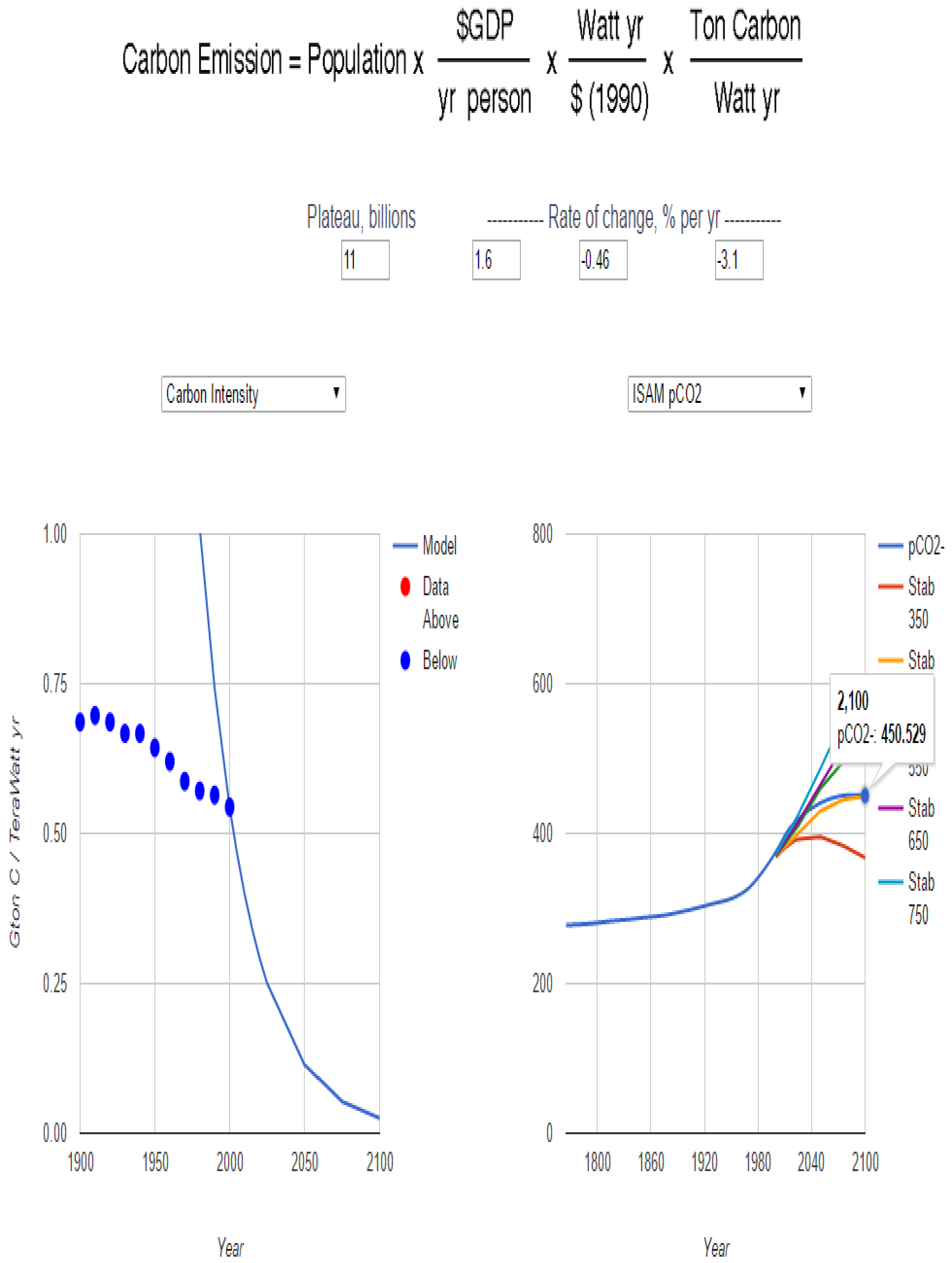

FIGURE 4.68 CARBON DIOXIDE CONCENTRATION CURVE FOR ENERGY INTENSITY = -0.46% AND CARBON INTENSITY = -3.1%

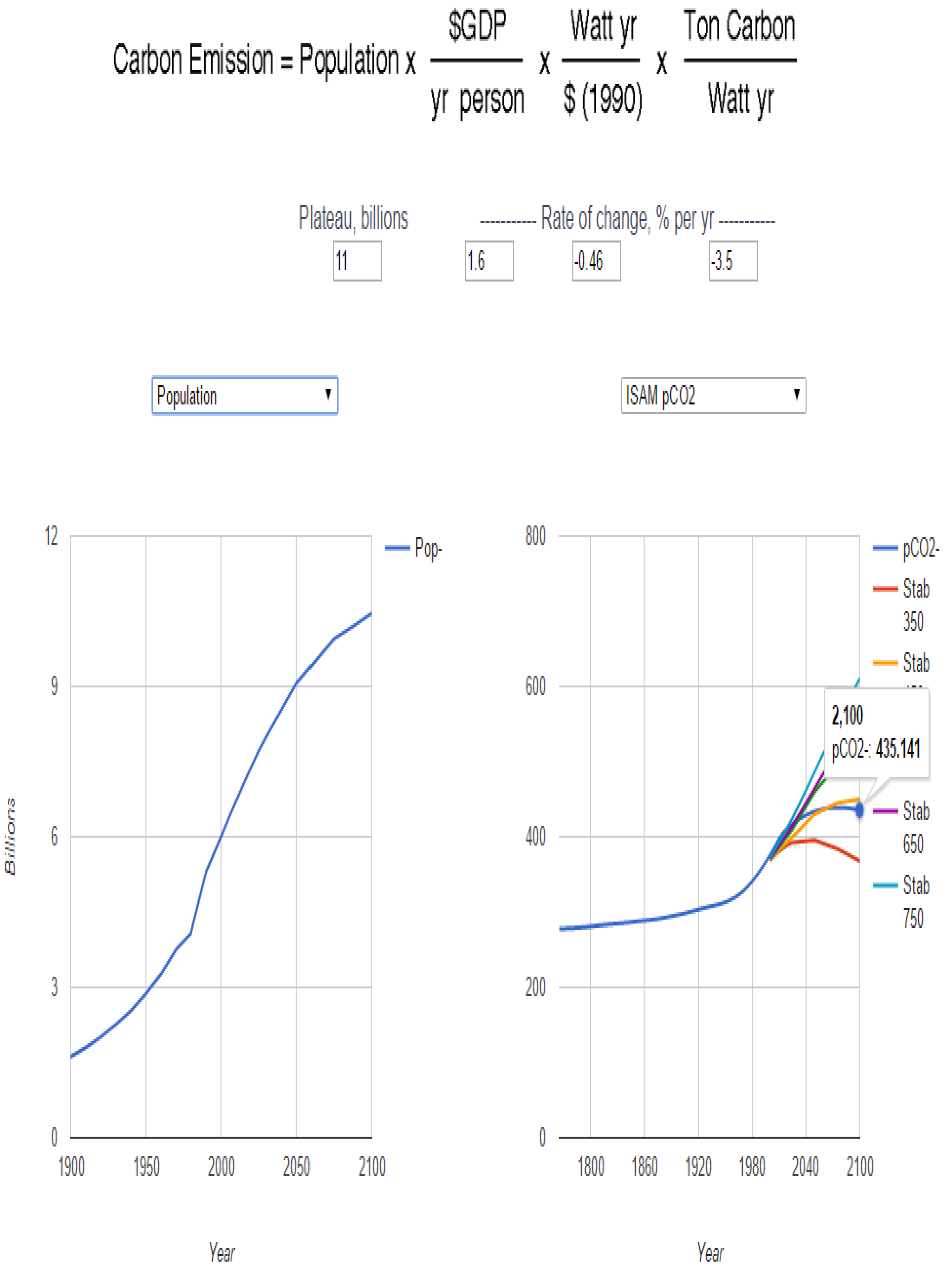

FIGURE 4.69 CARBON DIOXIDE CONCENTRATION CURVE FOR ENERGY INTENSITY = -0.46% AND CARBON INTENSITY = -3.5%

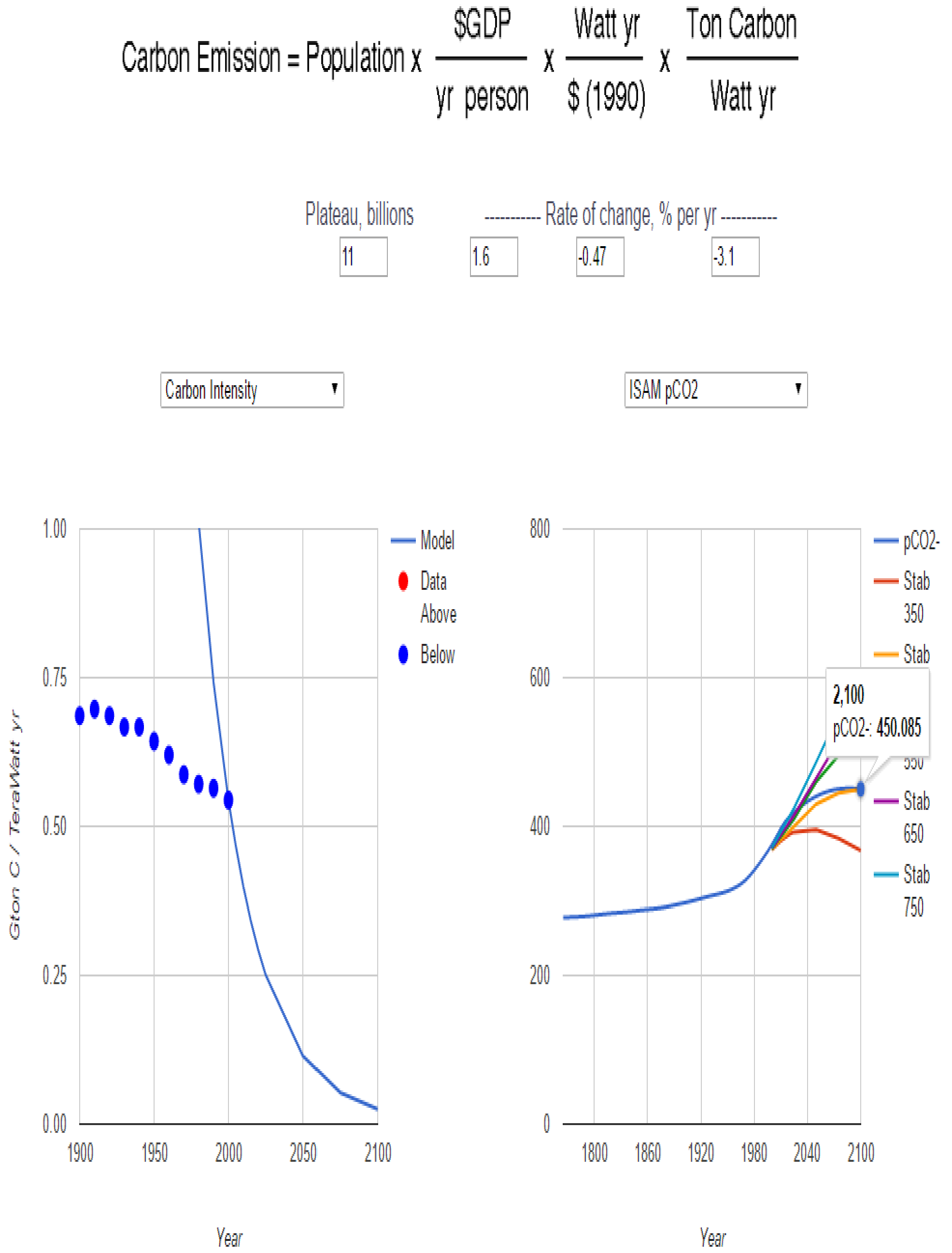

FIGURE 4.70 CARBON DIOXIDE CONCENTRATION CURVE FOR ENERGY INTENSITY = - 0.47% AND CARBON INTENSITY = -3.1%

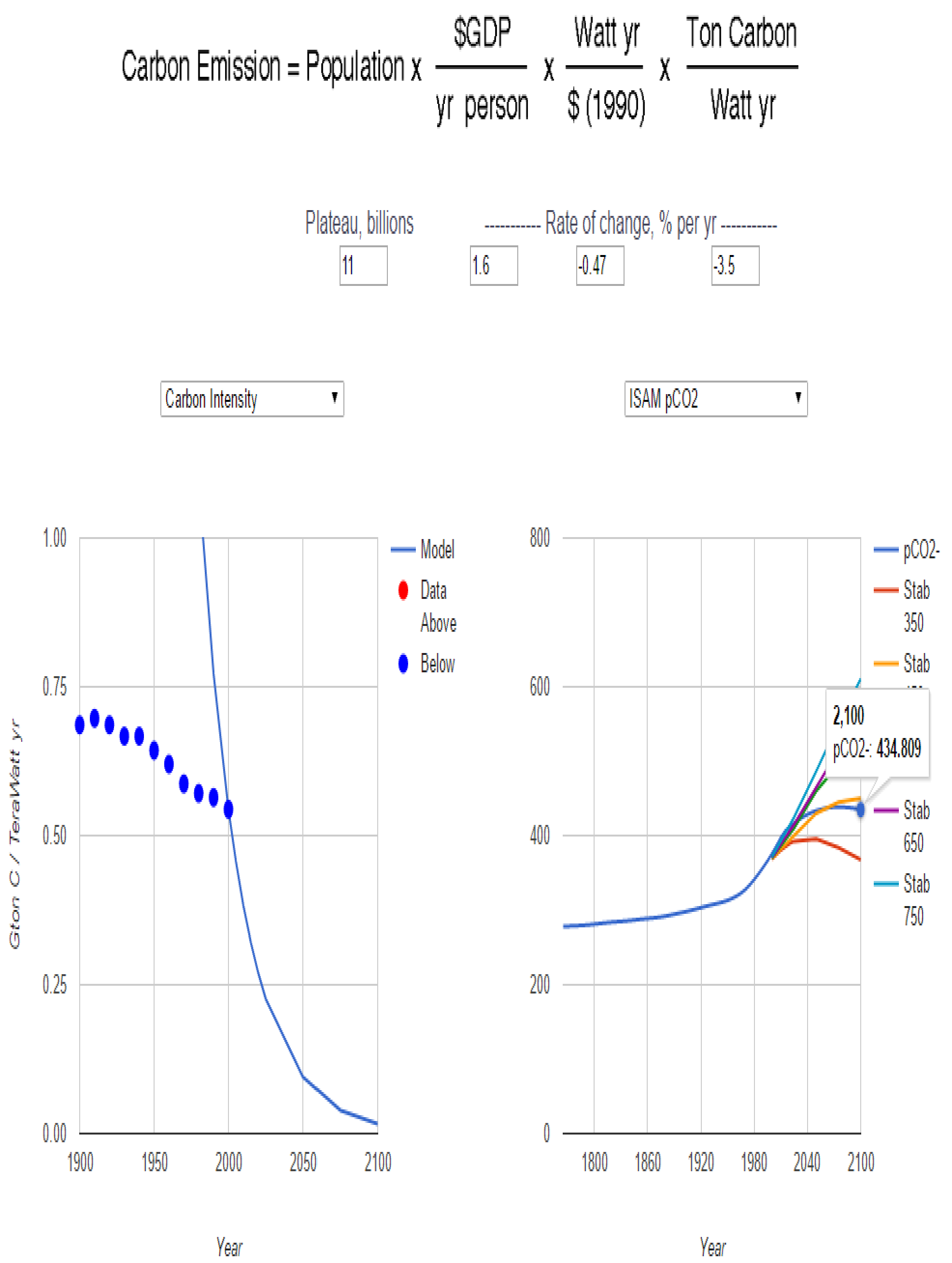

FIGURE 4.71 CARBON DIOXIDE CONCENTRATION CURVE FOR ENERGY INTENSITY = -0.47% AND CARBON INTENSITY = -3.5%

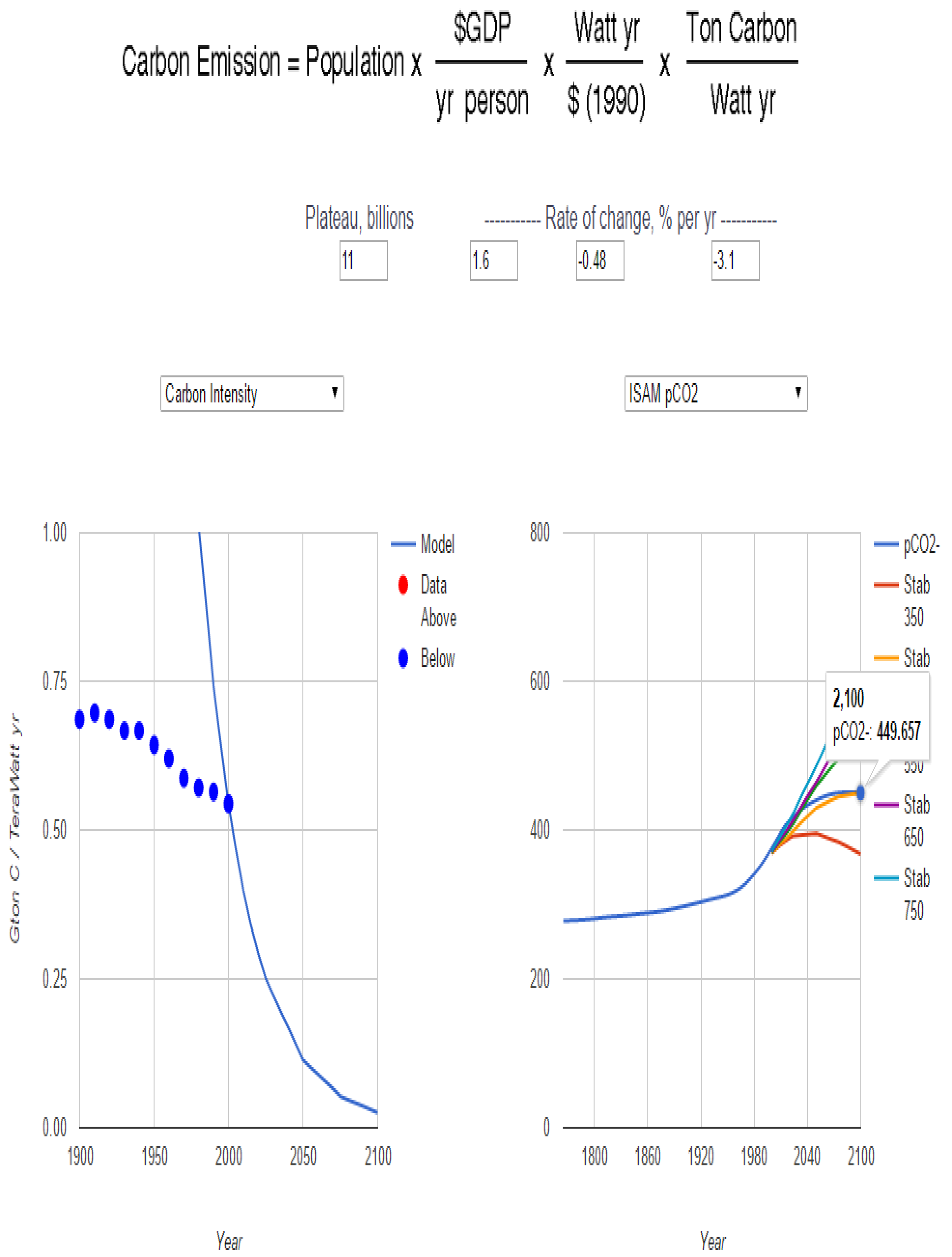

FIGURE 4.72 CARBON DIOXIDE CONCENTRATION CURVE FOR ENERGY INTENSITY = -0.48% AND CARBON INTENSITY = -3.1%

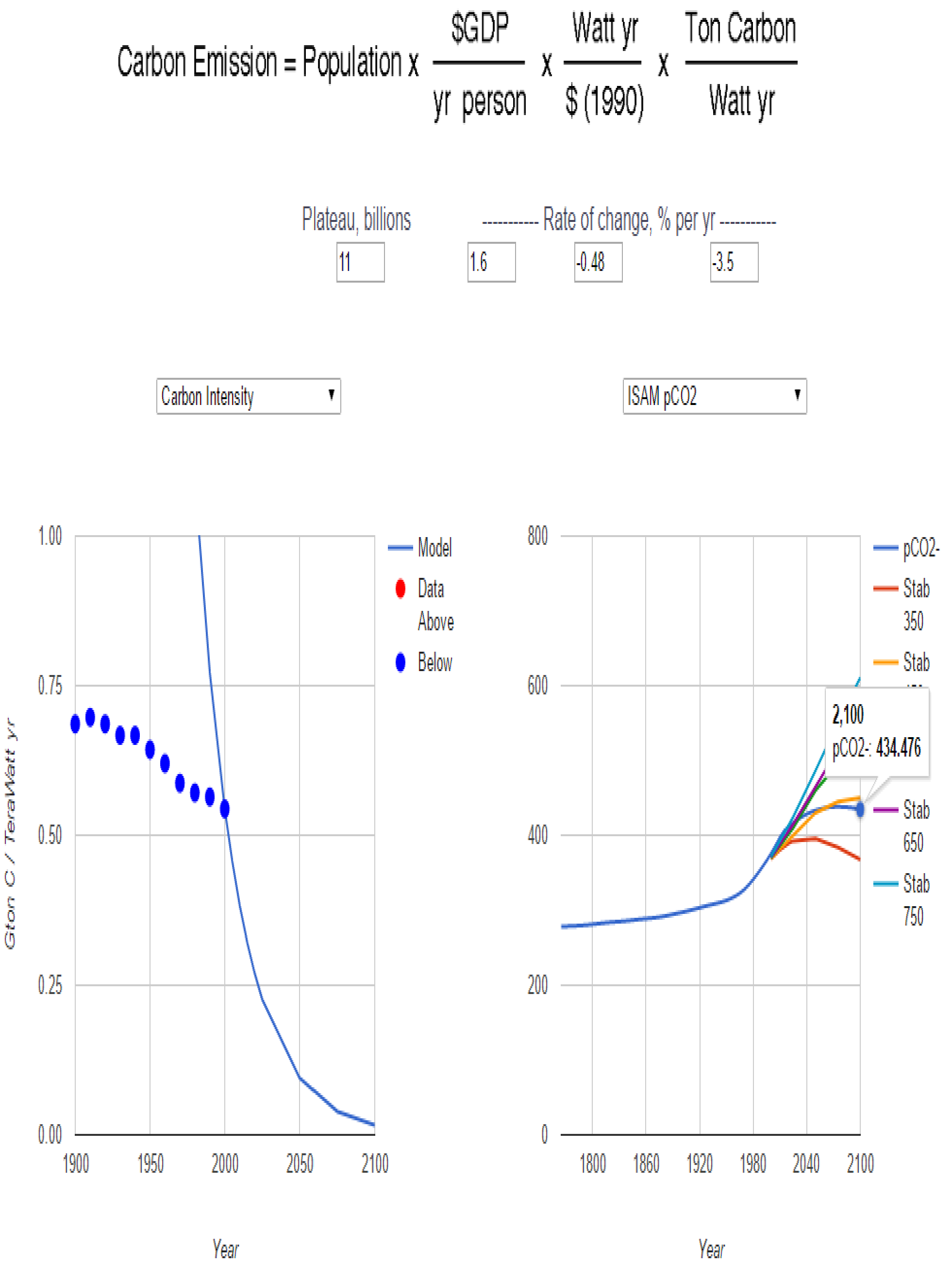

FIGURE 4.73 CARBON DIOXIDE CONCENTRATION CURVE FOR ENERGY INTENSITY = -0.48% AND CARBON INTENSITY = -3.5%

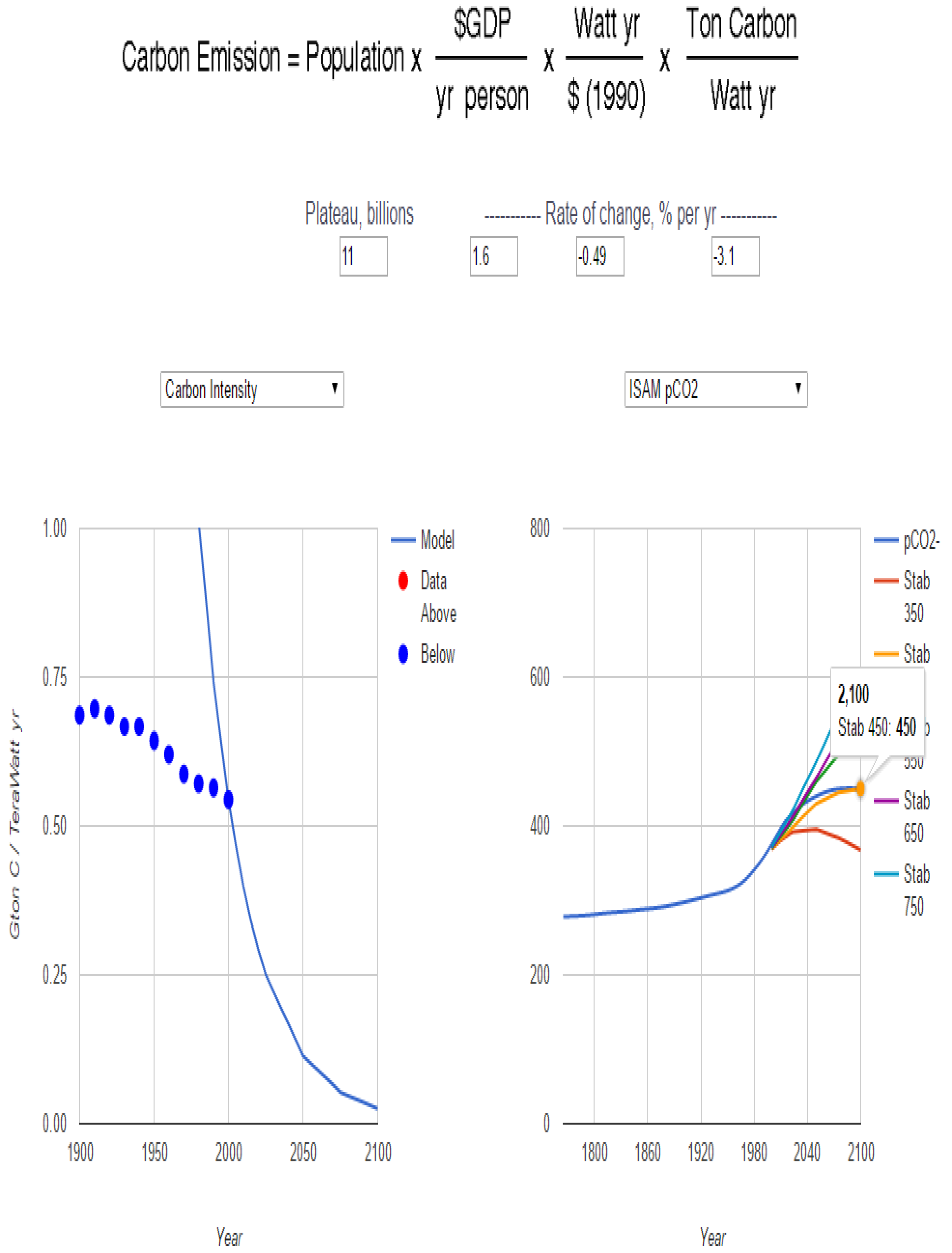

FIGURE 4.74 CARBON DIOXIDE CONCENTRATION CURVE FOR ENERGY INTENSITY = -0.49% AND CARBON INTENSITY = -3.1%

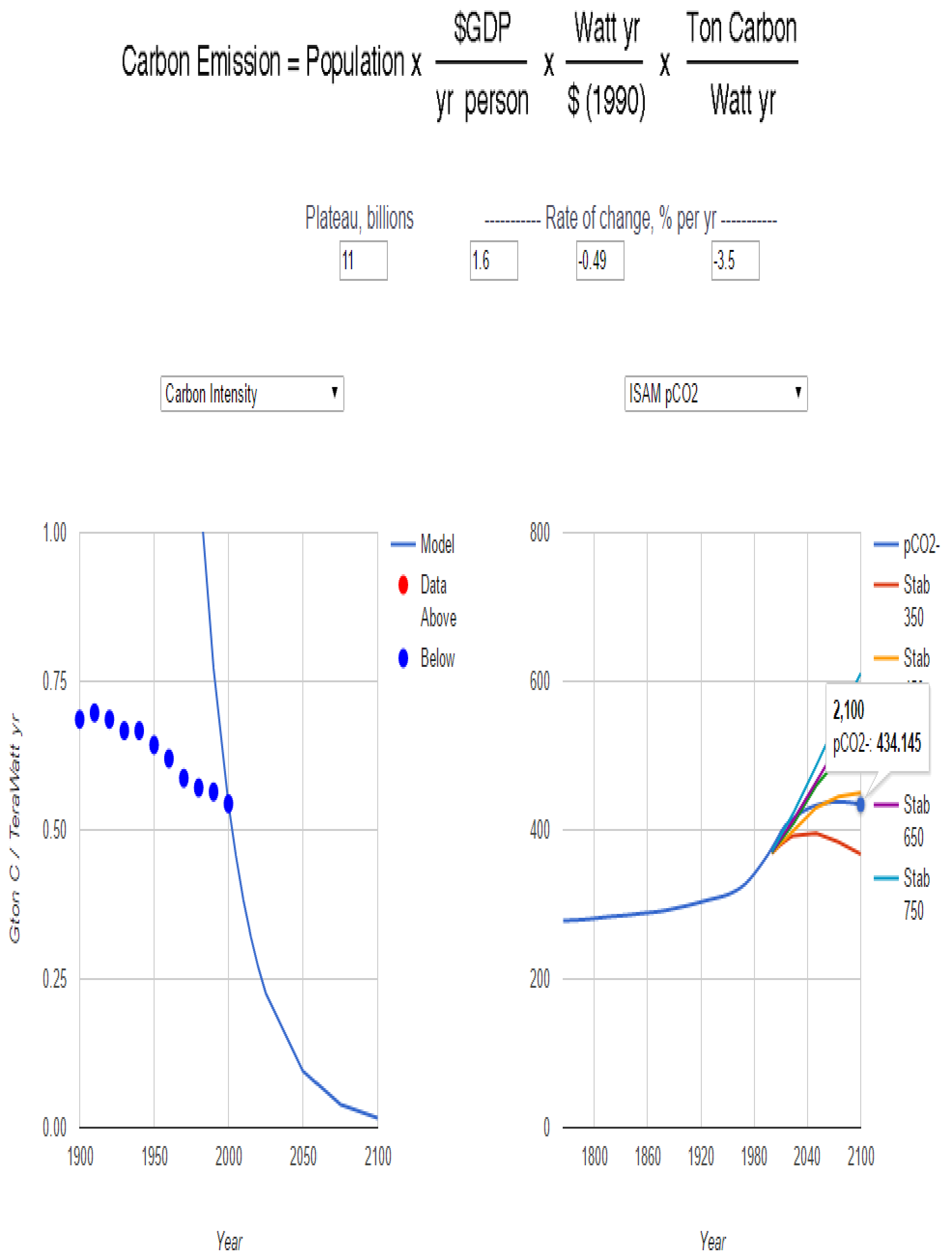

FIGURE 4.75 CARBON DIOXIDE CONCENTRATION CURVE FOR ENERGY INTENSITY = -0.49% AND CARBON INTENSITY = -3.5%

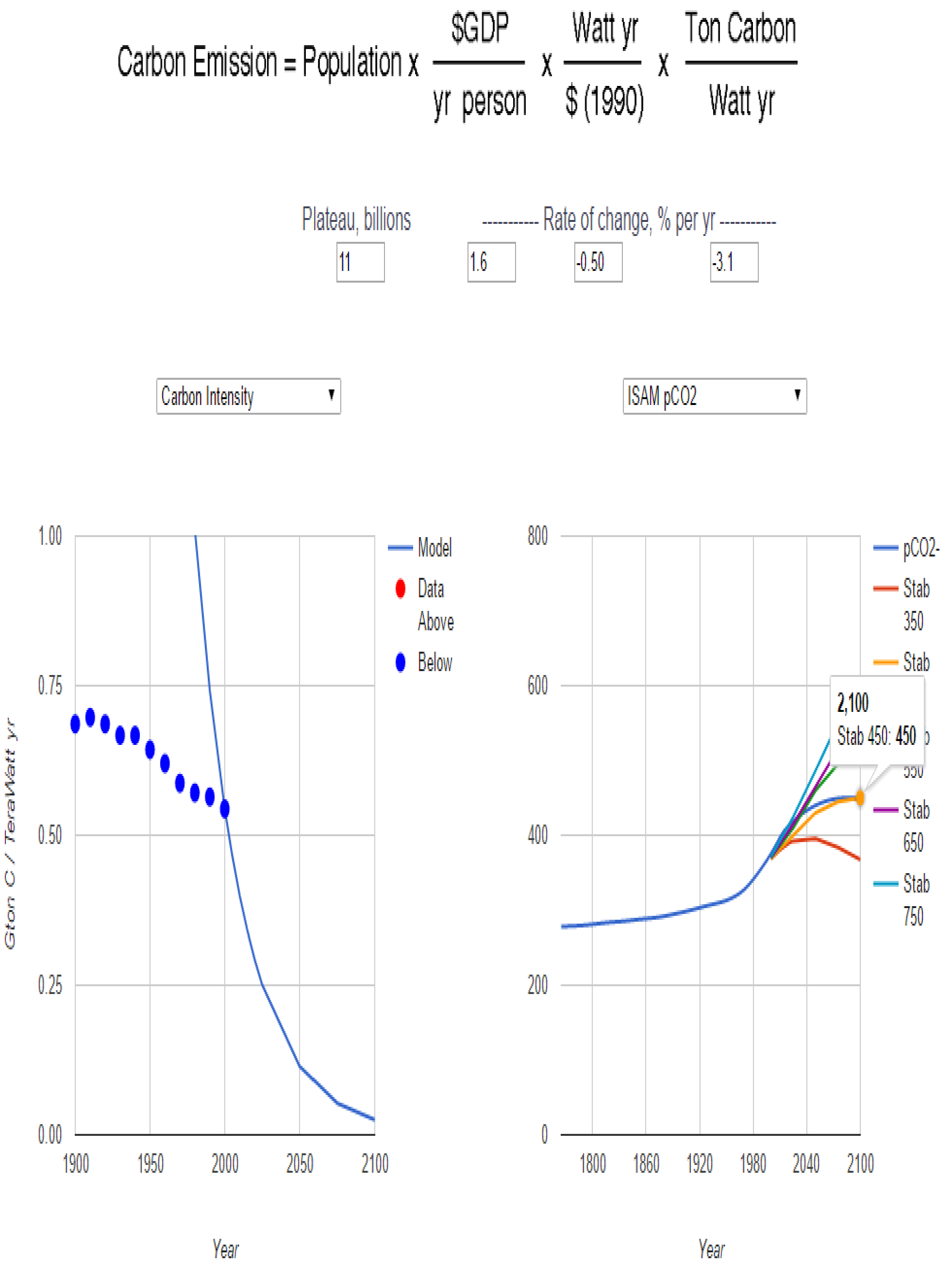

FIGURE 4.76 CARBON DIOXIDE CONCENTRATION CURVE FOR ENERGY INTENSITY = -0.50% AND CARBON INTENSITY = -3.1%

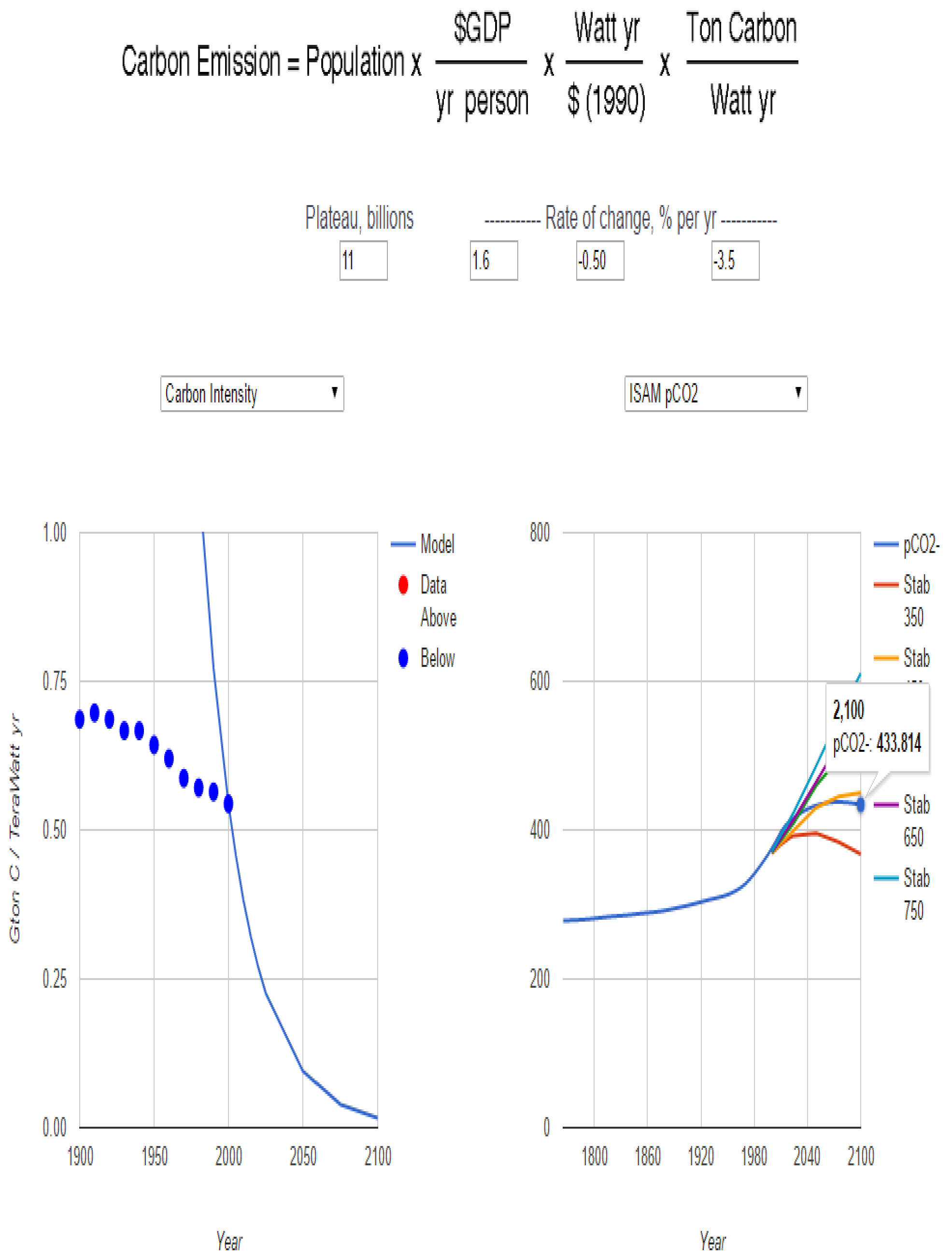

FIGURE 4.77 CARBON DIOXIDE CONCENTRATION CURVE FOR ENERGY INTENSITY = -0.50% AND CARBON INTENSITY = -3.5%

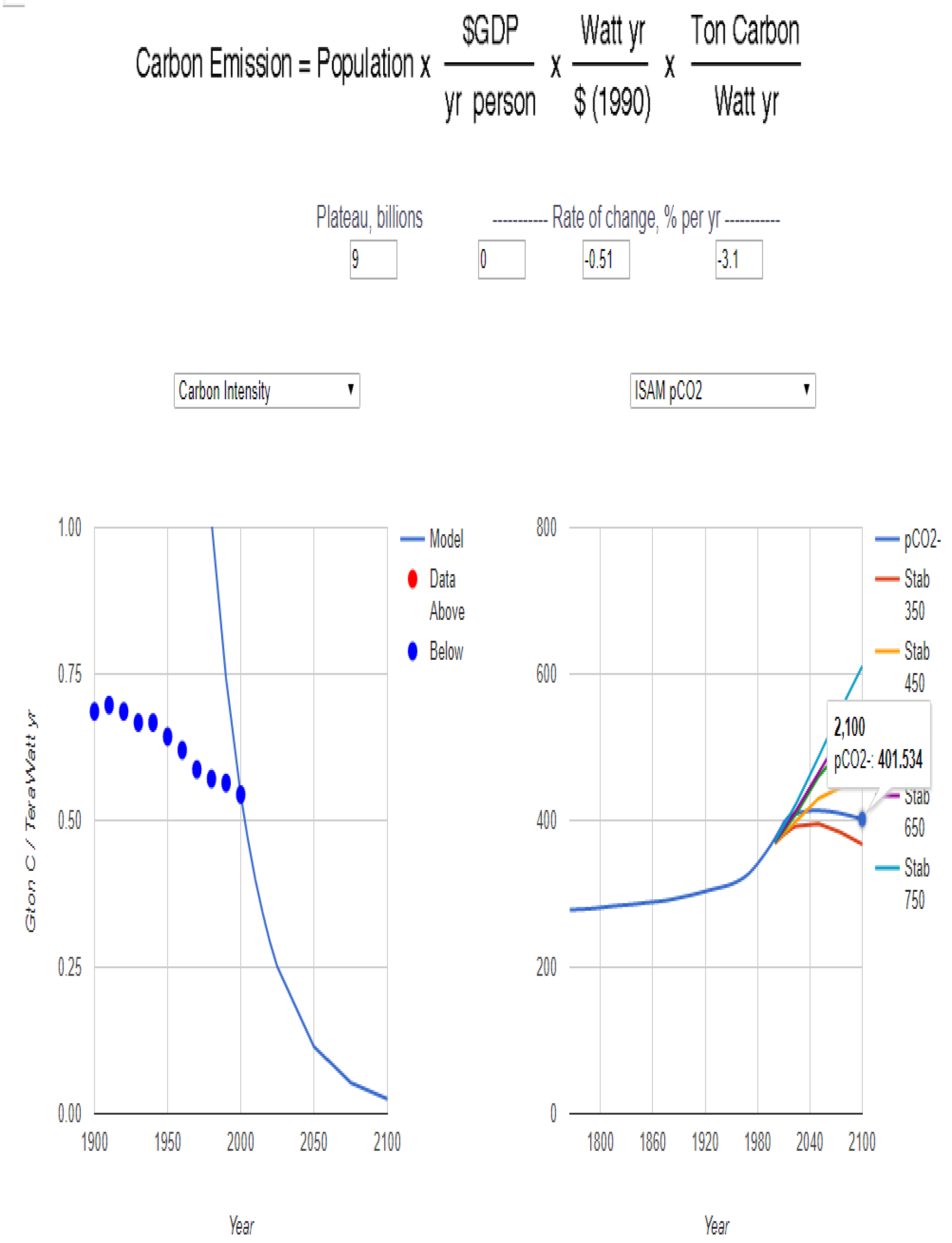

FIGURE 4.78 CARBON DIOXIDE CONCENTRATION CURVE FOR ENERGY INTENSITY = -0.51% AND CARBON INTENSITY = -3.1%

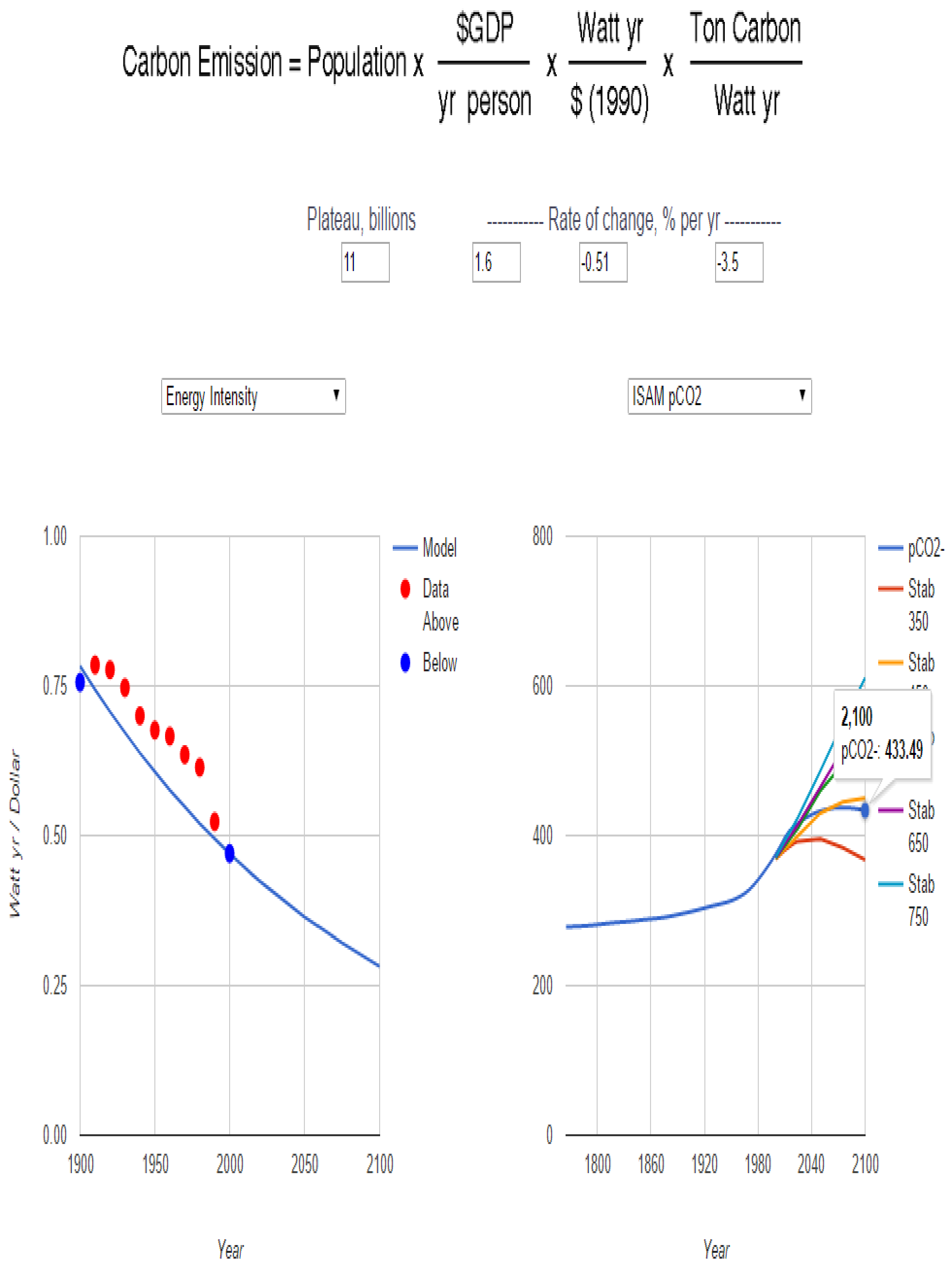

FIGURE 4.79 CARBON DIOXIDE CONCENTRATION CURVE FOR ENERGY INTENSITY = -0.51% AND CARBON INTENSITY = -3.5%

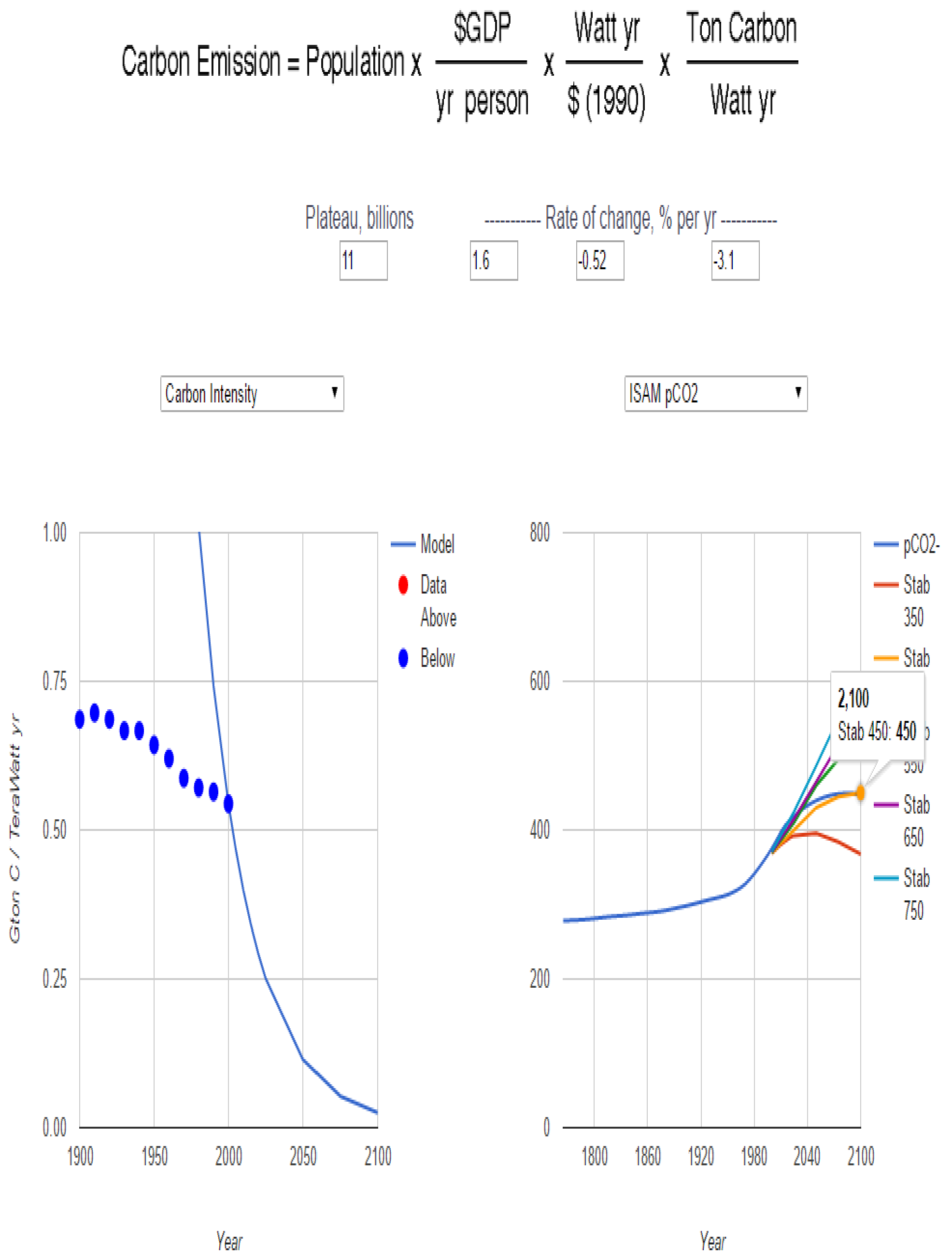

FIGURE 4.80 CARBON DIOXIDE CONCENTRATION CURVE FOR ENERGY INTENSITY = -0.52% AND CARBON INTENSITY = -3.1%

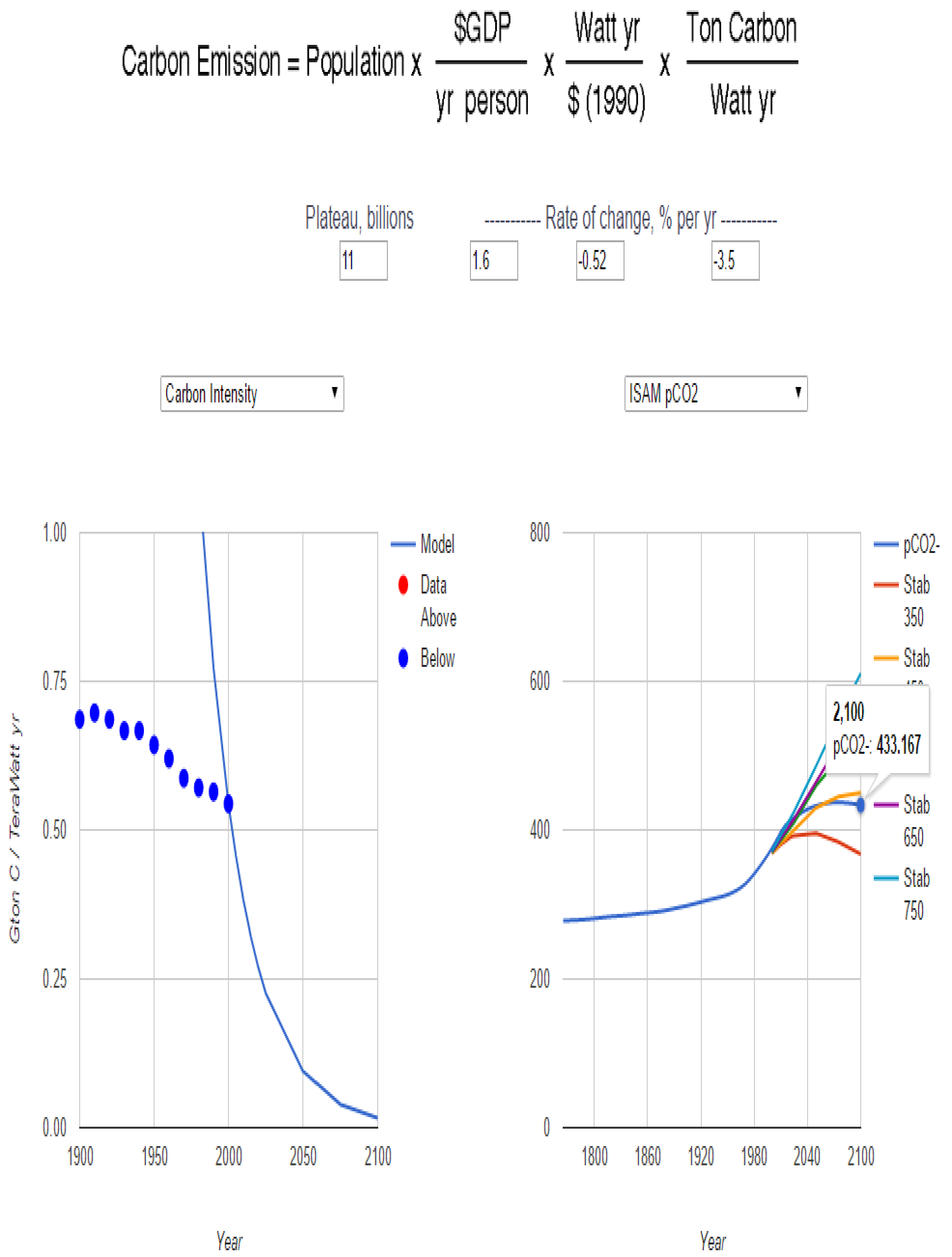

FIGURE 4.81 CARBON DIOXIDE CONCENTRATION CURVE FOR ENERGY INTENSITY = -0.52% AND CARBON INTENSITY = -3.5%

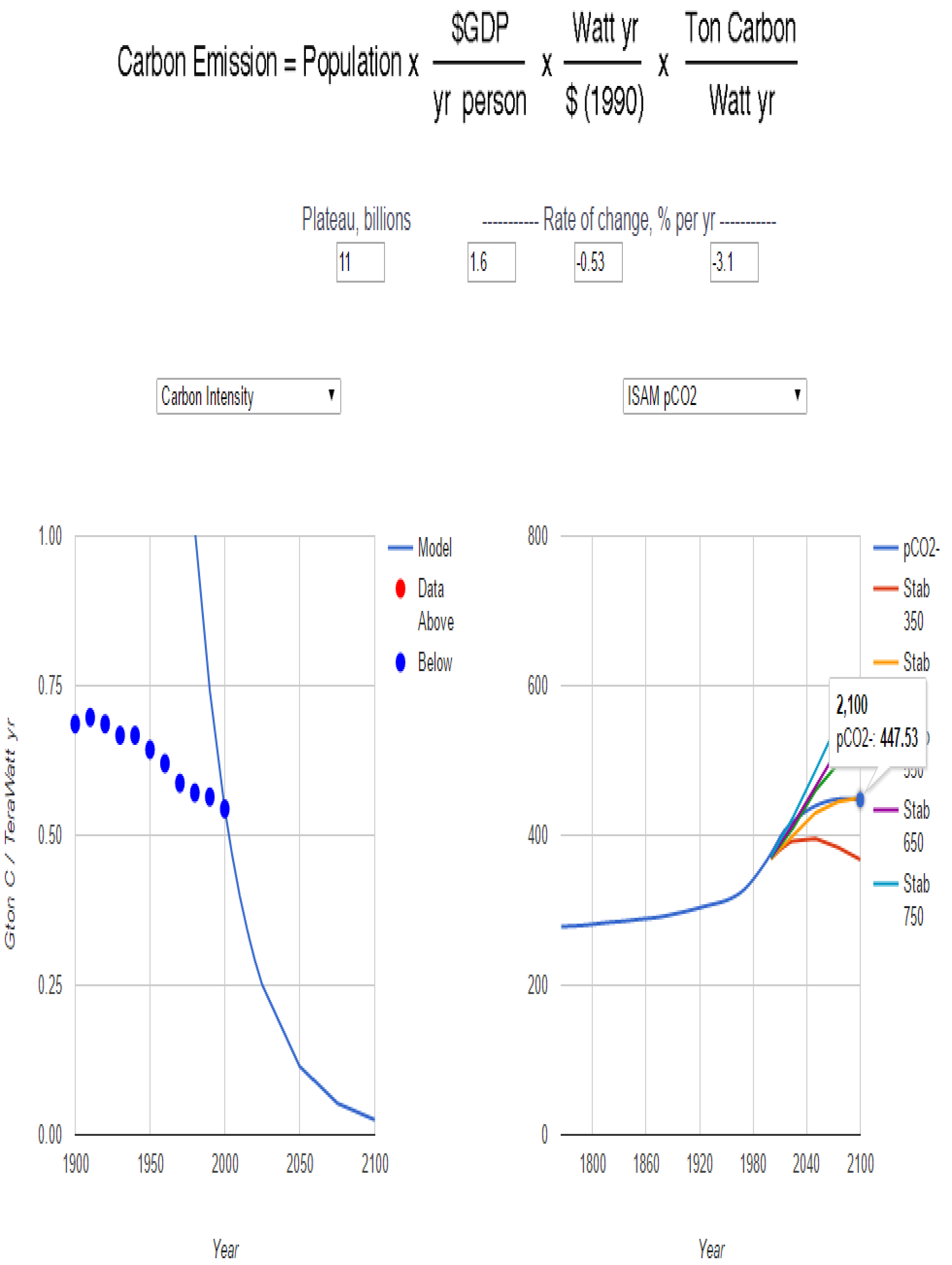

FIGURE 4.82 CARBON DIOXIDE CONCENTRATION CURVE FOR ENERGY INTENSITY = -0.53% AND CARBON INTENSITY = -3.1%

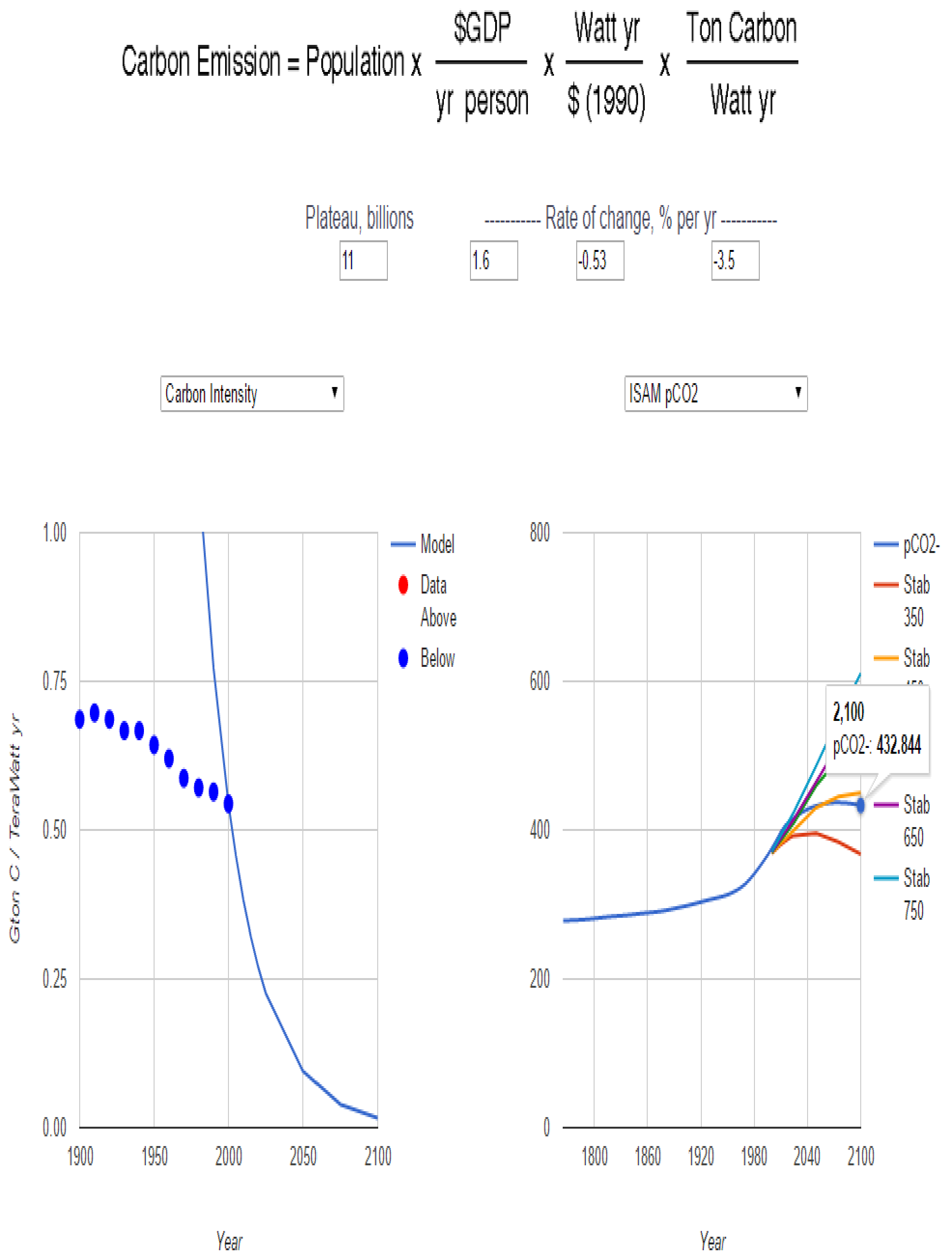

FIGURE 4.83 CARBON DIOXIDE CONCENTRATION CURVE FOR ENERGY INTENSITY = -0.53% AND CARBON INTENSITY = -3.5%

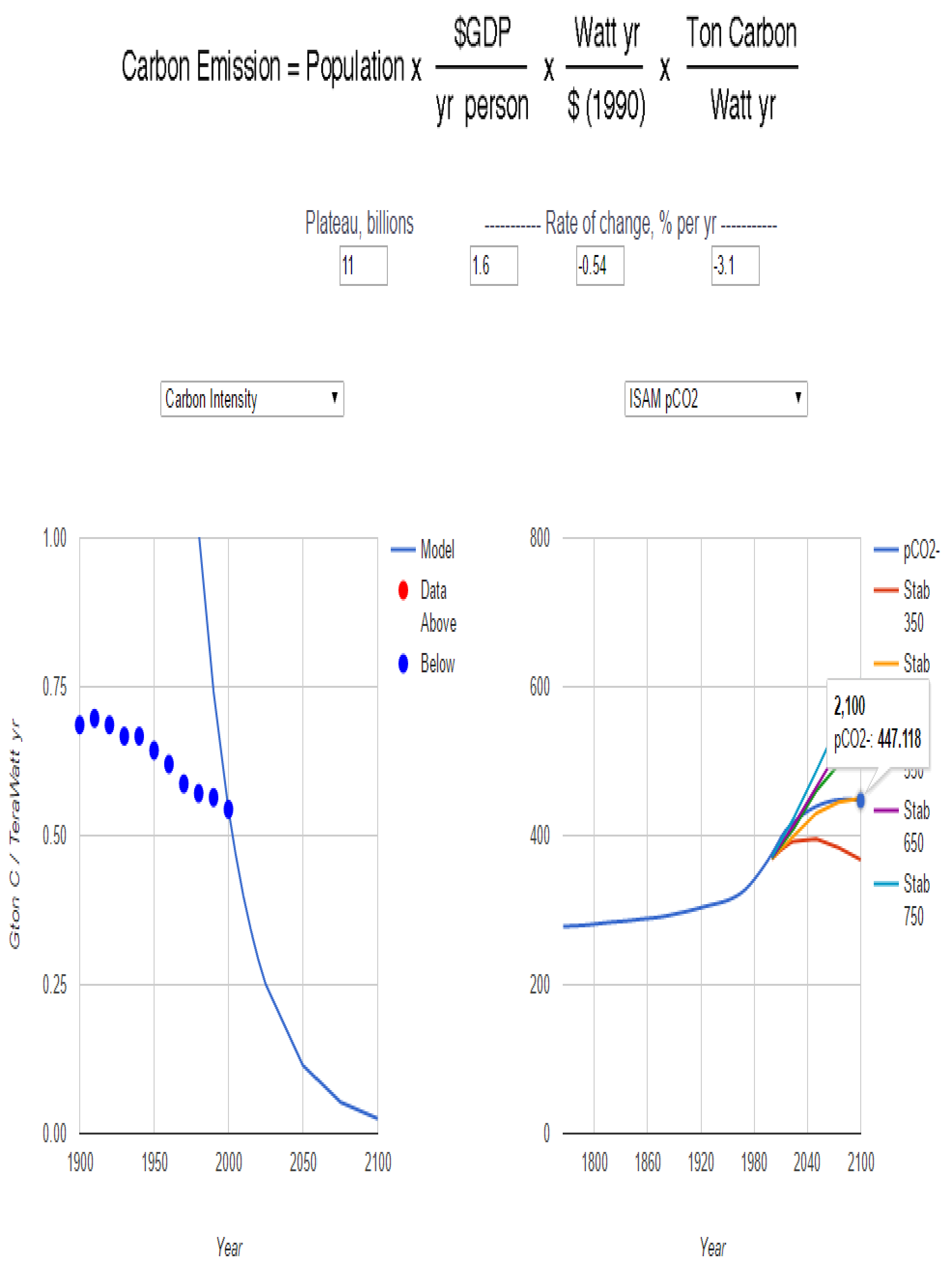

FIGURE 4.84 CARBON DIOXIDE CONCENTRATION CURVE FOR ENERGY INTENSITY = -0.54% AND CARBON INTENSITY = -3.1%

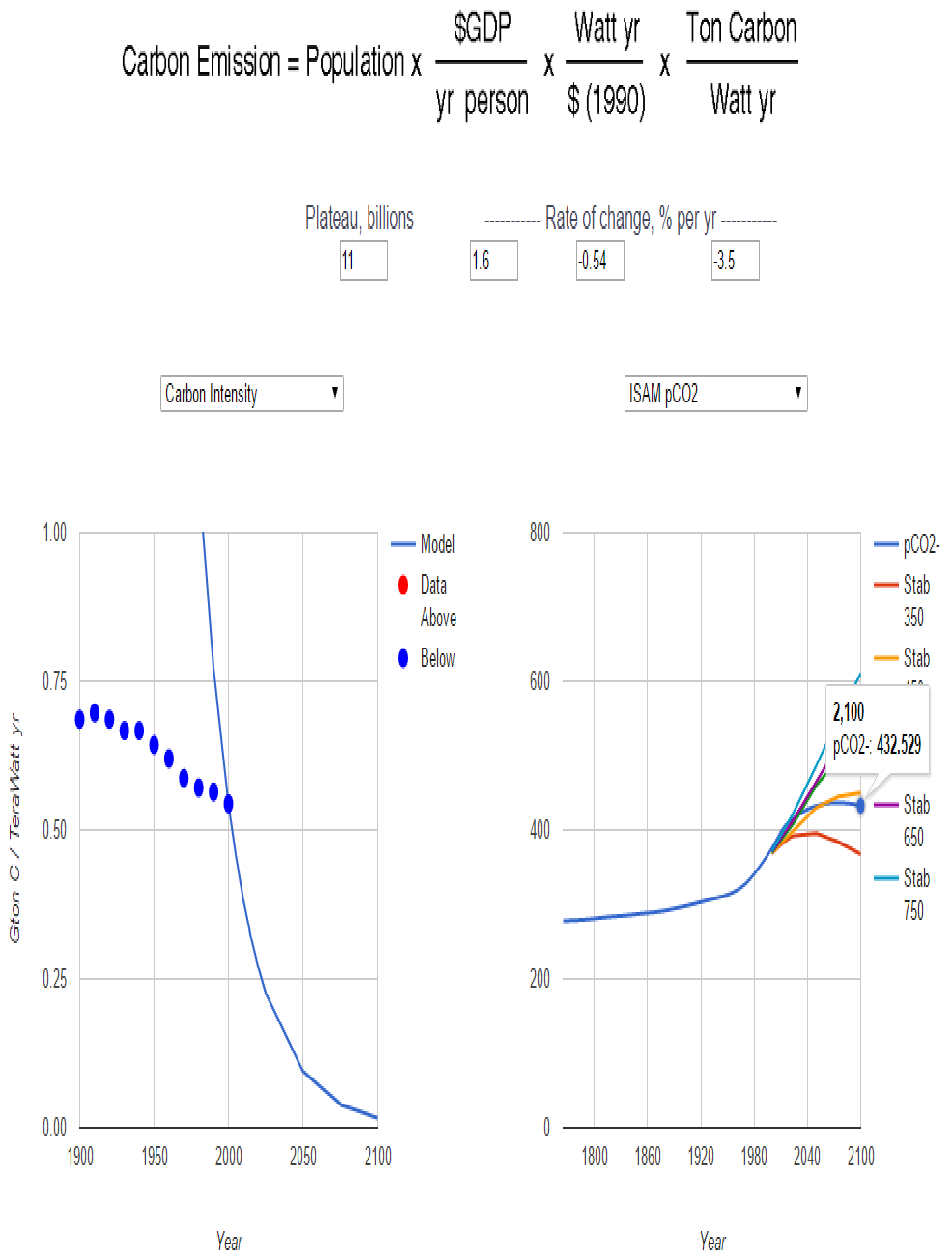

FIGURE 4.85 CARBON DIOXIDE CONCENTRATION CURVE FOR ENERGY INTENSITY = -0.54% AND CARBON INTENSITY = -3.5%

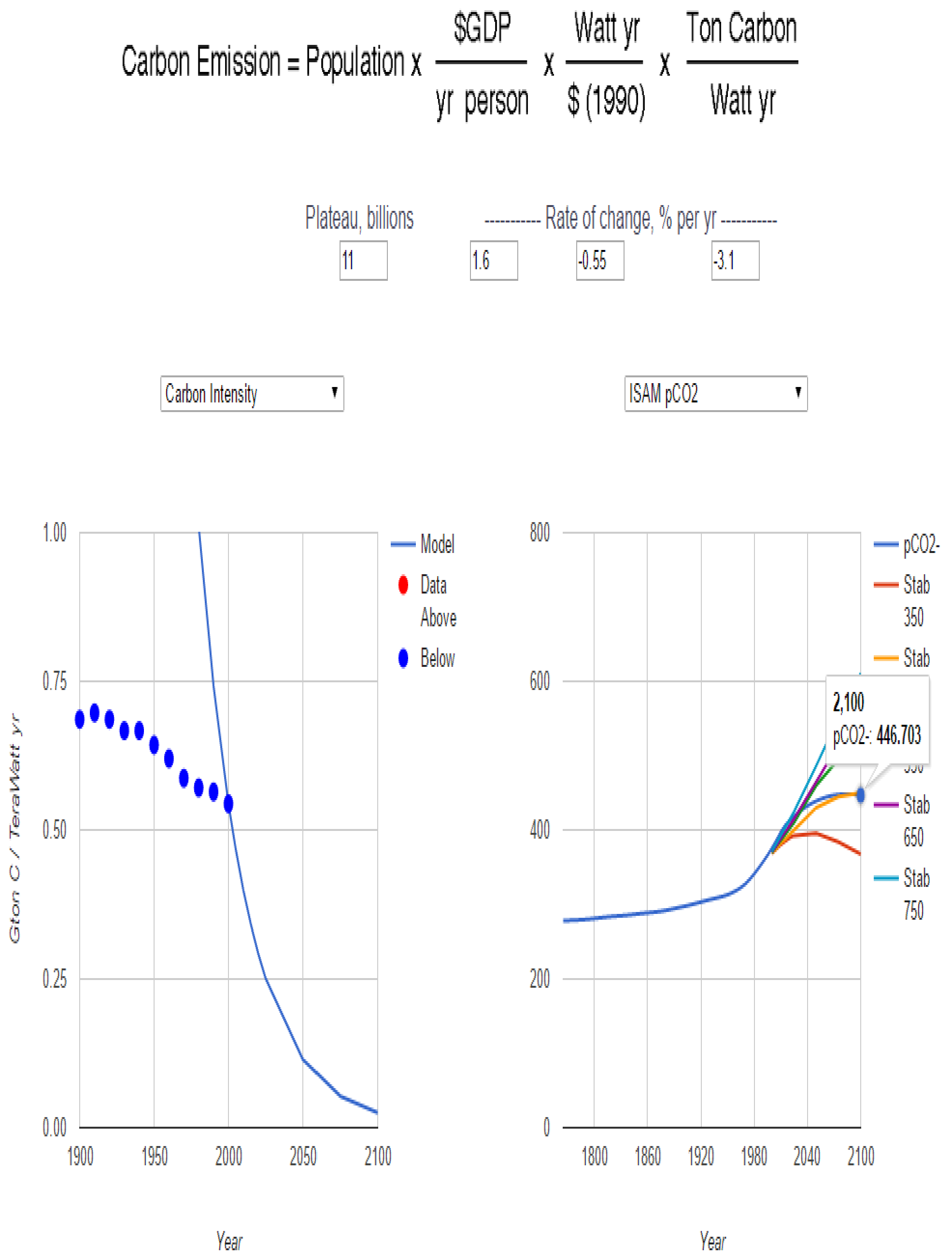

FIGURE 4.86 CARBON DIOXIDE CONCENTRATION CURVE FOR ENERGY INTENSITY = -0.55% AND CARBON INTENSITY = -3.1%

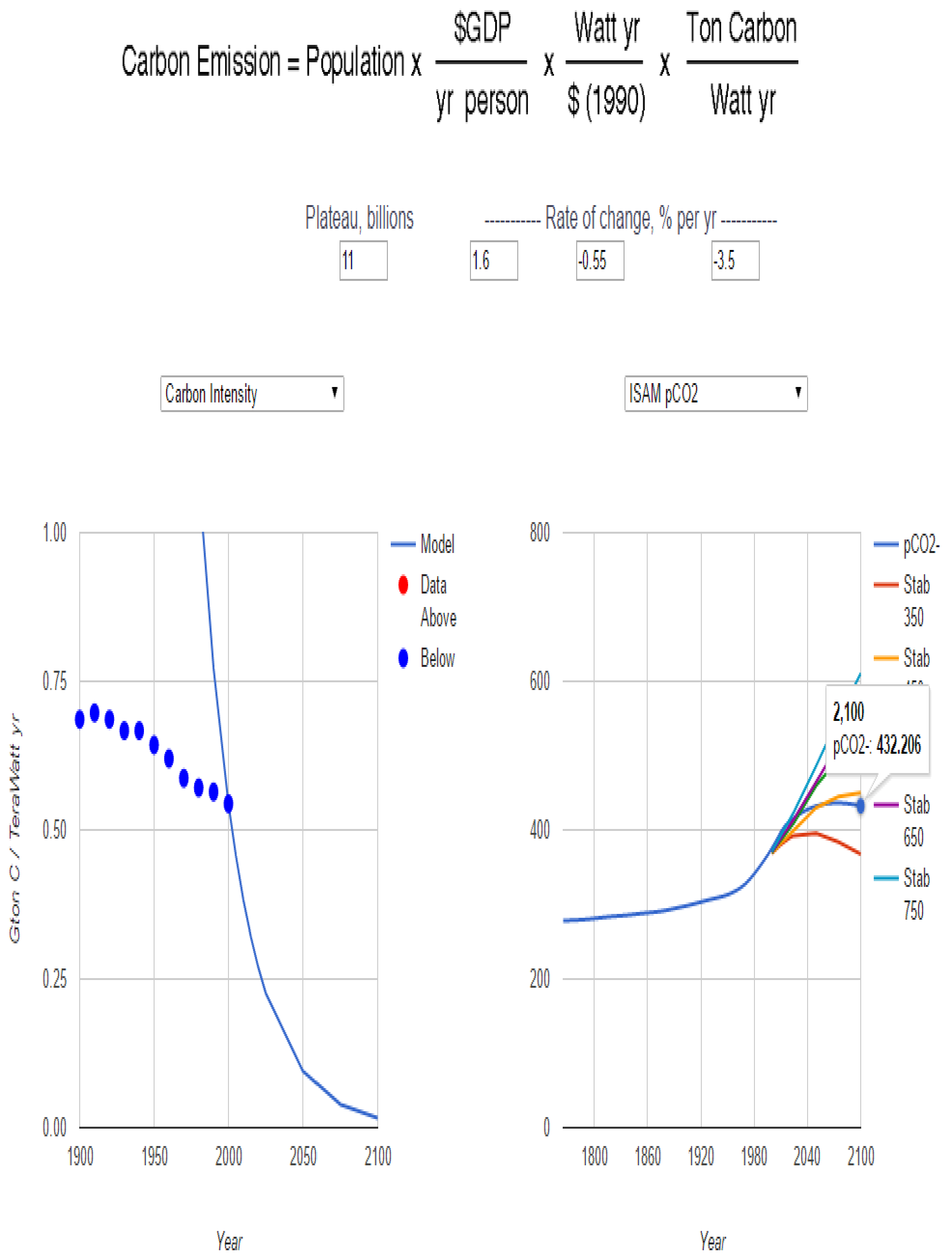

FIGURE 4.87 CARBON DIOXIDE CONCENTRATION CURVE FOR ENERGY INTENSITY = -0.55% AND CARBON INTENSITY = -3.5%

Table 4.2 STABILIZATION PATHWAY TO LIMIT CO2 CONCENTRATIONS UPTO 450 PPM

POPULATION (BILLIONS)	GDP PER CAPITA (%)	ENERGY INTENSITY (%)	CARBON INTENSITY (%)	CO2 CONC. BY 2100 IN PPM
11	1.6	-0.45	-3.1	450.958
11	1.6	-0.45	-3.5	435.484
11	1.6	-0.46	-3.1	450.529
11	1.6	-0.46	-3.5	435.141
11	1.6	-0.47	-3.1	450.085
11	1.6	-0.47	-3.5	434.809
11	1.6	-0.48	-3.1	449.657
11	1.6	-0.48	-3.5	434.476
11	1.6	-0.49	-3.1	450.000
11	1.6	-0.49	-3.5	434.145
11	1.6	-0.50	-3.1	450.000
11	1.6	-0.50	-3.5	433.814
11	1.6	-0.51	-3.1	401.534
11	1.6	-0.51	-3.5	433.490
11	1.6	-0.52	-3.1	450.000
11	1.6	-0.52	-3.5	433.167
11	1.6	-0.53	-3.1	447.530
11	1.6	-0.53	-3.5	432.840
11	1.6	-0.54	-3.1	447.118
11	1.6	-0.54	-3.5	432.529
11	1.6	-0.55	-3.1	446.783
11	1.6	-0.55	-3.5	432.206

CHAPTER 5

CONCLUSION

We have calculated the carbon emissions as carbon dioxide of the whole world by the end of 21st century along with a stabilization pathway to restrict the concentrations of carbon dioxide to around 450 ppm. We can see that the carbon intensity as well as the energy intensity values need to be drastically cut down from the recent trends to achieve this target principally the carbon intensity values. According to the IPCC Fifth Assessment Report, the average historical declining trend for the carbon intensity values upto 2010 is 0.8% which means that the carbon intensity value has declined by an average of 0.8% and in our pathway of stabilization we can see that it needs to be around 3.1-3.5% mark which is a lot of difference. It means we have to get a lot more carbon efficient. i.e. the value needs to decline by 2.1-2.7% more in the future. The lower the desired stabilization level, the lower and sooner the peak in emissions must be. To stabilize below 450 ppm, CO2 levels must be brought to a peak within the next decade, and brought down to 80% below 1990 levels by 2050. There is a need to make a holistic change in the energy extraction procedure so that less carbon is emitted. Also, new sequestration techniques of carbon need to be found to achieve our target along with investments in renewable sources of energy. Also, there is a need for strict carbon policies to be adopted across the globe coupled with strict implementation.

CHAPTER 6

LIMITATIONS

No value of the individual model parameters can give a perfect fit to the past data inherently fed in the model. It is due to the fact that there are a lot of uncertainties involved in the prediction of these quantities all over the world. There has been no consensus on the value of plateau population used for calculations and the data given by the UN has been used. Some assumptions have been made regarding the population and GDP Per Capita growth in different scenarios. The values obtained are not 100 percent accurate and precise due to the inherent assumptions in the climate model.

CHAPTER 7

FUTURE SCOPE

More stabilization pathways can be projected for the 450 ppm values as done in this one. Several other stabilization pathways for other values like 550 ppm or 750 ppm can be put forward. Using some more advanced techniques in the future, better predictions can be made regarding population estimates and other values too which can result in a more accurate prediction.

[REFERENCES]

[1] Kaya, Yoichi; Yokoburi, Keiichi (1997). Environment, energy, and economy : strategies for sustainability. Tokyo [u.a.]: United Nations Univ. ISBN: 928080911

[2] Nebojsa Nakicenovic and Rob Swart, ed. (2000). "IPCC SPECIAL REPORT ON EMISSION SCENARIOS”. Retrieved 19 September 2014.

[3] https://www.e-education.psu.edu/meteo469/node/213

[4] http://climatemodels.uchicago.edu/kaya/

[5] Bunge, Mario (2012). Evaluating Philosophies. Springer Dordrecht Heidelberg New York London. pp. 57–59. ISBN: 9789400744073.

[6] Marian R Chertow. The IPAT equation and its variants. Journal of Industrial Ecology, 4(4):13–29, October 2000.

[7] IEA. World energy outlook 2010. Technical report, International Energy Agency, Paris, 2010.

[8] N. Nakienovi, J. Alcamo, G. Davies, B. de Vries, J. Fenhann, S. Gaffin, K. Gregory, A. Grbler, T.Y.. Jung, T. Kram, E. Lebre, L. Rovere, L. Michaelis, S. Mori, T. Morita, W. Pepper, H. Pitcher, L. Price, K. Riahi, A Roehrl, H-H. Rogner, A. Sankovski, M. Schelsinger, P. Shukla, S. Smith, R. Swart, S. van Rooijen, N. Victor, and Z. Dadi. Special Report on Emissions Scenarios. Cambridge University Press, Cambridge, 2000.

[9] G.-Q. Xu, Z.-Y. Liu, and Z. H. Jiang, “Decomposition model and empirical study of carbon emissions for China, 1995–2004,” China Population, Resources and Environment, vol. 16, no. 6, pp. 158–161, 2006.

[10] W.-X. Wang, Y.-Q. Kuang, and N.-S. Huang, “Study on the decomposition of factors affecting energy-related carbon emissions in Guangdong province, China,” Energies, vol. 4, no. 12, pp. 2249–2272, 2011.

[11] Intergovernmental Panel on Climate Change (IPCC), “IPCC guidelines for national greenhouse gas inventories,” 2006