

Some Bounds on the Sensitivity of Human Population Dynamics to the Effects of Greenhouse Gas Depletion of Land Productivity

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Abstract

The 7 August 2019 IPCC special report on land and climate change predicts that the average global temperature will rise more than 1.5 C if human production of greenhouse gases (GHGs) continues at the 2019 rate to 2030, significantly compromising land productivity and the world food supply. Given a relationship between GHGs and land productivity, the World3 simulator can help to bound estimates of the sensitivity of human population dynamics to GHG depletion of land productivity. World3 projects that in the worst case the peak size of the human population could be reduced by 4% - 37% by GHG depletion of land productivity, compared to World3's "benchmark scenarios", during calendar years 1900-2100. In particular, World3's "business-as-usual" (BAU) scenario implies that in the worst case the peak size of the human population would be reduced by ~20% by depletion of land productivity. This BAU-specific result is consistent, to within a factor of two, with GHG/wheat-productivity relations described in the literature.

Keywords: *land productivity, climate change, greenhouse gases, human population dynamics*

1.0 Introduction

The 7 August 2019 IPCC special report on land and climate change predicts that the average global temperature will rise more than 1.5 C if human production of greenhouse gases (GHGs) continues at the 2019 rate (mass GHG per capita per unit time) to 2030. This temperature rise, the report states, will significantly compromise land productivity,¹ threatening the world food supply (IPCC 2019, Section A).

A fundamental question in IPCC 2019 is how we should model the relationship between GHGs and land productivity (which can strongly affect human population dynamics). In the absence of any other considerations, one might suppose that human population dynamics, particularly

¹ For the purposes of this paper, "land productivity" means "mass of food produced per unit land area per unit time".

human population size, varies linearly with GHG (concentration).² Such a model is mathematically simple, but is inadequate as a basis for policy guidance for at least the following reasons:

- i. GHGs affect climate change, and GHG-induced climate change is neither spatially nor temporally uniform enough (IPCC 2014) to sustain the assumption of linearity between GHG and land productivity.
- ii. Population dynamics can be strongly nonlinear in agricultural, capital, and non-renewable resources (FAO 2019).

In order to assess the relationship between GHGs and human population dynamics, therefore, we need a model that embraces (i)-(ii) and whose behavior is reasonably well understood. The *World3* simulator (Meadows et al. 1972b; Cellier 2008; Cellier 2019; Wolfram 2019a) models, at a high level, the dynamical interaction of world population, pollution, agriculture, capital, and non-renewable resources. *World3*'s behavior, furthermore, is reasonably well understood (Turner 2014). Thus, *given* a relationship between GHGs and land productivity, it is reasonable to hypothesize that *World3* could help to bound estimates of the sensitivity of human population dynamics to GHG depletion of land productivity.

That said, using *World3* to help bound estimates of the sensitivity of human population dynamics to GHGs has at least one potential limitation. It might be the case that *World3* cannot accommodate the full range of significant effects GHGs could have on land productivity. For example, it might be the case that the effects of GHGs on land productivity are twice what *World3* can represent. If so, using *World3* to help bound estimates of the effect of GHGs on human population dynamics could cause us to seriously mis-estimate those effects.

Though well taken, it should be noted that this kind of concern applies to *all* ampliative (non-deductive) inferences (Salmon 1967, 8-12). All of empirical science involves ampliative inference. The concern cannot be made to go away, furthermore, because we don't have certain, non-deductive knowledge of the future, regardless of what theory we adopt. (Hume 1739, Book I, Part III; Salmon 1967).

1.1 Brief history of *World3*

World3 evolved from the Club of Rome's "Limits to Growth" project (Meadows et al. 1972a) in the early 1970s. The objectives of the Limits to Growth project were to determine whether systems analysis techniques developed by Jay Forrester and colleagues at MIT "could provide

² IPCC 2019 does *not* assume a linear relation between GHGs and population dynamics.

new perspectives on the interlocking complex of costs and benefits inherent in continued physical growth on a finite planet” (Meadows et al. 1972b, vii).

World2, the immediate predecessor of *World3*, was written in DYNAMO (Pugh 1963) and was batch-oriented. By 2004, *World3* had been ported to the STELLA modeling language (Richmond 2013). Cellier 2019, the version of *World3* used in this paper, is François Cellier’s re-engineering (circa 2008) of the 2004 (STELLA) version of *World3* to the Modelica (Open Modelica 2019; The Modelica Organization 2019) simulation language under the *SystemModeler* (Wolfram 2019a) simulation framework ([7]), which can be executed interactively or invoked from *Mathematica* (Wolfram 2019b). The combined *Mathematica* and *SystemModeler* framework makes *World3* extensible (i.e, the framework provides read and write access to *World3*’s data structures, model-execution control, extensive visualization functionality, and support ports of applications written in the *Mathematica* framework to the C++ language).³

In the first few years of its existence, the Limits to Growth family of world dynamics simulators was extensively criticized (Simon and Kahn 1984; Simon 1996; Cole et al. 1973). More recent reassessments (Turner 2008; Turner 2014; Randers 2012; Nørgård, Peet, and Ragnarsdóttir 2010), however, argue that from 1980 to the present, *World3* (especially *World3*’s Benchmark Scenario 1; see Section 1.3 of this paper) has predicted the actual evolution of the world-state remarkably well.

1.2 High-level structure of *World3*

Software engineering distinguishes a purely conceptual representation of the structure a software system *S* from a representation of the structure of a physical implementation of *S*. In the vocabulary of software engineering, a purely conceptual representation of *S* is called a *logical* representation of *S*. A representation of a physical implementation of *S* describes how the concepts of the logical representation of *S* are realized in specific computer languages (together with hardware and human activities). In general, the mapping between the logical and physical representation of the structure of *S* can be many-to-many. (See Piccinini 2015 for a critical survey of issues arising from the logical/physical distinction.)

To close approximation, the theory and logical design (Boehm 1981, Section 5.4; Boehm et al 2000, 312-313) of *World3* can be found in Meadows et al. 1972b. Much of the detailed physical design (Boehm 1981, Section 5.4; Boehm et al. 2000, 312-313) of Cellier 2019 can be found in the online documentation that accompanies Cellier 2019.

³ The combined *Mathematica/SystemModeler/World3* framework is characterized as “experimental” by the *Mathematica* v12 documentation (Wolfram 2019b).

By design fiat, the state variables of the logical structure of *World3* are population, pollution, agriculture, capital, and non-renewable resources. In *World3*, these variables are interdependent.

Figure 1 shows a Level 1 dataflow diagram (DeMarco 1978) of the logical structure of *World3*. Note that there is a natural one-to-one correspondence between the state variables of the simulator and the processes in the diagram.⁴

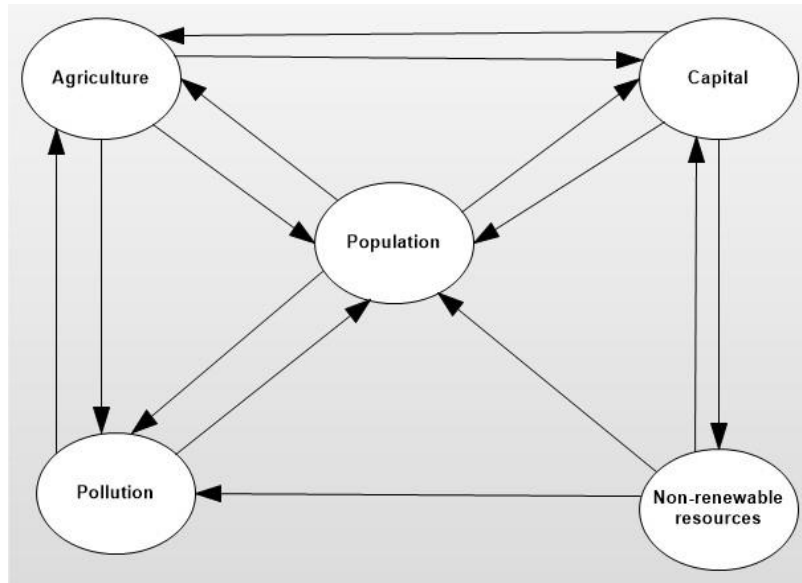


Figure 1. A Level 1 dataflow diagram (DeMarco 1978) of *World3*. An ellipse represents process. An arrow represents data flowing from the process at the tail of the arrow to the process at the head of the arrow.

The logical structure of *World3* can also be cast in object-oriented terms. In that idiom there is a one-to-one correspondence between the state variables of *World3* and its highest-level logical *objects* (Rumbaugh, Jacobson, and Booch 1999, 360; Smith 1996).⁵ The resulting object-diagram is highly similar to Figure 1, with objects substituted for the processes and object-relations substituted for dataflow arrows (see Rumbaugh, Jacobson, and Booch 1999 for a general account of how dataflow- and object-diagrams are related).

As built, the high-level physical decomposition of Cellier 2019 is more fine-grained than the structure shown in Figure 1 and the “sector” structure of Meadows et al. 1972b (whose network

⁴ Dataflow diagrams do not depict conditionality or temporality.

⁵ The relationship between state variables and objects can be many-to-many (Shlaer and Mellor 1992, 22; Rumbaugh, Jacobson, and Booch 1999, 48).

topology is isomorphic to the topology of the network shown in Figure 1). See Cellier 2008 for rationale for these differences.

1.3 The *World3* Benchmark Scenarios

Meadows, Randers, and Meadows 2004 describe, at a high level, nine *World3* scenarios that span regimes ranging from continuing the practices and policies of the 20th century, to a sequence of scenarios that increasingly diverges from the reference scenario through increasing:

- a. birth control and pollution controls
- b. industrial and agricultural investment
- c. food production technology
- d. resource conservation practices
- e. resource extraction efficiency

For the purposes of this paper, I will call these “the *World3* Benchmark Scenarios”, or more briefly, “the (nine) Benchmark Scenarios”.⁶ Collectively, the Benchmark Scenarios provide a de facto baseline for analyzing the sensitivity of *World3* to a wide range of variation in *World3* parameters.⁷ By default, the duration of each Benchmark Scenario spans simulated calendar years 1900 - 2100.⁸ Here is a brief description of the trajectories produced by the Benchmark Scenarios (details of these scenarios can be found in Meadows, Randers, and Meadows 2004; Cellier 2019).

Scenario 1 (the “reference”, or “business-as-usual” (BAU), scenario (Meadows, Randers, and Meadows 2004, 168-171)). In Scenario 1, human practices and policies continue without significant deviation from the those followed during most of the 20th century. As a result, population and production increases until growth is halted by increasingly inaccessible resources. Increasing investment is required to maintain resource flows. That investment, which must be re-directed from other sectors of the economy, leads to declining output of both industrial goods and services. The decline of industrial goods and services causes a reduction in the food supply and in health services, thereby decreasing life expectancy, resulting in population “collapse” (a 50% reduction of population size in ~50 years) beginning calendar year 2040.

⁶ What scenarios should be subsumed under this name might be debated, but it’s clear enough that the community of *World3* users has found the nine used in this paper are a convenient choice. Meadows, Randers, and Meadows 2004 describe a 10th scenario, which is Scenario 9 with the sustainability policies of Scenario 9 introduced 20 years earlier. Cellier 2019 includes a 10th and 11th scenario, neither of which identical to any of Scenarios 1-9. Scenarios 10 and 11 of Cellier 2019, moreover, will not compile on the platform described in Section 2 of this paper.

⁷ Unless otherwise noted, the term “parameter” in this paper means “a user-settable constant”.

⁸ *World3* projections past 2100 likely lie well outside the calibration range of the simulator.

Scenario 2 (Meadows, Randers, and Meadows 2004, 172-174). In this scenario, the nonrenewable resources assumed in Scenario 1 are doubled. Scenario 2 further postulates that advances in resource extraction technology postpone the onset of increasing extraction costs, thus allowing industry to grow 20 years longer than in Scenario 1. But as a consequence, pollution levels rise sharply, depressing land yields and requiring massive investments in agricultural recovery. The population finally declines because of food shortages and the health effects of pollution.

Scenario 3 (Meadows, Randers, and Meadows 2004, 210-214). This scenario assumes the nonrenewable resource supply and extraction technologies assumed in Scenario 2. It also assumes increasingly effective pollution control technology that reduces the amount of pollution generated per unit of output by up to 4 percent per year, starting in 2002. This allows much higher welfare for more people after 2040 because of fewer negative effects of pollution. But food production ultimately declines, drawing capital from the industrial sector and triggering a population collapse.

Scenario 4 (Meadows, Randers, and Meadows 2004, 214-216). This scenario adds to the pollution control technology of Scenario 3 and a set of technologies that greatly increase the food yield per unit of land. As a consequence, agricultural activities sharply increase the land loss rate. This scenario ultimately leads to a population collapse.

Scenario 5 (Meadows, Randers, and Meadows 2004, 216-218). This scenario assumes more accessible nonrenewable resources, a better land-preservation technology than Scenario 4, and the pollution-reducing technology of Scenario 4. This only slightly postpones the population collapse to near the end of the 21st century.

Scenario 6 (Meadows, Randers, and Meadows 2004, 218-220). This scenario assumes the world develops even more powerful pollution abatement and land protection than Scenario 5, and further assumes conservation of nonrenewable resources. All these technologies have costs and take 20 years to be fully implemented. In combination, they yield a fairly large and prosperous population until the accumulated cost of the technologies becomes unsustainable, ending in a population collapse.

Scenario 7 (Meadows, Randers, and Meadows 2004, 238-241). This scenario assumes that after 2002 all families are limited to two children. Because of the age-structure momentum, however, the population continues to grow for another generation. The slower population growth permits industrial output to rise, until it is stopped by the cost of dealing with rising pollution (as in Scenario 2).

Scenario 8 (Meadows, Randers, and Meadows 2004, 241-244). This scenario assumes that after 2002 families are limited to two children. The scenario sets a fixed goal for industrial output per

capita. As a result, there is a “golden period” of fairly high human welfare between 2020 and 2040. But rising pollution increasingly stresses agricultural resources. Per capita food production falls, eventually degrading life expectancy and population.

Scenario 9 (Meadows, Randers, and Meadows 2004, 244-247). In this scenario, population and industrial output are limited as in Scenario 8. In addition, technologies are added to aggressively abate pollution, conserve resources, increase land yield, and protect agricultural land. As a consequence, the planet’s 8 billion people enjoy a high standard of living, and the human ecological footprint continuously declines.

Of Scenarios 1 - 9, only in Scenario 9 is the human population sustainable past calendar year 2100.⁹

2.0 Method

2.1 Selection of parameters to vary

Two criteria of adequacy must be satisfied in order to evaluate the sensitivity of a quantity, Y , to another quantity, X , in a given simulation/model M . Assume X' is a proxy for X . Then

A1. In M , we vary X (X') and observe the effect of that variation on Y .

A2. The values of all *independent* variables and parameters in M other than $X(X')$ are kept constant.

Note that when “sensitivity analysis” is used in the sense of A1-A2, the analysis is not concerned with whether M “correctly” models the world per se. The analysis is instead concerned with the question how, within M , Y varies with $X(X')$. How that sensitivity maps to the world external to M involves “validation” questions (i.e., conformance of M to the world M is intended to model) that are briefly mentioned in Section 4 of this paper.¹⁰

World3 does not explicitly model GHGs or climate change. The simulator does, however, model the effect of loss of land productivity on human population dynamics in ways that satisfy A1-

⁹ The values of a few initial conditions and parameter values in the Benchmark Scenarios as described Cellier 2019 differ slightly from those in Meadows et al. 1972. These differences are the result of re-calibration of *World3* between about 1975 and about 2010. The differences between the projections of the Baseline Scenarios in Meadows et al. 1972 and the corresponding Baseline Scenarios in Cellier 2019 that arise from the differences in the initial conditions and parameter values in Meadows et al. 1972 and Cellier 2019 are minor.

¹⁰ Following IEEE 2011, I distinguish “verification”, which concerns a satisfaction relation between a software system S and its specification, from “validation”, which concerns the relationship between the specification and something (naively, the “real world”) that is independent of the specification and software.

A2. Thus, *given* a relationship between GHGs and land productivity, *World3* can help to bound estimates of the sensitivity of human population dynamics to land-productivity-related effects of GHGs. More specifically, we can use *World3* to help bound estimates of the effect of GHG-related loss of land productivity on human population dynamics by assessing the sensitivity of human population dynamics to land productivity *within World3*.

In *World3*, the term “land yield” means land productivity *as a function of the use of fertilizer, pesticides, and machinery*. In *World3*, in contrast, the term “land fertility” refers to intrinsic ability of the soil to produce food *without* modern agricultural practices such as the use of fertilizer, pesticides, and machinery (Meadows et al. 1972b, 259). Note that both “land yield” and “land fertility” in the sense of *World3* are special cases of “land productivity” as defined in Section 1.

Within *World3* there are *only two*¹¹ (table-defined) parameters, `Pollution_Dynamics1.P_Yield_Mlt_Air_Poll` (“land yield multiplier due to air pollution”), and `Land_Fert_Degr_Rt` (“land fertility degradation rate multiplier”), that can be used unambiguously to simulate the sensitivity of human population dynamics to loss of land yield, and land fertility, respectively, regardless of the cause (such as GHGs). In *World3*, `Pollution_Dynamics1.P_Yield_Mlt_Air_Poll` modifies only land yield directly; `Land_Fert_Degr_Rt` modifies only land fertility directly.

The parameter name “`Pollution_Dynamics1.P_Yield_Mlt_Air_Poll`” suggests that it concerns air pollution per se. That interpretation of the parameter, however, is not intrinsically limited by the *World3* software as such to air pollution. In a sensitivity analysis (though not in a validation task), this parameter could be regarded as any quantity that is (i) a function of pollution, and (ii) affects land yield, provided that this interpretation is uniformly applied to *World3*. As a result, we can use `Pollution_Dynamics1.P_Yield_Mlt_Air_Poll` as a proxy for any effect on land productivity. For the same reasons, in a sensitivity analysis the parameter “`Land_Fert_Degr_Rt`” can be regarded as any parameter that affects land productivity and satisfies (i) and (ii).

The alternative within the *World3* idiom to expanding the interpretation of `Pollution_Dynamics1.P_Yield_Mlt_Air_Poll` and `Land_Fert_Degr_Rt` to be proxies for the effect of climate change on land yield/fertility requires introducing additional parameters dedicated to the effect of climate change per se on yield and land fertility. There are tradeoffs between introducing those complexities on the one hand vs. expanding -- where possible -- the semantics of the parameters mentioned above. It could be argued, for example, that re-purposing the indicated parameters “overloads” the intended semantics of the parameters. All other considerations being the same, semantic overloading of program elements can increase software

¹¹ This claim can be confirmed by analyzing the *World3* software. Other *World3* parameters are related to the effects of land yield on population, but each of those parameters has additional effects that, within the domain of the simulator, are not specifically attributable to the effects of land productivity on population.

and conceptual complexity and thereby increase the risk of programming or usage errors (see, for example, Ullman 1988, esp. Chap. 7; Aho, Hopcroft, and Ullman 1983, esp. Section 1.6; Booch and Bryan 1993; Parnas 1972). Against this, it can be argued that at least some kinds of semantic overloading allow us to aggregate similar items better¹² than alternative approaches; indeed, some modern programming languages (e.g., ISO/IEC 2017; MITRE Corporation 2000) have mechanisms to regiment such overloading. In any case, this study varies *World3*'s Pollution_Dynamics1.P_Yield_Mlt_Air_Poll and Land_Fert_Degr_Rt parameters to help bound the effects that (any, including GHG-induced) land-productivity loss could have on human population dynamics in *World3*.

2.1.1 Modeling land yield loss due to “air pollution” (used as a proxy for GHGs)

In the *World3* software, two tables, Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1 and Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_2, define the effect of “air” pollution on land yield. The values of this parameter are defined as a function of IOC/IO70, where IOC is current Industrial Output and IO70 is Industrial Output in 1970.¹³ These tables are initialized as shown in Figure 2. A value (“yval”) of 1.0 for Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1 or Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_2 means that the effect of air pollution on land yield is “no different” from air pollution effects on land yield in 1970; a yval of the form 0.n, n = 1, 2, ..., implies that land yield is 0.n times the value of land yield in 1970, all else being the same.

World3 uses the value of a calendric switch parameter, t_air_poll_time, to determine which of Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1 or Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_2 defines the parameter. The default value of t_air_poll_time in Scenario 1 is calendar year 4000, well past the time interval defined in the Benchmark Scenarios (1900-2100). If the current scenario time is equal to or less than t_air_poll_time, Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1 values are in play; else, the values in Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_2 are in play.

Note that in Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1, the effect of the y_vals is on the whole more severe than in Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_2; in the most extreme case (Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[4]) air pollution decreases land yield to 0.4 of nominal, i.e., to 0.4 of the land yield when air pollution is at its 1970 level (IOC/IO70 = 1).

Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.x_vals[1]→0.,

¹² Where “better” must be defined with respect to specific objectives.

¹³ *World3* assumes that pollution is an increasing, but not linear, function of industrial output.

Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.x_vals[2]→10.,
Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.x_vals[3]→20.,
Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.x_vals[4] →30.,
Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[1]→1.,
Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[2]→1.,
Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[3]→0.7,
Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[4]→0.4

Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_2.x_vals[1]→0.,
Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_2.x_vals[2]→10.,
Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_2.x_vals[3]→20.,
Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_2.x_vals[4]→30.,
Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_2.y_vals[1]→1.,
Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_2.y_vals[2]→1.,
Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_2.y_vals[3]→0.98,
Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_2.y_vals[4]→0.95

Figure 2. *World3* tables `Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1` and `Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_2` in Scenario 1, with default values. The xvals are IOC/IO70, where IOC is current industrial output (as computed by the simulator) normalized to industrial output in calendar year 1970 (IO70). For example, the combination of “`Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.x_vals[3]→20.`” and ”`Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[3]→0.7`” means that if table `Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1` values are in effect, and if the current Industrial Output is 20 times the Industrial Output of 1970, then the multiplier for the effect of air pollution on land yield is 0.7 (i.e., all else being the same, the land yield is 70% of the 1970 value of land yield.)

For each of Benchmark Scenarios 1-9, each of the five experiments described below was executed under Wolfram 2019a running under *Mathematica* (Wolfram 2019b) with Dynamic Updating enabled, all under Windows 10, on a Dell Inspiron 545 desktop containing an Intel Q8200 quadprocessor clocked at 2.33 GHz and 8 GB of physical memory. Microsoft C++ Visual Studio provided the software development and build environments required by Wolfram 2019a. The variables shown in Figure 3 were plotted (as a function of time).

1. Population
2. Land Yield
3. Life_Expectancy
4. Human_Welfare_Index

5. Human_Ecological_Footprint
6. Food_Production_Per_Capita
7. Food_Production, Industrial_Production (on same set of axes)
8. Services_Output_Per_Capita, Industrial_Output_Per_Capita (on same set of axes)
9. Persistent_Pollution_Index
10. Non-Renewable_Resources_Remaining

Figure 3. *World3* variables (see Meadows et al. 1972b and Cellier 2019 for definitions) plotted in this study.

Experiment 1. The baseline Benchmark Scenario was executed as is (which assumes the values defined in Figure 1 for `Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1`).

Experiment 2. The value of variable `t_air_poll_time` in the baseline Benchmark Scenario was changed to calendar year 2020 (thus switching to the “mitigated-air-pollution” values defined in `Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_2` at calendar year 2020).

Experiment 3. The value of `t_air_poll_time` in the baseline Benchmark Scenario was set to calendar year 1970 (thus switching to the “mitigated-air-pollution” values defined in `Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_2` at calendar year 1970).

Experiment 4. The value of `t_air_poll_time` was defaulted to calendar year 4000. The values of `Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals` in the baseline Benchmark Scenario were changed to those shown in Figure 4:

`Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[1]`→0.7,
`Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[2]`→0.5,
`Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[3]`→0.3,
`Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[4]`→0.1

Figure 4. `Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals` for Experiment 4.

Experiment 5. The value of `t_air_poll_time` was defaulted to calendar year 4000. The values of `Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals` in the given Benchmark Scenario were changed to those shown in Figure 5

Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[1]→0.7,
Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[2]→0.1,
Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[3]→0.1,
Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[4]→0.1

Figure 5. Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals for Experiment 5.

2.1.2 Modeling land fertility loss due to pollution

In *World3*, the effect of “persistent pollution” on land fertility degradation rate is modeled as a (table-defined) function of the “persistent pollution index”, where the persistent pollution index is defined as persistent pollution normalized to the value of persistent pollution in 1970. This table is initialized as shown in Figure 6.

Land_Fertility1.Land_Fert_Degr_Rt.x_vals[1]→0.0
Land_Fertility1.Land_Fert_Degr_Rt.x_vals[2]→10.0
Land_Fertility1.Land_Fert_Degr_Rt.x_vals[3]→20.0
Land_Fertility1.Land_Fert_Degr_Rt.x_vals[4]→30.0
Land_Fertility1.Land_Fert_Degr_Rt.x_vals[5]→100.0
Land_Fertility1.Land_Fert_Degr_Rt.y_vals[1]→0.0
Land_Fertility1.Land_Fert_Degr_Rt.y_vals[2]→0.1
Land_Fertility1.Land_Fert_Degr_Rt.y_vals[3]→0.3
Land_Fertility1.Land_Fert_Degr_Rt.y_vals[4]→0.5
Land_Fertility1.Land_Fert_Degr_Rt.y_vals[5]→0.5

Figure 6. Table Land_Fertility1.Land_Fert_Deg_Rt, with default values. A value of 0.0 for Land_Fertility1.Land_Fert_Deg_Rt of 0.0 signifies that the pollution effect on land fertility degradation rate “no different” from pollution effects on the land fertility degradation rate in 1970; a value 0.n strictly between 0 and 1 implies that the land fertility degradation rate, is 1.n times the land fertility degradation rate in 1970. For example, if the persistent pollution index is 20 times that of 1970 (Land_Fertility1.Land_Fert_Degr_Rt.x_vals[3]→20.0), the resulting Land_Fertility1.Land_Fert_Deg_Rt (Land_Fertility1.Land_Fert_Degr_Rt.y_vals[3]→0.3), i.e., the land fertility degradation rate is 1.3 times what it was in 1970.

For each of Benchmark Scenarios 1-9, the Land Fertility Degradation Rate yvals were changed as shown in Figure 7, and the results were executed on the platform described in Section 2. The variables shown in Figure 3 were plotted.

Land_Fertility1.Land_Fert_Degr_Rt.y_vals[1]→0.0
Land_Fertility1.Land_Fert_Degr_Rt.y_vals[2]→0.3
Land_Fertility1.Land_Fert_Degr_Rt.y_vals[3]→0.5
Land_Fertility1.Land_Fert_Degr_Rt.y_vals[4]→0.7
Land_Fertility1.Land_Fert_Degr_Rt.y_vals[5]→0.7

Figure 7. Modified values of Land Fertility Degradation Rates. (These values represent, to one significant figure, the largest Land_Fertility1.Land_Fert_Degr_Rt.y_vals consistent with World3’s internal smoothing functions, integration algorithms, and explicit limits on the values of its parameters and variables.)

Because of memory-management limitations of the platform described in Section 2, I distributed the computations in the study across 18 *Mathematica* “notebook” files, one file for each line in Figure 8 for Appendices 1-45, and one file each of Appendices 46-54 as shown in Figure 8.

Appendices 1-5:	Experiments 1-5 on Benchmark Scenario 1
Appendices 6-10:	Experiments 1-5 on Benchmark Scenario 2
Appendices 11-15:	Experiments 1-5 on Benchmark Scenario 3
Appendices 16-20:	Experiments 1-5 on Benchmark Scenario 4
Appendices 21-25:	Experiments 1-5 on Benchmark Scenario 5
Appendices 26-30:	Experiments 1-5 on Benchmark Scenario 6
Appendices 31-35:	Experiments 1-5 on Benchmark Scenario 7
Appendices 36-40:	Experiments 1-5 on Benchmark Scenario 8
Appendices 41-45:	Experiments 1-5 on Benchmark Scenario 9
Appendices 46-54:	Land Fertility Degradation experiments on Benchmark Scenarios 1-9

Figure 8. Cross-reference of Benchmark Scenarios/Experiments and Appendices.

Each execution run was saved both as a *Mathematica* “notebook” (executable) file, and as a PDF file. The resulting PDF files were concatenated under *PDF Shaper* (Burnaware 2019).

The Appendices (~370 pages) can be found on #AUTHORPERSONALWEBSITE.

3.0 Results

The Appendices provide an expansive picture of the sensitivity of the variables in Figure 3 to the conditions described in Experiments 1-5 (on the Benchmark Scenarios). Table 1 summarizes the effects, in *World3*, of loss of land productivity on some population-size metrics.

Table 1. Some *World3* population-size metrics as a function of scenario. The population minimum in all scenarios is 1.6 billion; the year of population minimum, 1900. Maximum and minimum population values were extracted by the software shown in the Appendices. The time of maximum population was obtained by interactively querying plots in the Appendices using the *Mathematica* function “Get Coordinates”. Values in rightmost column of the table are rounded.

Base Scenario	Parameters changed (relative to base scenario)	Population Maximum (billion)	Time of Population Maximum	Percentage change of population max. compared to base scenario
Benchmark 1	none	8.4	2032	0
Benchmark 1	Figure 4	6.8	2056	-19
Benchmark 1	Figure 5	6.4	2058	-24
Benchmark 1	t_air_poll_time = 1970	8.4	2032	0
Benchmark 1	t_air_poll_time = 2020	8.4	2032	0
Benchmark 1	Figure 6	7.6	2031	-10
Benchmark 2	none	9.2	2046	0
Benchmark 2	Figure 4	7.1	2069	-23
Benchmark 2	Figure 5	6.6	2069	-28
Benchmark 2	t_air_poll_time = 1970	9.2	2045	0
Benchmark 2	t_air_poll_time = 2020	9.2	2044	0
Benchmark 2	Figure 6	7.8	2034	-15

Benchmark 3	none	9.3	2050	0
Benchmark 3	Figure 4	7.8	2100	-15
Benchmark 3	Figure 5	7.0	2100	-25
Benchmark 3	t_air_poll_time = 1970	9.3	2047	0
Benchmark 3	t_air_poll_time = 2020	9.3	2048	0
Benchmark 3	Figure 6	8.2	2100	-12
Benchmark 4	none	9.5	2055	0
Benchmark 4	Figure 4	8.1	2087	-15
Benchmark 4	Figure 5	7.5	2084	-21
Benchmark 4	t_air_poll_time = 1970	9.5	2057	0
Benchmark 4	t_air_poll_time = 2020	9.5	2054	0
Benchmark 4	Figure 6	9.1	2071	-4
Benchmark 5	none	10	2079	0
Benchmark 5	Figure 4	8.8	2100	-12
Benchmark 5	Figure 5	7.8	2100	-22
Benchmark 5	t_air_poll_time = 1970	10	2080	0
Benchmark 5	t_air_poll_time = 2020	10	2078	0
Benchmark 5	Figure 6	10	2100	0
Benchmark 6	none	10	2100	0
Benchmark 6	Figure 4	8.3	2100	-17
Benchmark 6	Figure 5	7.5	2100	-25
Benchmark 6	t_air_poll_time = 1970	10	2100	0
Benchmark 6	t_air_poll_time = 2020	10	2100	0
Benchmark 6	Figure 6	9.1	2100	-9
Benchmark 7	none	7.9	2042	0
Benchmark 7	Figure 4 ¹⁴	ND	ND	ND

¹⁴ This scenario aborts due an ASSERT failure.

Benchmark 7	Figure 5	5	2060	-37
Benchmark 7	t_air_poll_time = 1970	7.9	2044	0
Benchmark 7	t_air_poll_time = 2020	7.9	2044	0
Benchmark 7	Figure 6	6.9	2035	-14
Benchmark 8	none	7.8	2039	0
Benchmark 8	Figure 4	5.5	2060	-29
Benchmark 8	Figure 5	5.1	2055	-35
Benchmark 8	t_air_poll_time = 1970	7.8	2040	0
Benchmark 8	t_air_poll_time = 2020	7.8	2038	0
Benchmark 8	Figure 6	7.0	2030	-11
Benchmark 9	none	8.5	2100	0
Benchmark 9	Figure 4	5.8	2090	-32
Benchmark 9	Figure 5	5.6	2090	-35
Benchmark 9	t_air_poll_time = 1970	8.5	2100	0
Benchmark 9	t_air_poll_time = 2020	8.5	2100	0
Benchmark 9	Figure 6	7.8	2100	-8

Each of the notebooks for Appendices 1-45 executed in ~20 minutes on the platform described in Section 2.0; each of the notebooks for Appendices 46-54 on the same platform executed in ~5 minutes.

4.0 Discussion and conclusions

The results in Section 3 show that in the scenarios described in Section 2, *World3* projects that (in the worst case) the peak size of the human population would be reduced by 19% - 37% by the effects of land yield loss due to the modifications shown in Figures 4 and 5, depending on scenario, compared to the peak human population size in the unmodified *World3* Benchmark scenarios. The simulator projects that (in the worst case) the peak size of the human population would be reduced by 4% - 15%, depending on scenario, due to the modifications shown in Figure 6, compared to the peak human population size in the unmodified *World3* Benchmark scenarios.

Experiments 1-5 probe *World3*'s sensitivity to a range of values of `Pollution_Dynamics1.P_Yield_Mult_Air_Poll` without regard to whether these values correspond to anything in the actual trajectory of the world system. If *World3* is to be used to help estimate the sensitivity of human population dynamics to loss of land productivity due to GHGs in the *actual* world system, we must provide *World3* with at least a rough approximation of the GHG/land_productivity relationship in the actual world system. That relationship is not uniform across GHG and temperature scaling. For increases of < 2 C above the 2019 average global temperature, the relationship is plausibly linear. For increases of > 5 C above the 2019 average global temperature, highly nonlinear climate changes including widespread changes in precipitation patterns are likely to have strong nonlinear effects on land productivity (IPCC 2019, Chap. 2).

Liu et al. 2016 and Asseng et al. 2015 have estimated that a 1 – 5 C increase in temperature above 2015/2016 values will result in a loss of ~5% of wheat production. If we adopt this “wheat”-oriented temperature-land-productivity-loss relationship as a proxy for land productivity, a 2 C increase in temperature above 2015/2016 values would result in a ~10% loss of land productivity, corresponding to a nominal value of $(1 - 0.1 =) 0.9$ for `Pollution_Dynamics1.P_Yield_Mult_Air_Poll`. 0.9 is well above the largest `yval` (0.7) in Figure 4. In that case, we would expect that a linearized effect of a 2 C temperature increase on population size to be smaller than what is shown in Table 1 for Figure 4. Table 1 shows that Benchmark Scenario 1 (“business-as-usual”), modified as noted in Figure 4, implies that depletion of land productivity will reduce the peak size of the human population by ~20%. Subject to all the caveats and assumptions above, therefore, the *World3* prediction of the sensitivity of population size to GHGs is consistent, to within a factor of two, with the linearized extrapolation of the GHG/wheat-production relationship estimated by Liu et al. 2016 and Asseng et al. 2015.

Changing (only) the value of `t_air_poll_time` in any of the Benchmark Scenarios has no effect on the predictions of population peak size, under the conditions simulated, compared to the peak population predicted by the unmodified Benchmark Scenarios.

5.0 Acknowledgements

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6.0 References

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APPENDIX 1. BENCHMARK SCENARIO 1, Experiment 1

Define a function that extracts range data from scenario data. (The right-hand-side of this definition is specific to a *World3* data structure and assumes that the function whose range is being extracted is globally (i.e., not piecewise) defined.)

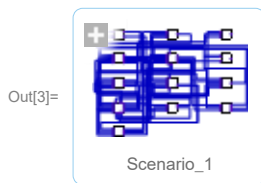
```
In[1]:= RangeData[data_] := data[[1]][[4]][[3]];
```

Define a procedure to determine and print minimum and maximum of “y” values.

```
In[2]:= MinAndMax[data_] := (myscenseries = RangeData[data];  
Print["Maximum is ", Max[myscenseries]]; Print["Minimum is ", Min[myscenseries]])
```

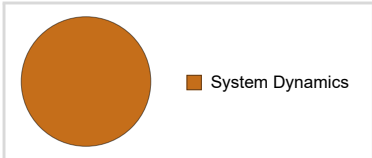
Here are some high-level properties of Benchmark Scenario 1.

```
In[3]:= mysim = SystemModel["SystemDynamics.WorldDynamics.World3.Scenario_1"]
```



```
In[4]:= mysummary = mysim["Summary"]
```

Out[4]=

ModelName	SystemDynamics.WorldDynamics.World3.Scenario_1
Description	Original WORLD3 model
SimulationModel	True
Plots	0
Components	106
Balanced	True
SystemEquations	1583
SystemVariables	1583
Domain	

Show the value of `t_air_poll_time`.

```
In[5]:= SystemModel[mysim][{"ParameterValues", "t_air_poll_time"}]
```

```
Out[5]= {t_air_poll_time → 4000}
```

Show `Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals`.

```
In[6]:= SystemModel[mysim][
  {"ParameterValues", "Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[1]"}]
```

```
Out[6]= {Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[1] → 1}
```

```
In[7]:= SystemModel[mysim][
  {"ParameterValues", "Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[2]"}]
```

```
Out[7]= {Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[2] → 1}
```

```
In[8]:= SystemModel[mysim][
  {"ParameterValues", "Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[3]"}]
```

```
Out[8]= {Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[3] → 0.7}
```

```
In[9]:= SystemModel[mysim][
  {"ParameterValues", "Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[4]"}]
```

```
Out[9]= {Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[4] → 0.4}
```

Show `Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_2.y_vals`.

```
In[10]:= SystemModel[mysim][
  {"ParameterValues", "Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_2.y_vals[1]"}]
```

```
Out[10]= {Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_2.y_vals[1] → 1}
```

```
In[11]:= SystemModel[mysim][
  {"ParameterValues", "Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_2.y_vals[2]"}]
```

```
Out[11]= {Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_2.y_vals[2] → 1}
```

```
In[12]:= SystemModel[mysim][
  {"ParameterValues", "Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_2.y_vals[3]"}]
```

```
Out[12]= {Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_2.y_vals[3] → 0.98}
```

```
In[13]:= SystemModel[mysim][
  {"ParameterValues", "Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_2.y_vals[4]"}]
```

```
Out[13]= {Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_2.y_vals[4] → 0.95}
```

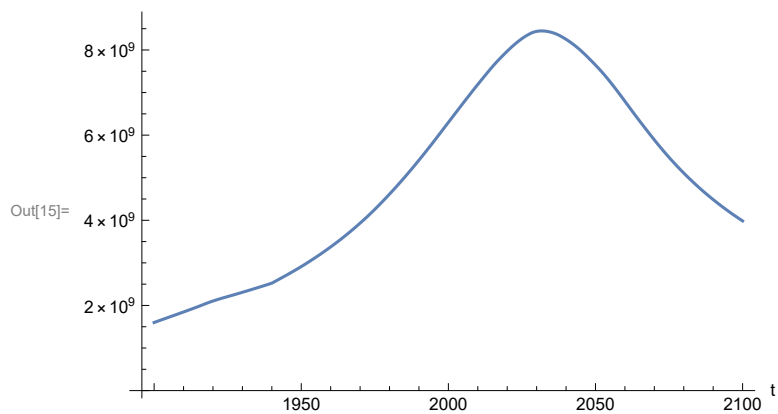
Execute Benchmark Simulation 1 and plot the variables shown in Figure 2.

In[14]:= **basesim = SystemModelSimulate[mysim]**

Out[14]= SystemModelSimulationData [ Model: Scenario_1
Time: 1.90×10^3 to 2.10×10^3]

Plot total population, people.

In[15]:= **SystemModelPlot[basesim, {"Population_Dynamics1.Birth_Rate.pop"}]**



Find max and min of population values.

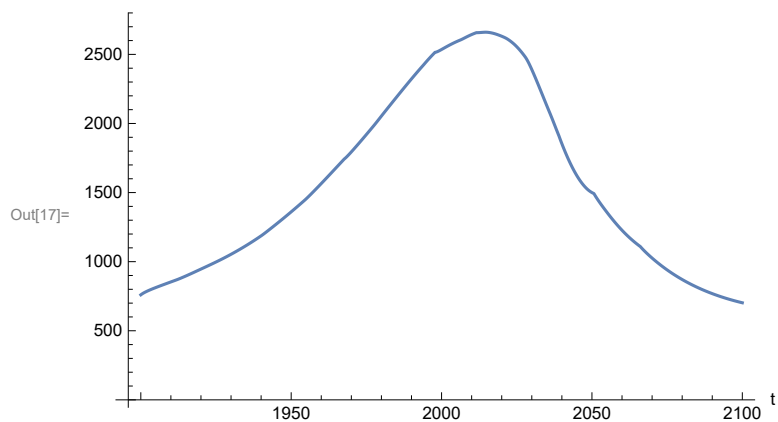
In[16]:= **MinAndMax[basesim[{"Population_Dynamics1.Birth_Rate.pop"}]]**

Maximum is 8.4473×10^9

Minimum is 1.6×10^9

Plot land yield.

In[17]:= **SystemModelPlot[basesim, {"Food_Production1.Land_Yield.y"}]**



Find max and min of y values.

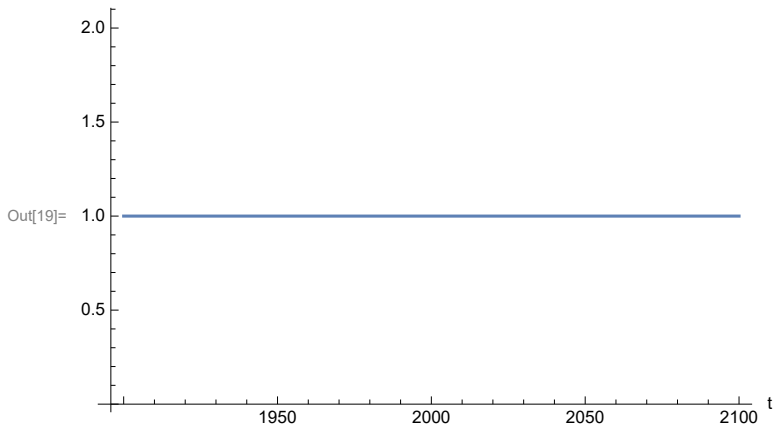
```
In[18]:= MinAndMax[basesim[{"Food_Production1.Land_Yield.y"}]]
```

Maximum is 2660.5

Minimum is 702.5

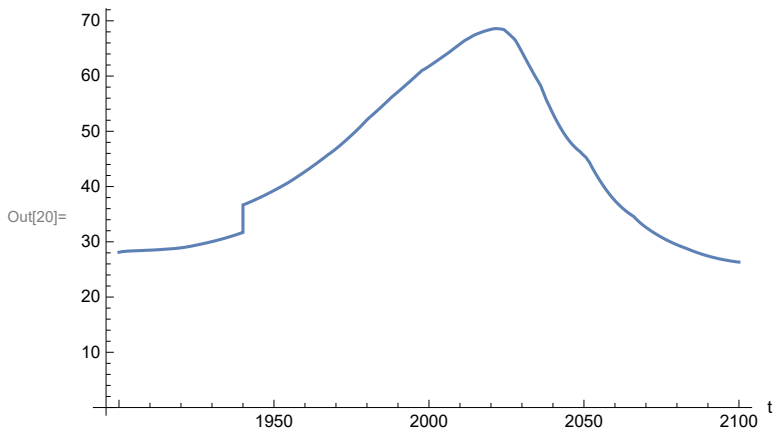
Plot multiplier of air pollution on land yield.

```
In[19]:= SystemModelPlot[basesim, {"Food_Production1.s_yield_mlt_air_poll"}]
```



Plot life expectancy, years.

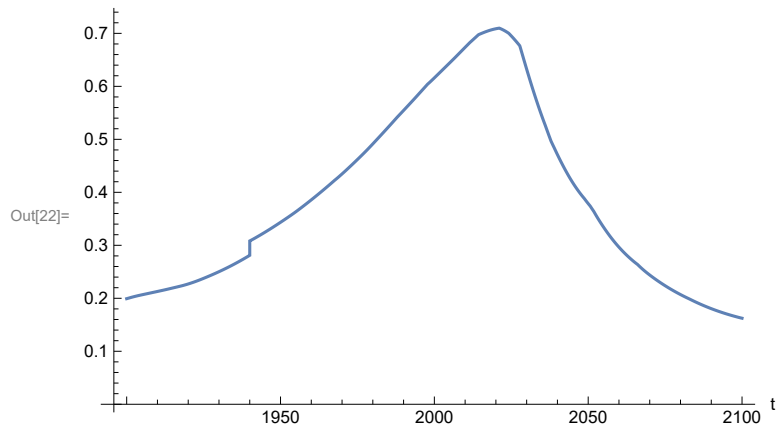
```
In[20]:= SystemModelPlot[basesim, {"Life_Expectancy1.Life_Expectancy.y"}]
```



```
In[21]:=
```

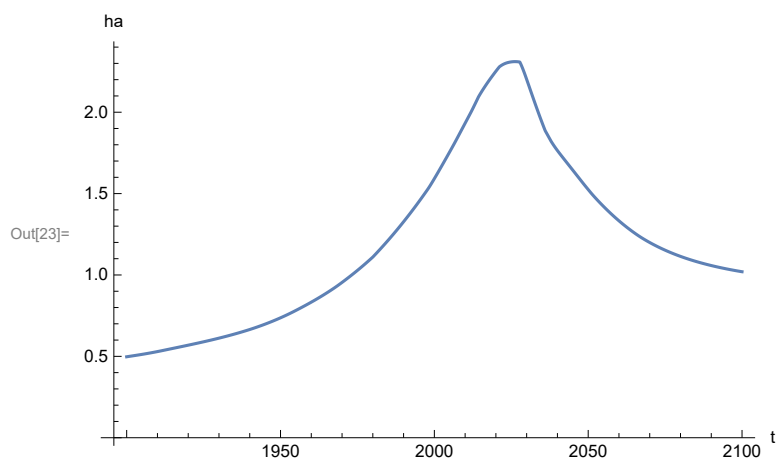
Plot human welfare index.

```
In[22]:= SystemModelPlot[basesim,
  {"Human_Welfare_Index1.HWI_Human_Welfare_Index.hwi_human_welfare_index"}]
```



Plot per capita ecological footprint, hectares.

```
In[23]:= SystemModelPlot[basesim,
  {"Human_Ecological_Footprint1.HEF_Human_Ecological_Footprint.hef_human_ecological_
    _footprint"}]
```



Find max and min of y values.

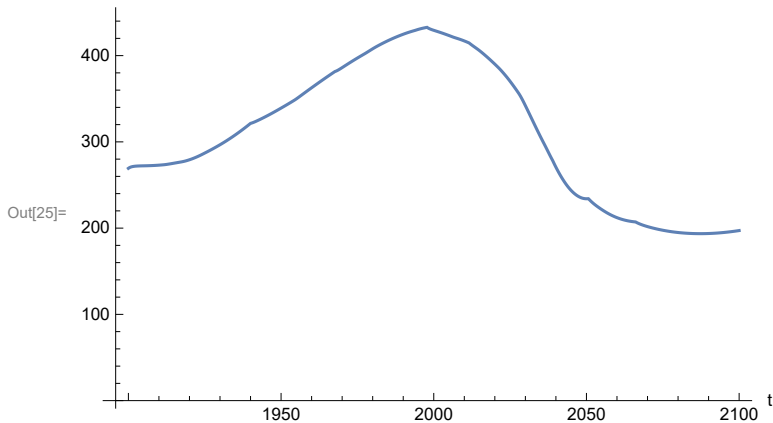
```
In[24]:= MinAndMax[basesim[
  {"Human_Ecological_Footprint1.HEF_Human_Ecological_Footprint.hef_human_ecological_
    _footprint"}]]
```

Maximum is 2.31082

Minimum is 0.497387

Plot food production per capita (kg/year).

```
In[25]:= SystemModelPlot[basesim, {"Food_Production1.Food_PC.y"}]
```



Find max and min of y values.

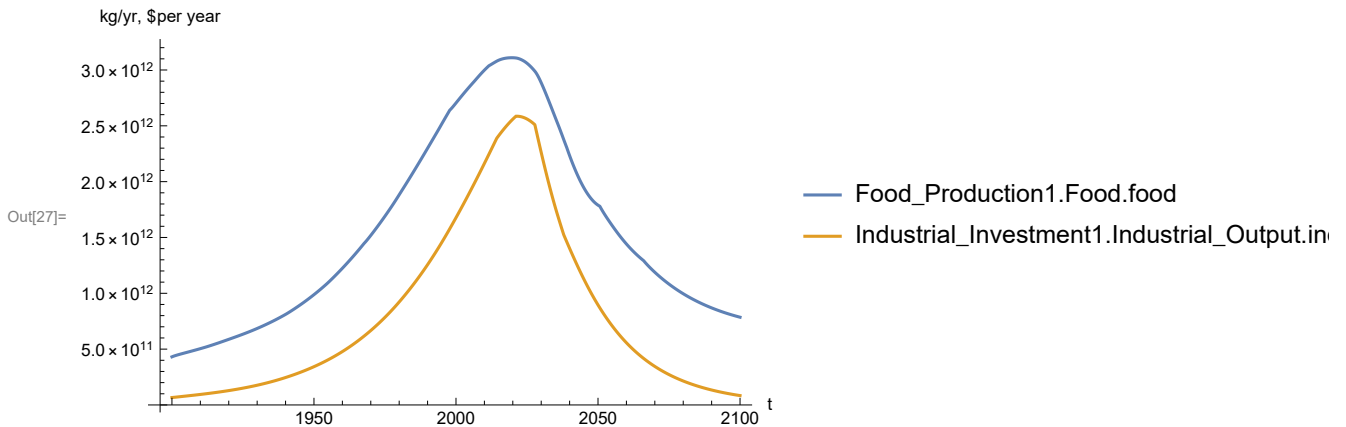
```
In[26]:= MinAndMax[basesim[{"Food_Production1.Food_PC.y"}]]
```

Maximum is 432.786

Minimum is 193.587

Plot total food production (kg/year), and industrial output (dollars/year).

```
In[27]:= SystemModelPlot[basesim, {"Food_Production1.Food.food",
    "Industrial_Investment1.Industrial_Output.industrial_output"}]
```



Find max and min of y values.

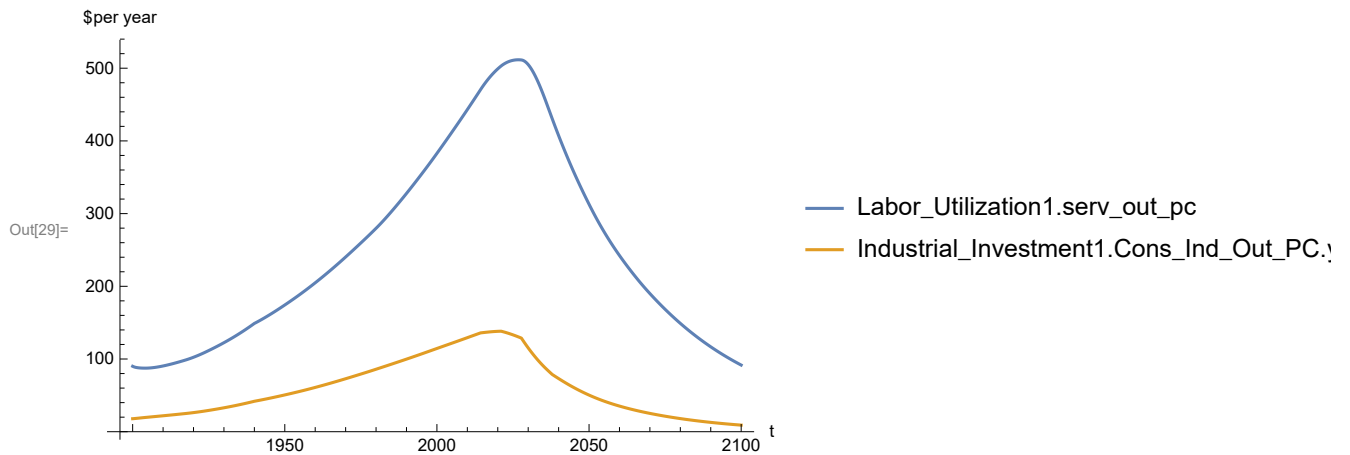
```
In[28]:= MinAndMax[basesim[{"Industrial_Investment1.Industrial_Output.industrial_output"}]]
```

Maximum is 2.58591×10^{12}

Minimum is 6.65×10^{10}

Plot labor utilization per capita (dollars/year), and consolidated industrial output per capita (dollars/year)

```
In[29]:= SystemModelPlot[basesim,
  {"Labor_Utilization1.serv_out_pc", "Industrial_Investment1.Cons_Ind_Out_PC.y"}]
```



Find max and min of y values.

```
In[30]:= MinAndMax[basesim[{"Labor_Utilization1.serv_out_pc"}]]
```

Maximum is 511.592

Minimum is 87.4451

Find max and min of y values.

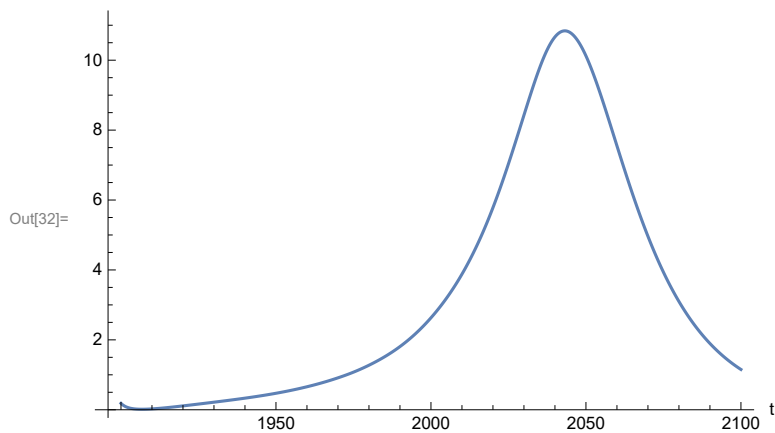
```
In[31]:= MinAndMax[basesim[{"Industrial_Investment1.Cons_Ind_Out_PC.y"}]]
```

Maximum is 138.222

Minimum is 9.05277

Plot persistent pollution index.

```
In[32]:= SystemModelPlot[basesim, {"Pollution_Dynamics1.PPoll_Index.y"}]
```



Find max and min of y values.

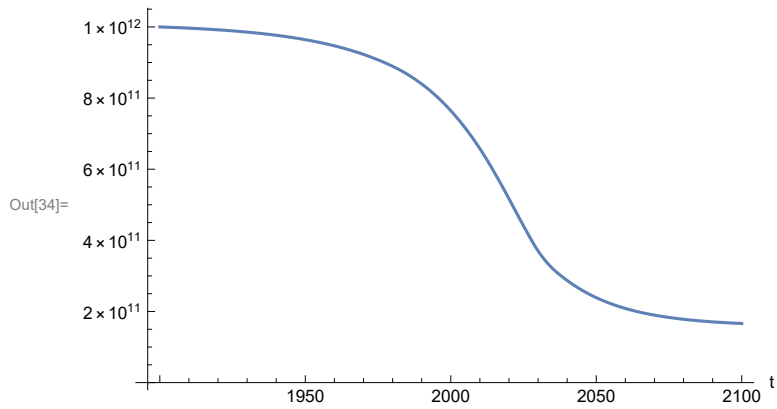

```
In[33]:= MinAndMax[basesim[{"Pollution_Dynamics1.PPoll_Index.y"}]]
```

Maximum is 10.8395

Minimum is 0.0150765

Plot non-renewable resources remaining.

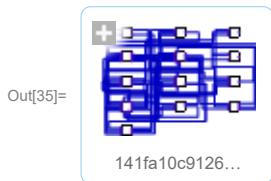
```
In[34]:= SystemModelPlot[basesim, {"NR_Resource_Utilization1.NR_Resources.y"}]
```



APPENDIX 2. Effects of mitigating the impact of air pollution on agricultural land yield, beginning calendar year 2020, Benchmark Scenario 1, Experiment 2

Change the value of the air pollution effect multiplier switch time `t_air_poll_time`, to calendar year 2020, and execute the resulting scenario, plotting the variables shown in Figure 2.

```
In[35]:= newmysim = SystemModel[mysim, <|"ParameterValues" → {"t_air_poll_time" → 2020}|>]
```



```
In[36]:= testsim = SystemModelSimulate[newmysim]
```

Out[36]= SystemModelSimulationData [  Model: W141fa10c912641e9bd4db3e109a1ff32
Time: 1.90×10^3 to 2.10×10^3]

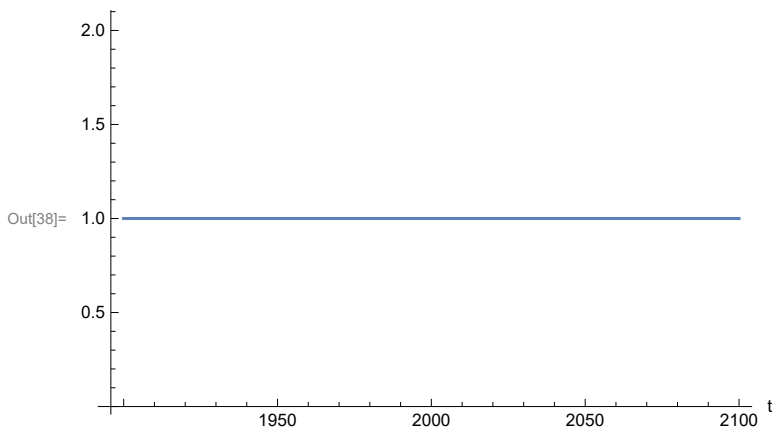
Show the value of `t_air_poll_time` (calendar year).

```
In[37]:= SystemModel[newmysim][{"ParameterValues", "t_air_poll_time"}]
```

Out[37]= {t_air_poll_time → 2020}

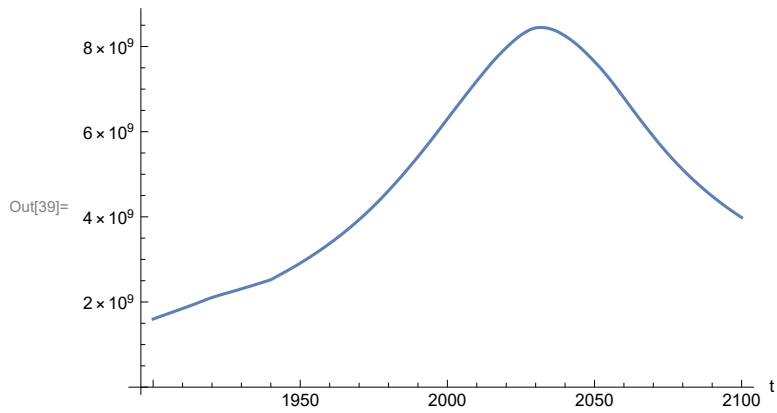
Plot air pollution multiplier of land yield.

```
In[38]:= SystemModelPlot[testsim, {"Food_Production1.s_yield_mlt_air_poll"}]
```



Plot the world population, people.

```
In[39]:= SystemModelPlot[testsim, {"Population_Dynamics1.Birth_Rate.pop"}]
```



Find max and min of y values.

```
In[40]:= MinAndMax[testsim[{"Population_Dynamics1.Birth_Rate.pop"}]]
```

Maximum is 8.4473×10^9

Minimum is 1.6×10^9

Plot land yield.

```
In[41]:= SystemModelPlot[testsim, {"Food_Production1.Land_Yield.y"}]
```



Find max and min of y values.

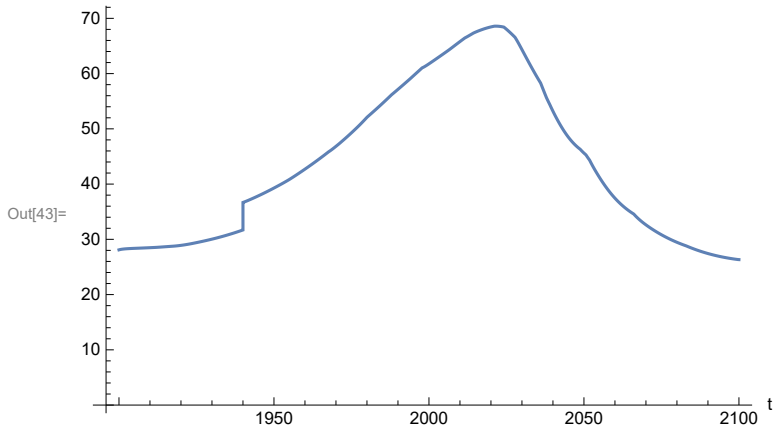
```
In[42]:= MinAndMax[testsim[{"Food_Production1.Land_Yield.y"}]]
```

Maximum is 2660.5

Minimum is 702.5

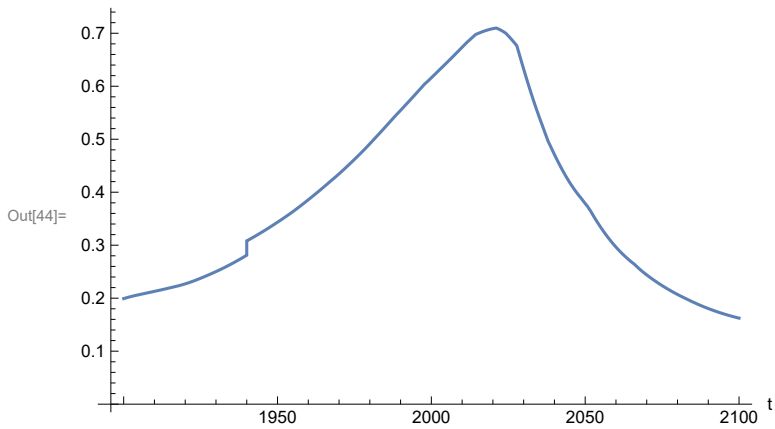
Plot life expectancy, in years.

```
In[43]:= SystemModelPlot[testsim, {"Life_Expectancy1.Life_Expectancy.y"}]
```



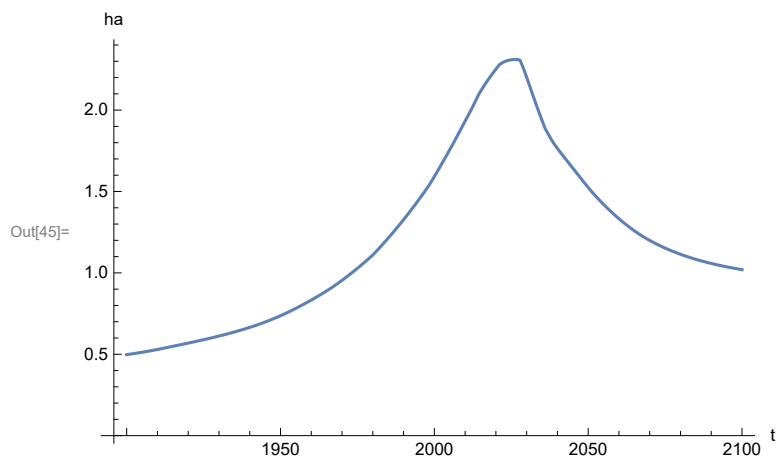
Plot the human welfare index.

```
In[44]:= SystemModelPlot[testsim, {"Human_Welfare_Index1.HWI_Human_Welfare_Index.hwi_human_welfare_index"}]
```



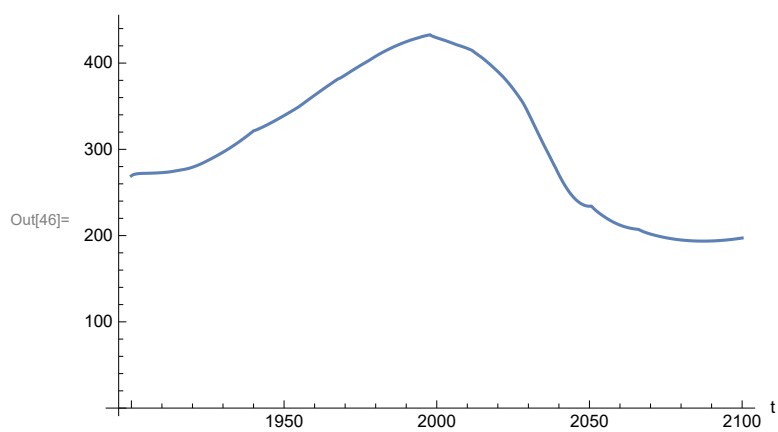
Plot the human ecological footprint, in hectares.

```
In[45]:= SystemModelPlot[testsim,
  {"Human_Ecological_Footprint1.HEF_Human_Ecological_Footprint.hef_human_ecological_
    _footprint"}]
```



Plot per capita food production, kg/year.

```
In[46]:= SystemModelPlot[testsim, {"Food_Production1.Food_PC.y"}]
```



Find max and min of y values.

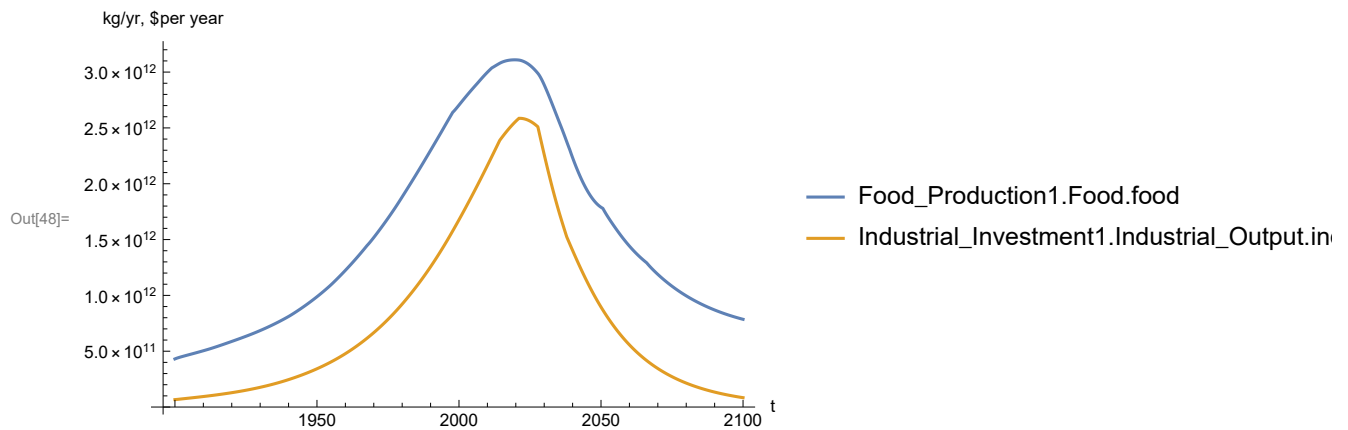
```
In[47]:= MinAndMax[testsim[{"Food_Production1.Food_PC.y"}]]
```

Maximum is 432.786

Minimum is 193.587

Plot total food production (kg/yr) and industrial output (in dollars).

```
In[48]:= SystemModelPlot[testsim, {"Food_Production1.Food.food",
  "Industrial_Investment1.Industrial_Output.industrial_output"}]
```



Find max and min of y values.

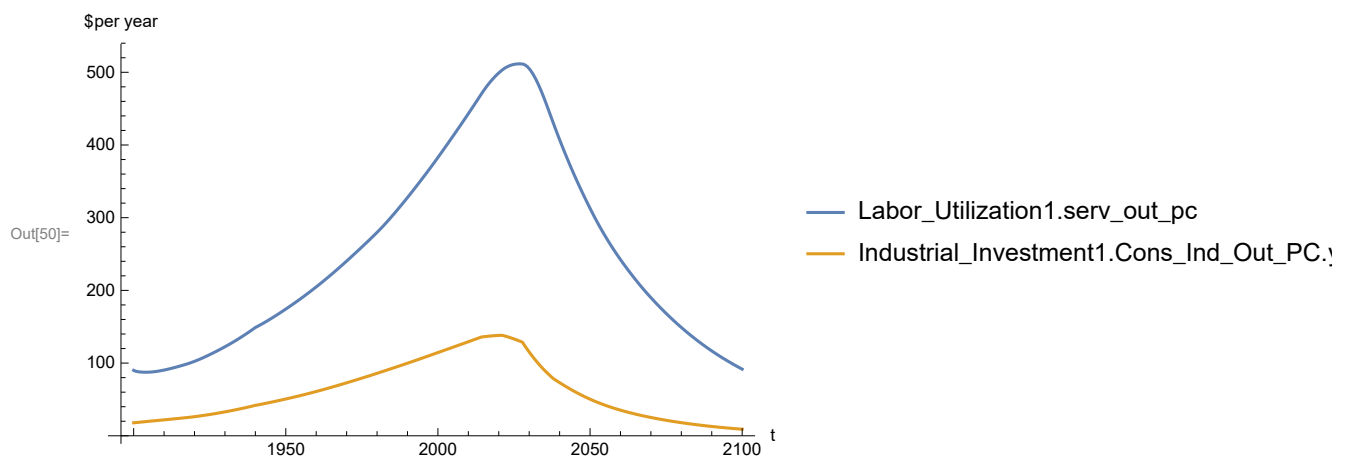
```
In[49]:= MinAndMax[testsim[{"Industrial_Investment1.Industrial_Output.industrial_output"}]]
```

Maximum is 2.58591×10^{12}

Minimum is 6.65×10^{10}

Plot consolidated industrial output per capita (dollars/year).

```
In[50]:= SystemModelPlot[testsim,
  {"Labor_Utilization1.serv_out_pc", "Industrial_Investment1.Cons_Ind_Out_PC.y"}]
```



Find max and min of y values.

```
In[51]:= MinAndMax[testsim[{"Labor_Utilization1.serv_out_pc"}]]
```

Maximum is 511.592

Minimum is 87.4451

Find max and min of y values.

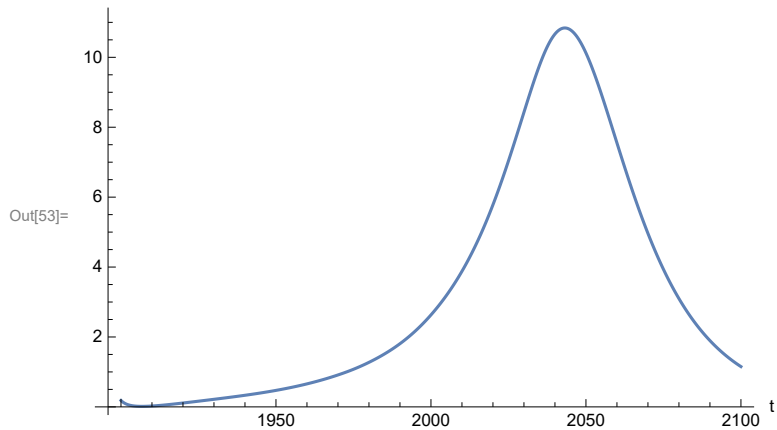
```
In[52]:= MinAndMax[testsim[{"Industrial_Investment1.Cons_Ind_Out_PC.y"}]]
```

Maximum is 138.222

Minimum is 9.05278

Plot persistent pollution index (normalized to 1970 value).

```
In[53]:= SystemModelPlot[testsim, {"Pollution_Dynamics1.PPoll_Index.y"}]
```



Find max and min of y values.

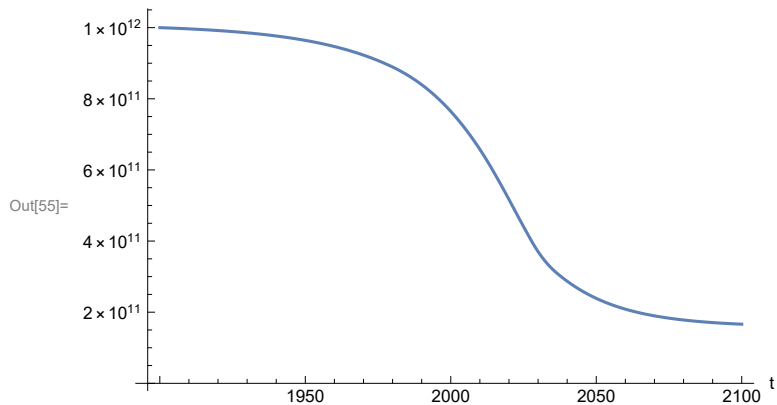
```
In[54]:= MinAndMax[testsim[{"Pollution_Dynamics1.PPoll_Index.y"}]]
```

Maximum is 10.8395

Minimum is 0.0150765

Plot non-renewable resources remaining.

```
In[55]:= SystemModelPlot[testsim, {"NR_Resource_Utilization1.NR_Resources.y"}]
```



APPENDIX 3. Effects of mitigating the impact of air pollution on agricultural land yield, beginning calendar year 1970, Benchmark Scenario 1, Experiment 3

Change the value of the air pollution effect multiplier switch time `t_air_poll_time`, to calendar year 1970, and execute the resulting scenario, plotting the variables shown in Figure 2.

```
In[56]:= newmysim1970 = SystemModel[mysim, <|"ParameterValues" → {"t_air_poll_time" → 1970} |>]
```



```
In[57]:= testsim1970 = SystemModelSimulate[newmysim1970]
```

Out[57]= SystemModelSimulationData [  Model: W39f8393b68184ba7816659eeb5fed82e
Time: 1.90×10^3 to 2.10×10^3]

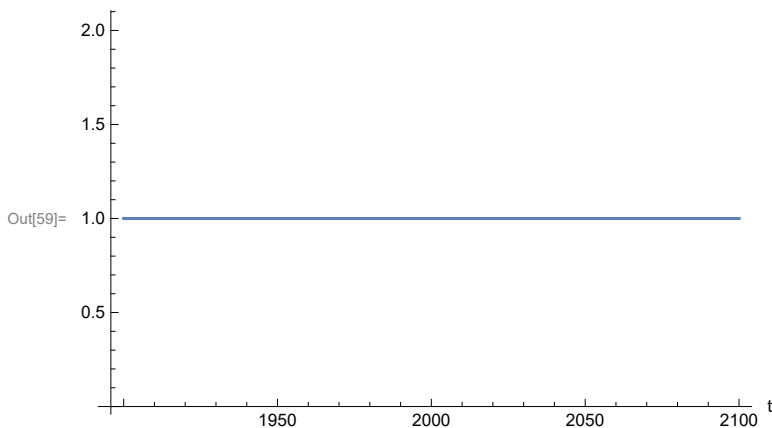
Show the value of `t_air_poll_time` (calendar year).

```
In[58]:= SystemModel[newmysim1970][{"ParameterValues", "t_air_poll_time"}]
```

Out[58]= {t_air_poll_time → 1970}

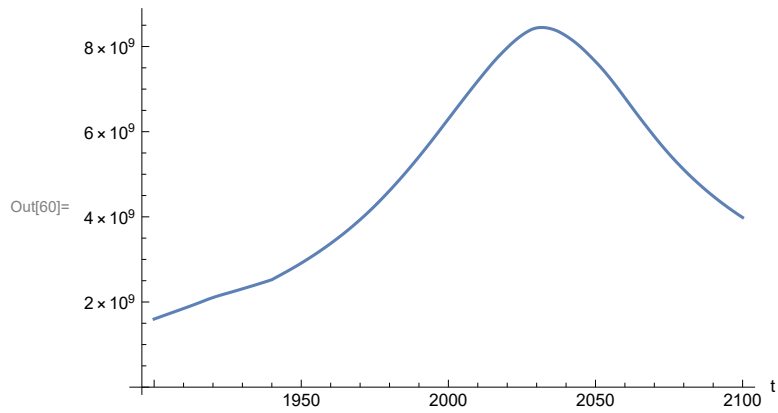
Plot air pollution multiplier of land yield.

```
In[59]:= SystemModelPlot[testsim1970, {"Food_Production1.s_yield_mlt_air_poll"}]
```



Plot the world population, people.

```
In[60]:= SystemModelPlot[testsim1970, {"Population_Dynamics1.Birth_Rate.pop"}]
```



Find max and min of y values.

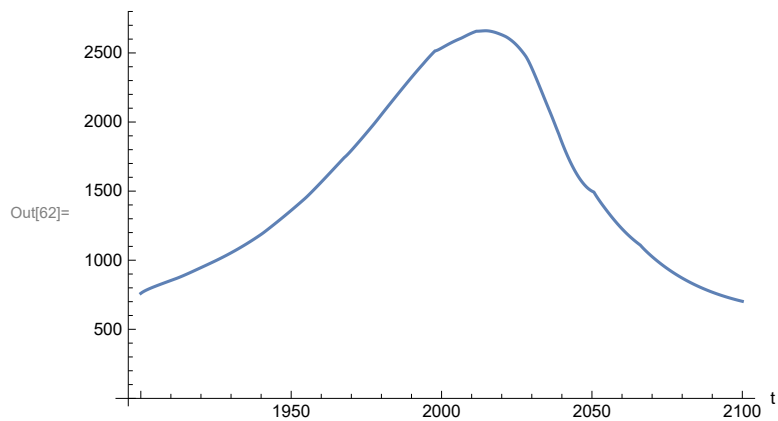
```
In[61]:= MinAndMax[testsim1970[{"Population_Dynamics1.Birth_Rate.pop"}]]
```

Maximum is 8.4473×10^9

Minimum is 1.6×10^9

Plot land yield.

```
In[62]:= SystemModelPlot[testsim1970, {"Food_Production1.Land_Yield.y"}]
```



Find max and min of y values.

```
In[63]:= MinAndMax[testsim1970[{"Food_Production1.Land_Yield.y"}]]
```

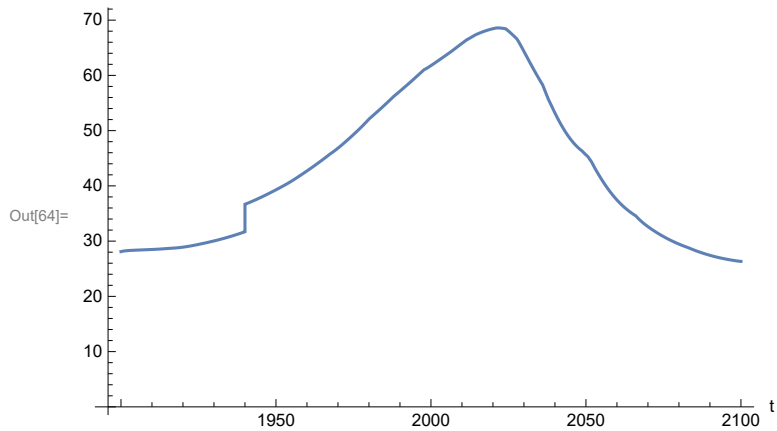
Maximum is 2660.5

Minimum is 702.501

Plot life expectancy, years.

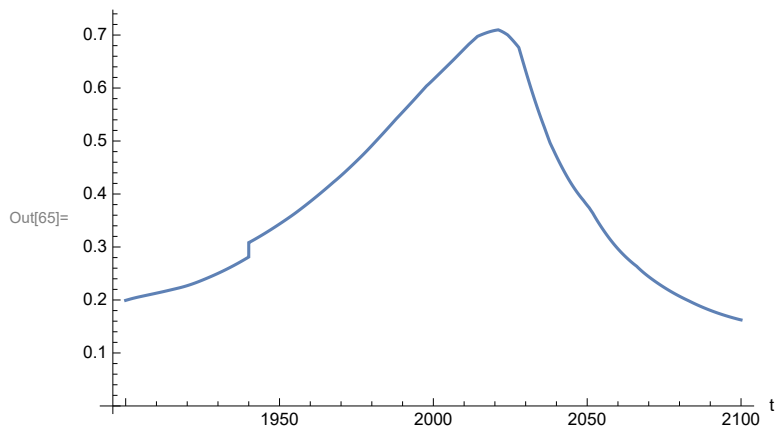
Plot life expectancy, in years.

```
In[64]:= SystemModelPlot[testsim1970, {"Life_Expectancy1.Life_Expectancy.y"}]
```



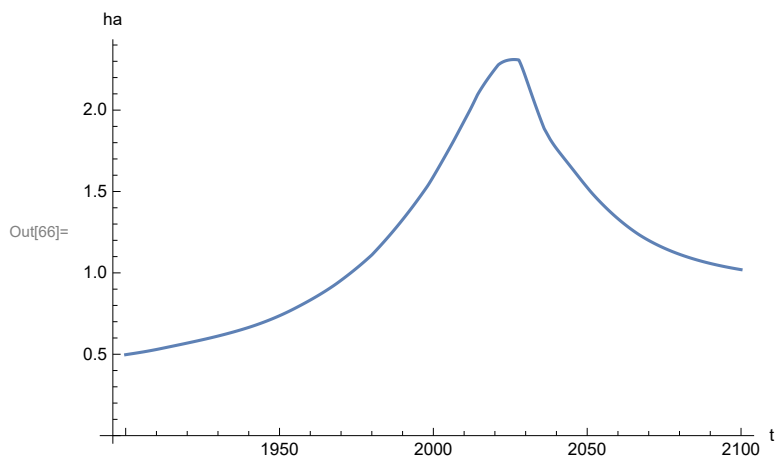
Plot the human welfare index.

```
In[65]:= SystemModelPlot[testsim1970, {"Human_Welfare_Index1.HWI_Human_Welfare_Index.hwi_human_welfare_index"}]
```



Plot the human ecological footprint, in hectares.

```
In[66]:= SystemModelPlot[testsim1970,
  {"Human_Ecological_Footprint1.HEF_Human_Ecological_Footprint.hef_human_ecological_
    _footprint"}]
```



Find max and min of y values.

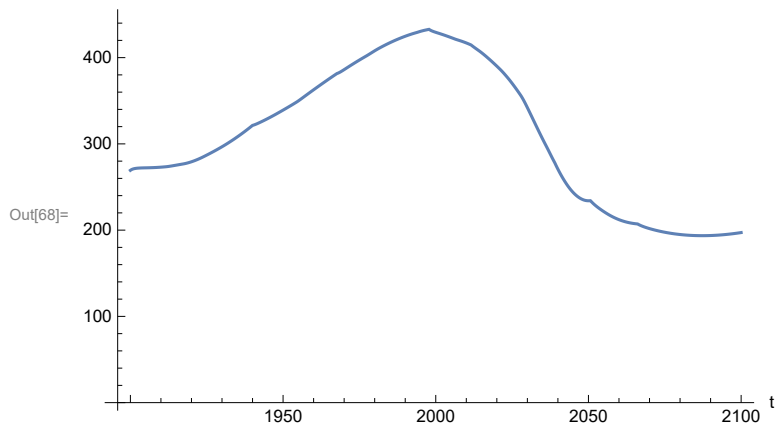
```
In[67]:= MinAndMax[testsim1970[
  {"Human_Ecological_Footprint1.HEF_Human_Ecological_Footprint.hef_human_ecological_
    _footprint"}]]
```

Maximum is 2.31082

Minimum is 0.497387

Plot per capita food production, kg/year.

```
In[68]:= SystemModelPlot[testsim1970, {"Food_Production1.Food_PC.y"}]
```



Find max and min of y values.

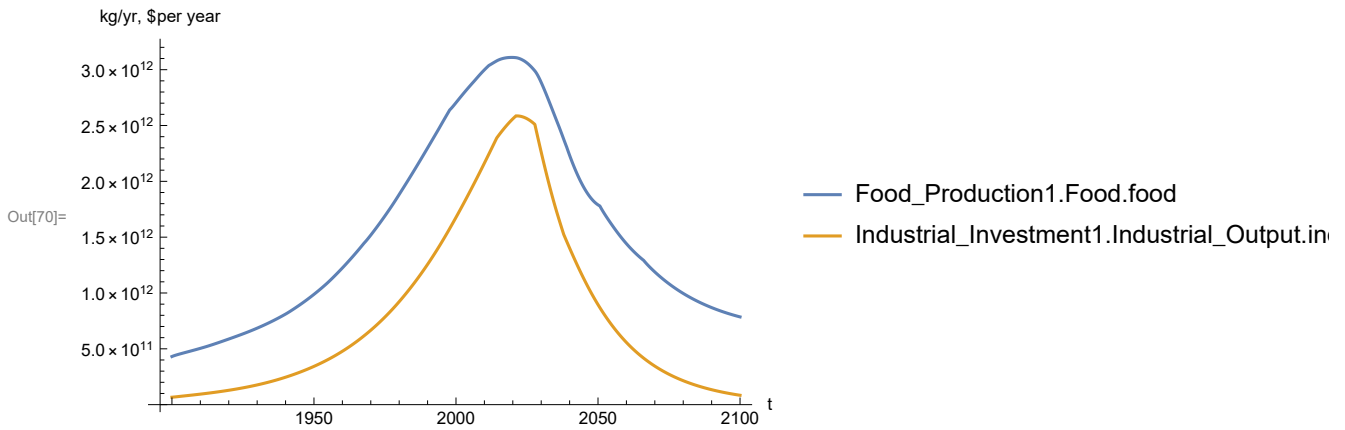
```
In[69]:= MinAndMax[testsim1970[{"Food_Production1.Food_PC.y"}]]
```

Maximum is 432.786

Minimum is 193.587

Plot total food production (kg/yr) and industrial output (in dollars).

```
In[70]:= SystemModelPlot[testsim1970, {"Food_Production1.Food.food",
  "Industrial_Investment1.Industrial_Output.industrial_output"}]
```



Find max and min of y values.

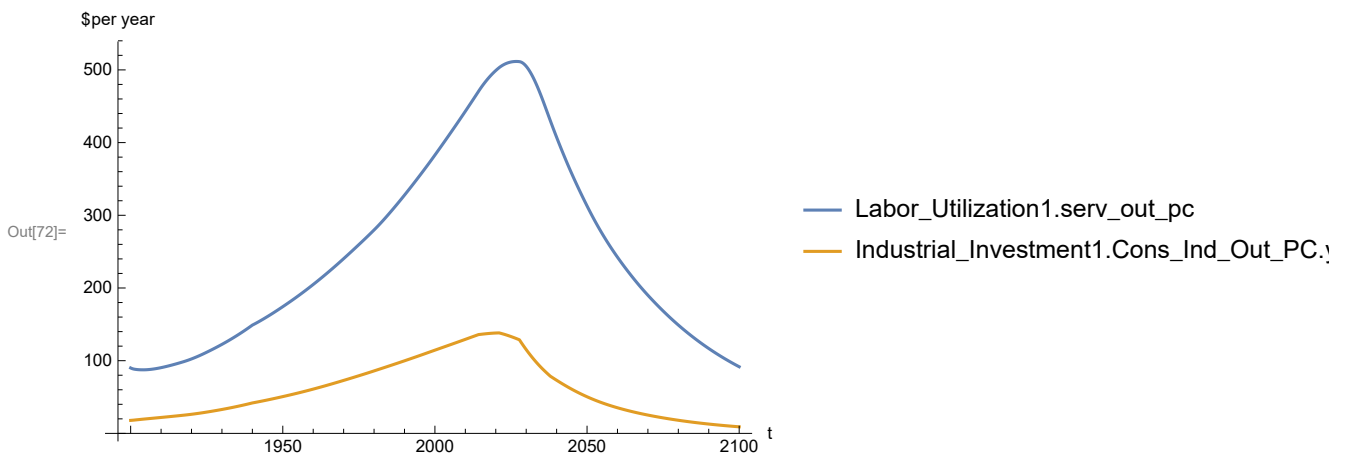
```
In[71]:= MinAndMax[testsim1970[{"Industrial_Investment1.Industrial_Output.industrial_output"}]]
```

Maximum is 2.58591×10^{12}

Minimum is 6.65×10^{10}

Plot labor utilization and consolidated industrial output per capita (dollars/year).

```
In[72]:= SystemModelPlot[testsim1970,
  {"Labor_Utilization1.serv_out_pc", "Industrial_Investment1.Cons_Ind_Out_PC.y"}]
```



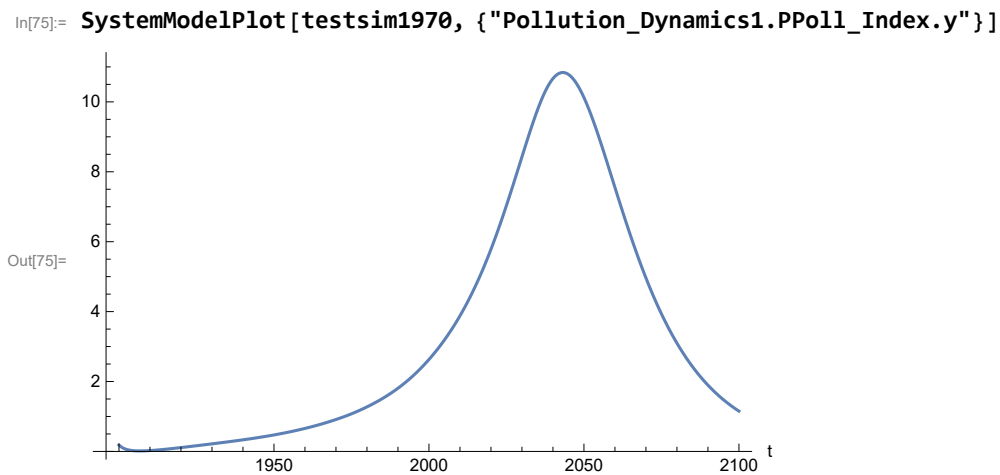
Find max and min of y values.

```
In[73]:= MinAndMax[testsim1970[{"Labor_Utilization1.serv_out_pc"}]]
Maximum is 511.592
Minimum is 87.4451
```

Find max and min of y values.

```
In[74]:= MinAndMax[testsim1970[{"Industrial_Investment1.Cons_Ind_Out_PC.y"}]]
Maximum is 138.222
Minimum is 9.05278
```

Plot persistent pollution index (normalized to 1970 value).

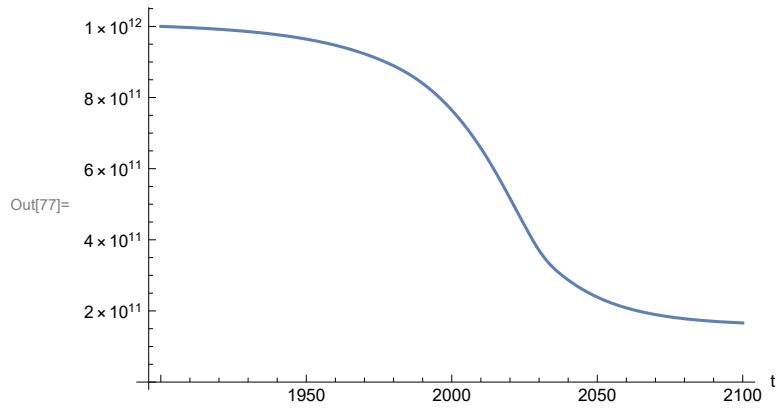


Find max and min of y values.

```
In[76]:= MinAndMax[testsim1970[{"Pollution_Dynamics1.PPoll_Index.y"}]]
Maximum is 10.8395
Minimum is 0.0150765
```

Plot non-renewable resources remaining.

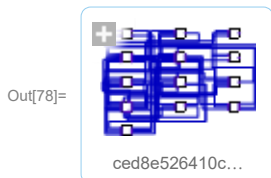
```
In[77]:= SystemModelPlot[testsim1970, {"NR_Resource_Utilization1.NR_Resources.y"}]
```




APPENDIX 4. "STRONG AIR POLLUTION" EFFECTS SCENARIO, Scenario 1, Experiment 4

Scenario 1 with air pollution effect on land yield changed as noted.

```
In[78]:= strsim = SystemModel[mysim, <|"ParameterValues" ->
      {"Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals" -> {0.7, 0.5, 0.3, 0.1}}|>]
```



```
In[79]:= basestrsim = SystemModelSimulate[strsim]
```

Out[79]= SystemModelSimulationData [ Model: Wced8e526410c4f00a58ddece14daee2f
Time: 1.90×10^3 to 2.10×10^3]

Show Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals.

```
In[80]:= SystemModel[strsim] [
      {"ParameterValues", "Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[1]"}]
```

Out[80]= {Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[1] → 0.7}

```
In[81]:= SystemModel[strsim] [
      {"ParameterValues", "Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[2]"}]
```

Out[81]= {Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[2] → 0.5}

```
In[82]:= SystemModel[strsim] [
      {"ParameterValues", "Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[3]"}]
```

Out[82]= {Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[3] → 0.3}

```
In[83]:= SystemModel[strsim] [
      {"ParameterValues", "Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[4]"}]
```

Out[83]= {Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[4] → 0.1}

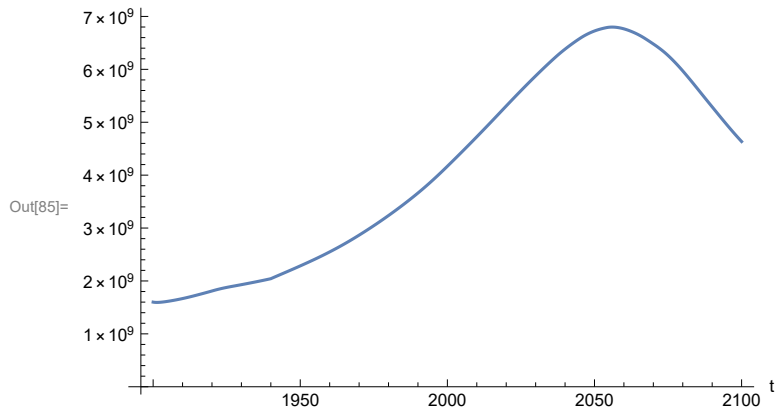
Show the value of t_air_poll_time (calendar year).

```
In[84]:= SystemModel[strsim] [{"ParameterValues", "t_air_poll_time"}]
```

Out[84]= {t_air_poll_time → 4000}

Plot the world population, people.

```
In[85]:= SystemModelPlot[basestransim, {"Population_Dynamics1.Birth_Rate.pop"}]
```



Find max and min of y values.

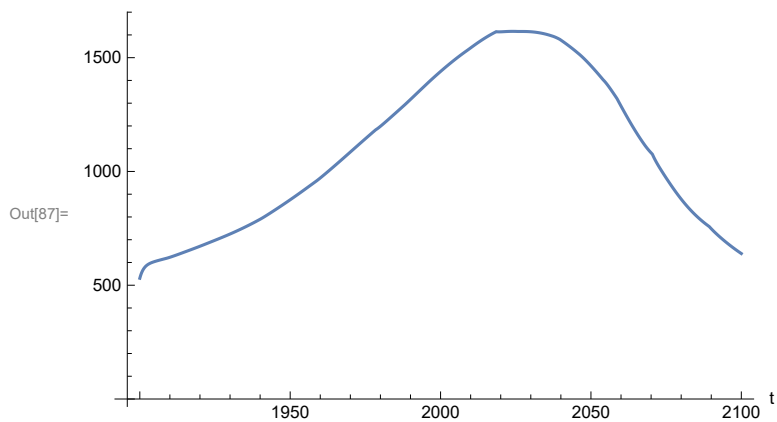
```
In[86]:= MinAndMax[basestransim[{"Population_Dynamics1.Birth_Rate.pop"}]]
```

Maximum is 6.79862×10^9

Minimum is 1.59431×10^9

Plot land yield.

```
In[87]:= SystemModelPlot[basestransim, {"Food_Production1.Land_Yield.y"}]
```



Find max and min of y values.

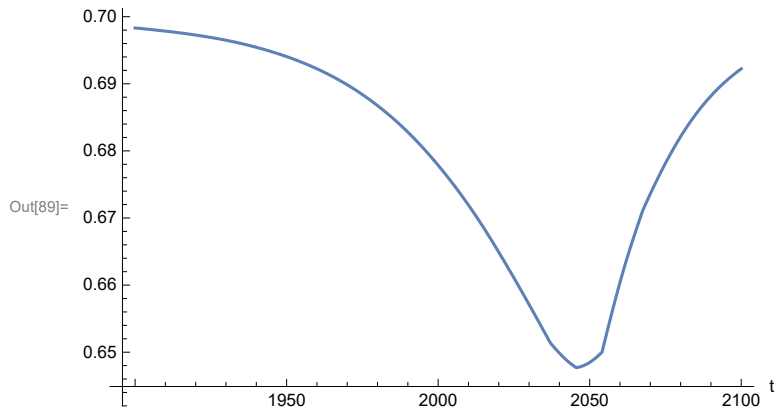
```
In[88]:= MinAndMax[basestransim[{"Food_Production1.Land_Yield.y"}]]
```

Maximum is 1615.65

Minimum is 530.721

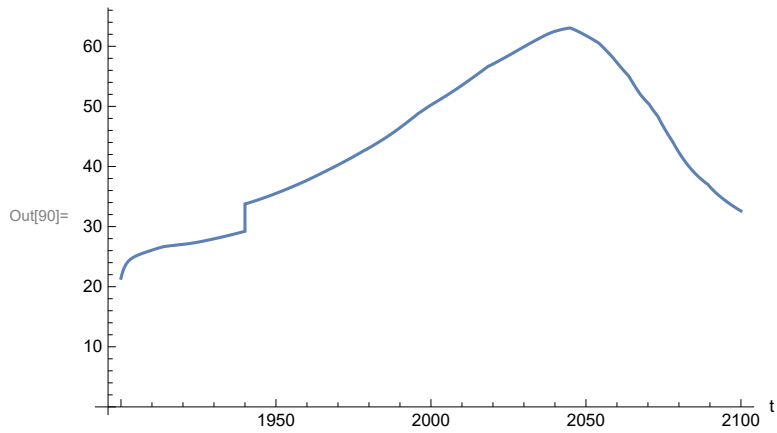
Plot multiplier of air pollution on land yield.

In[89]:= `SystemModelPlot[basestransim, {"Food_Production1.s_yield_mlt_air_poll"}]`



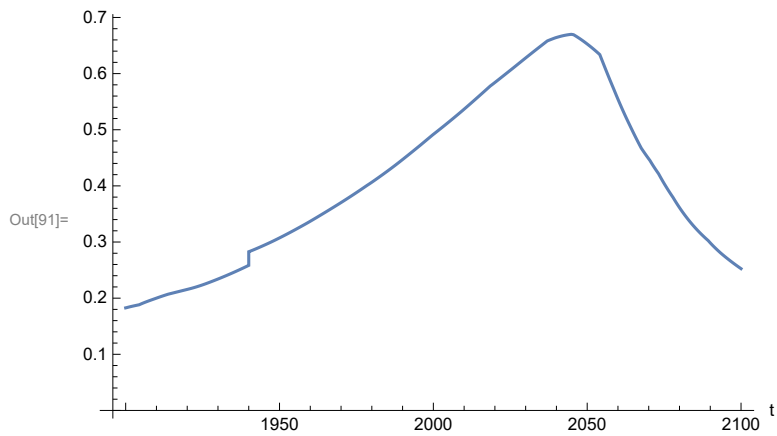
Plot life expectancy, in years.

In[90]:= `SystemModelPlot[basestransim, {"Life_Expectancy1.Life_Expectancy.y"}]`



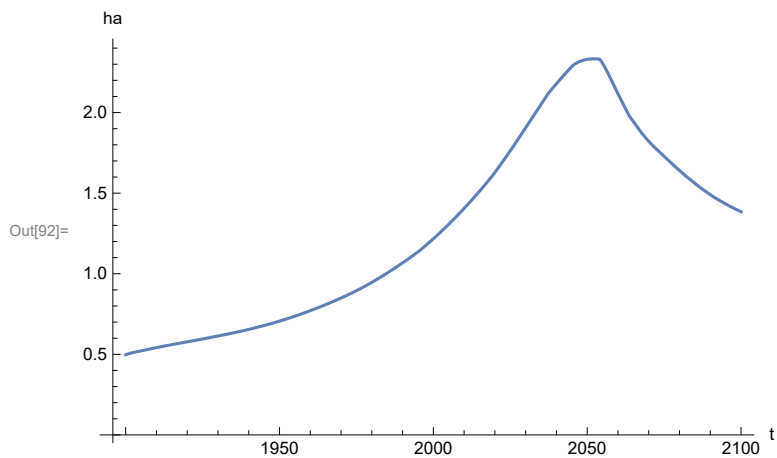
Plot the human welfare index.

```
In[91]:= SystemModelPlot[basestrsim,
  {"Human_Welfare_Index1.HWI_Human_Welfare_Index.hwi_human_welfare_index"}]
```



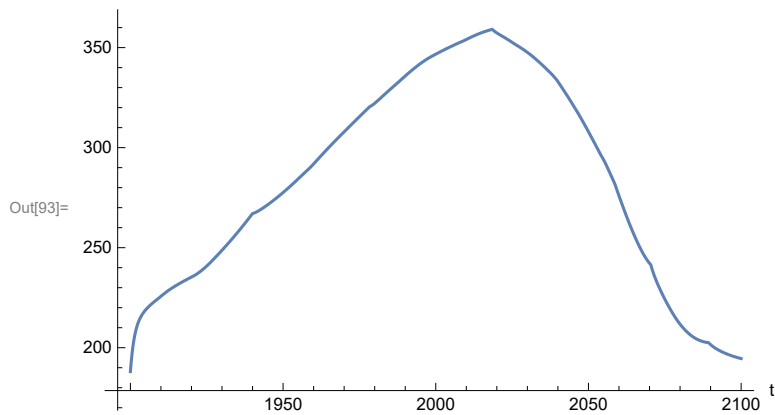
Plot the human ecological footprint, in hectares.

```
In[92]:= SystemModelPlot[basestrsim,
  {"Human_Ecological_Footprint1.HEF_Human_Ecological_Footprint.hef_human_ecological_footprint"}]
```



Plot per capita food production, kg/year. Note that food production per capita in 2100 has fallen to approximately the level it had in 1900 (before the rise of mechanized agriculture).

```
In[93]:= SystemModelPlot[basestransim, {"Food_Production1.Food_PC.y"}]
```



Find max and min of y values.

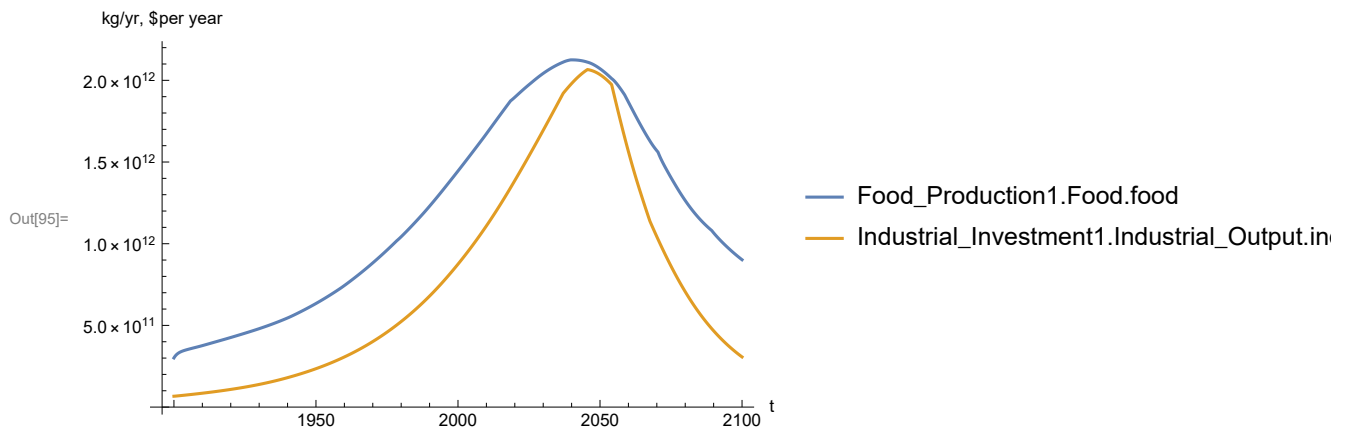
```
In[94]:= MinAndMax[basestransim[{"Food_Production1.Food_PC.y"}]]
```

Maximum is 359.131

Minimum is 188.074

Plot total food production (kg/yr) and industrial output (in dollars).

```
In[95]:= SystemModelPlot[basestransim, {"Food_Production1.Food.food",
    "Industrial_Investment1.Industrial_Output.industrial_output"}]
```



Find max and min of y values.

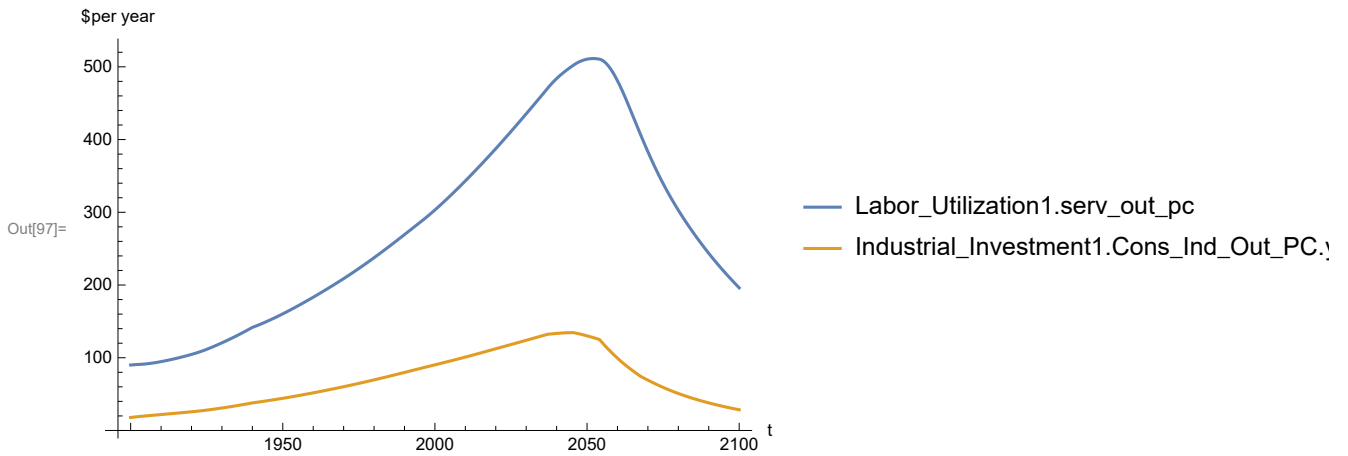
```
In[96]:= MinAndMax[basestransim[{"Industrial_Investment1.Industrial_Output.industrial_output"}]]
```

Maximum is 2.06587×10^{12}

Minimum is 6.65×10^{10}

Plot consolidated industrial output per capita (dollars/year).

```
In[97]:= SystemModelPlot[basestransim,
  {"Labor_Utilization1.serv_out_pc", "Industrial_Investment1.Cons_Ind_Out_PC.y"}]
```



Find max and min of y values.

```
In[98]:= MinAndMax[basestransim[{"Labor_Utilization1.serv_out_pc"}]]
```

Maximum is 511.369

Minimum is 89.9974

Find max and min of y values.

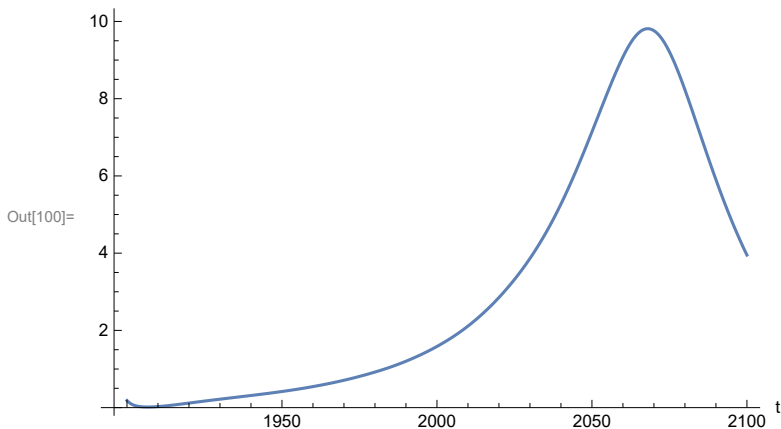
```
In[99]:= MinAndMax[basestransim[{"Industrial_Investment1.Cons_Ind_Out_PC.y"}]]
```

Maximum is 134.533

Minimum is 17.8719

Plot persistent pollution index (normalized to 1970 value).

```
In[100]:= SystemModelPlot[basestransim, {"Pollution_Dynamics1.PPoll_Index.y"}]
```



Find max and min of y values.

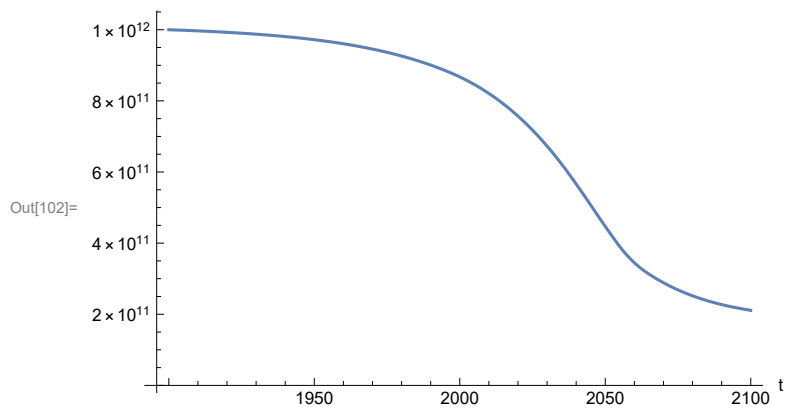
```
In[101]:= MinAndMax[basestrsim[{"Pollution_Dynamics1.PPoll_Index.y"}]]
```

Maximum is 9.81179

Minimum is 0.0157768

Plot non-renewable resources remaining.

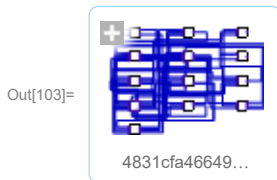
```
In[102]:= SystemModelPlot[basestrsim, {"NR_Resource_Utilization1.NR_Resources.y"}]
```



APPENDIX 5. SEVERE LAND LOSS DUE TO AIR POLLUTION, Scenario 1, Experiment 5

Scenario 1 with air pollution effect on land yield changed as noted.

```
In[103]:= sevsim = SystemModel[mysim, <|"ParameterValues" ->
  {"Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals" -> {0.7, 0.1, 0.1, 0.1}}|>]
```



```
In[104]:= basesevsim = SystemModelSimulate[sevsim]
```

Out[104]= SystemModelSimulationData [Model: W4831cfa466494ec49b162cfc0f911ee
Time: 1.90×10^3 to 2.10×10^3]

Show Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals.

```
In[105]:= SystemModel[sevsim] [
  {"ParameterValues", "Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[1]"}]
```

Out[105]= {Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[1] → 0.7}

```
In[106]:= SystemModel[sevsim] [
  {"ParameterValues", "Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[2]"}]
```

Out[106]= {Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[2] → 0.1}

```
In[107]:= SystemModel[sevsim] [
  {"ParameterValues", "Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[3]"}]
```

Out[107]= {Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[3] → 0.1}

```
In[108]:= SystemModel[sevsim] [
  {"ParameterValues", "Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[4]"}]
```

Out[108]= {Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[4] → 0.1}

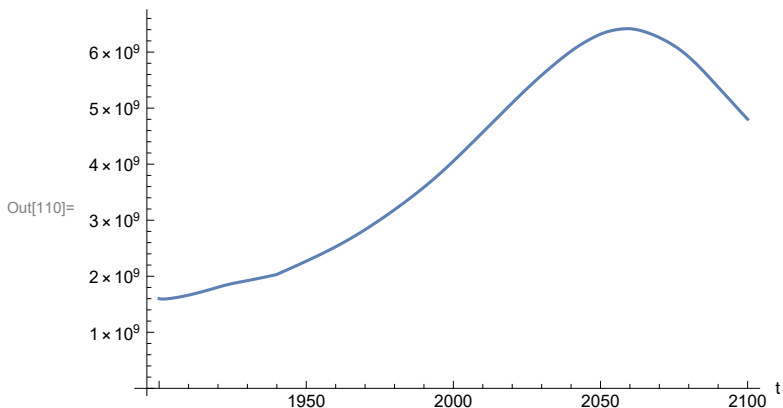
Show the value of t_air_poll_time (calendar year).

```
In[109]:= SystemModel[sevsim][{"ParameterValues", "t_air_poll_time"}]
```

```
Out[109]:= {t_air_poll_time → 4000}
```

Plot the world population, people. Note that the peak population is about one billion less, and about 20 years later, than the peak population forecast by Experiments 1-3.

```
In[110]:= SystemModelPlot[basesevsim, {"Population_Dynamics1.Birth_Rate.pop"}]
```



Find max and min of y values.

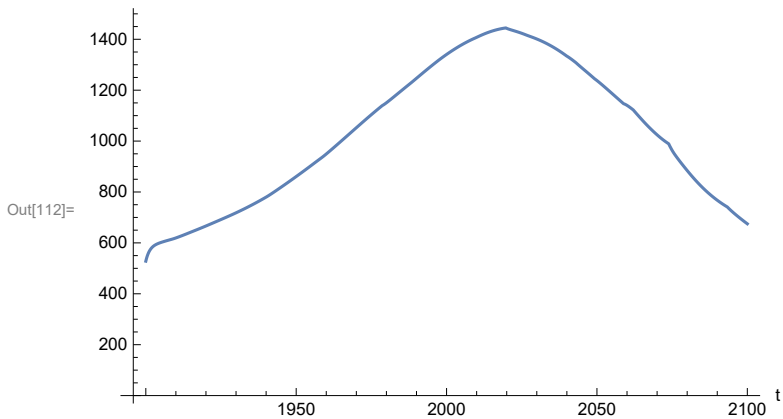
```
In[111]:= MinAndMax[basesevsim[{"Population_Dynamics1.Birth_Rate.pop"}]]
```

Maximum is 6.418×10^9

Minimum is 1.59367×10^9

Plot land yield.

```
In[112]:= SystemModelPlot[basesevsim, {"Food_Production1.Land_Yield.y"}]
```



Find max and min of y values.

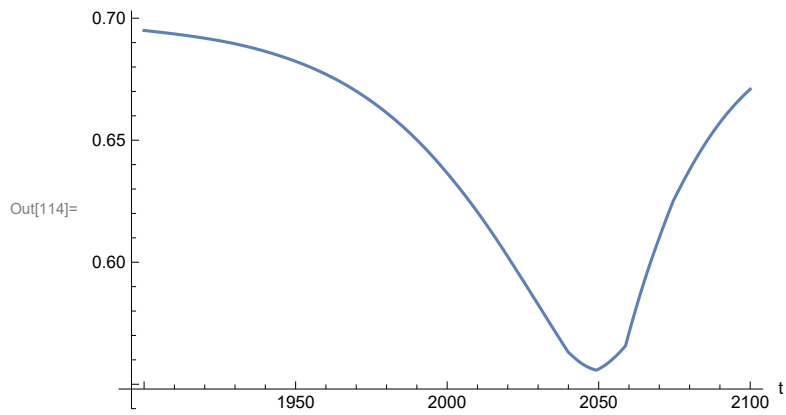
```
In[113]:= MinAndMax[basesevsim[{"Food_Production1.Land_Yield.y"}]]
```

Maximum is 1444.56

Minimum is 528.162

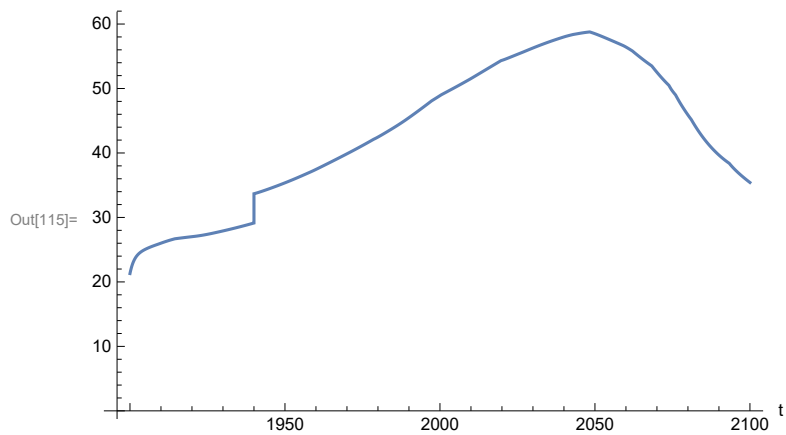
Plot multiplier of air pollution on land yield.

```
In[114]:= SystemModelPlot[basesevsim, {"Food_Production1.s_yield_mlt_air_poll"}]
```



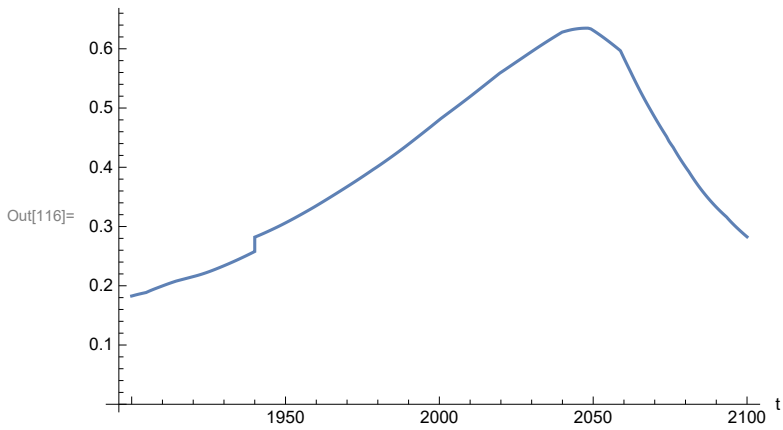
Plot life expectancy, in years.

```
In[115]:= SystemModelPlot[basesevsim, {"Life_Expectancy1.Life_Expectancy.y"}]
```



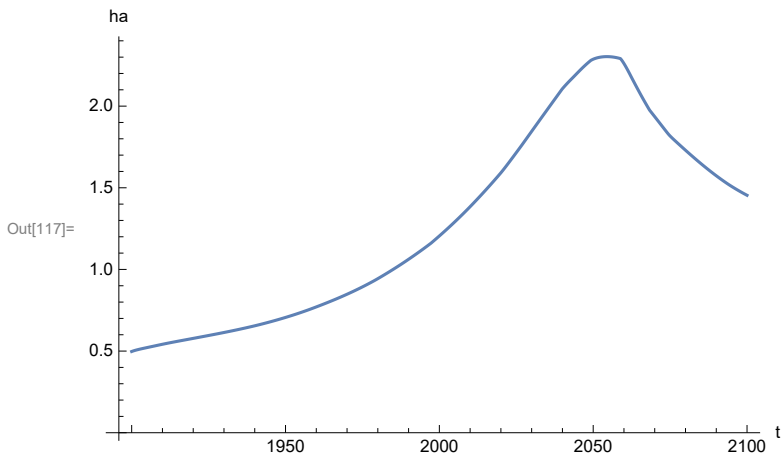
Plot the human welfare index.


```
In[116]:= SystemModelPlot[basesevsim,
  {"Human_Welfare_Index1.HWI_Human_Welfare_Index.hwi_human_welfare_index"}]
```



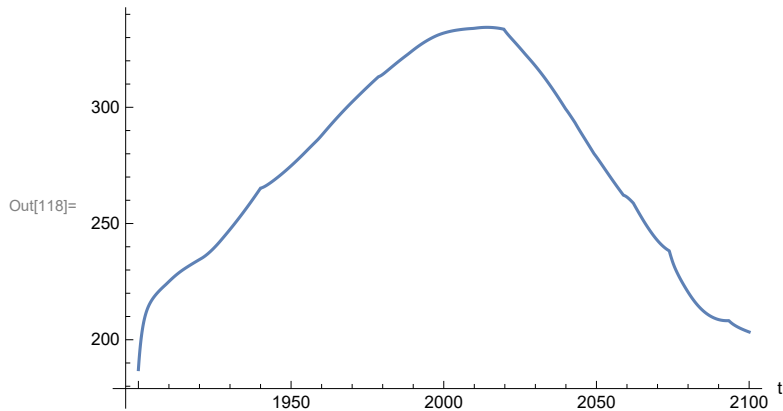
Plot the human ecological footprint, in hectares.

```
In[117]:= SystemModelPlot[basesevsim,
  {"Human_Ecological_Footprint1.HEF_Human_Ecological_Footprint.hef_human_ecological_
    _footprint"}]
```



Plot per capita food production, kg/year.

```
In[118]:= SystemModelPlot[basesevsim, {"Food_Production1.Food_PC.y"}]
```



Find max and min of y values.

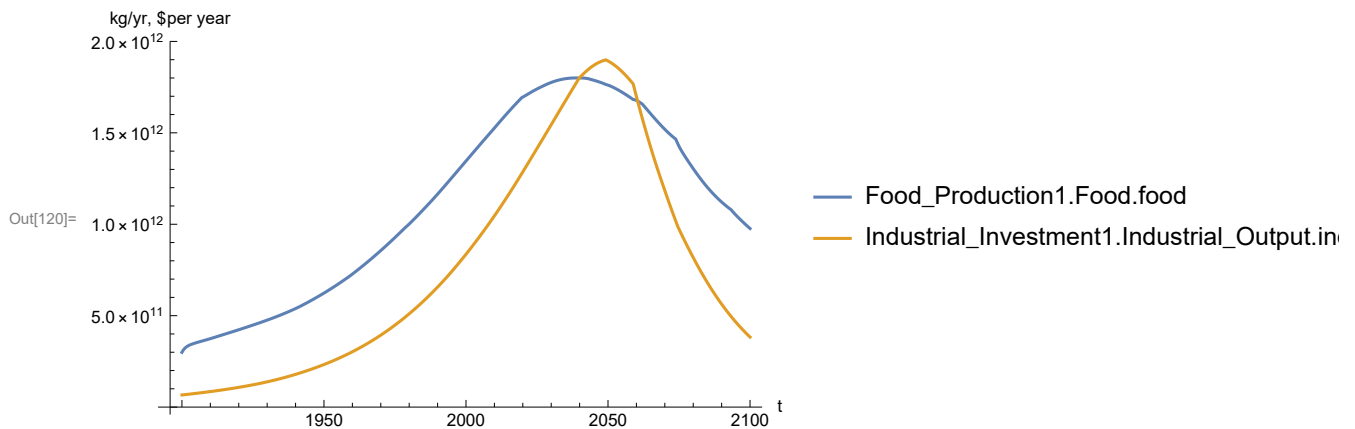
```
In[119]:= MinAndMax[basesevsim[{"Food_Production1.Food_PC.y"}]]
```

Maximum is 334.399

Minimum is 187.167

Plot total food production (kg/yr) and industrial output (in dollars).

```
In[120]:= SystemModelPlot[basesevsim, {"Food_Production1.Food.food",
  "Industrial_Investment1.Industrial_Output.industrial_output"}]
```



Find max and min of y values.

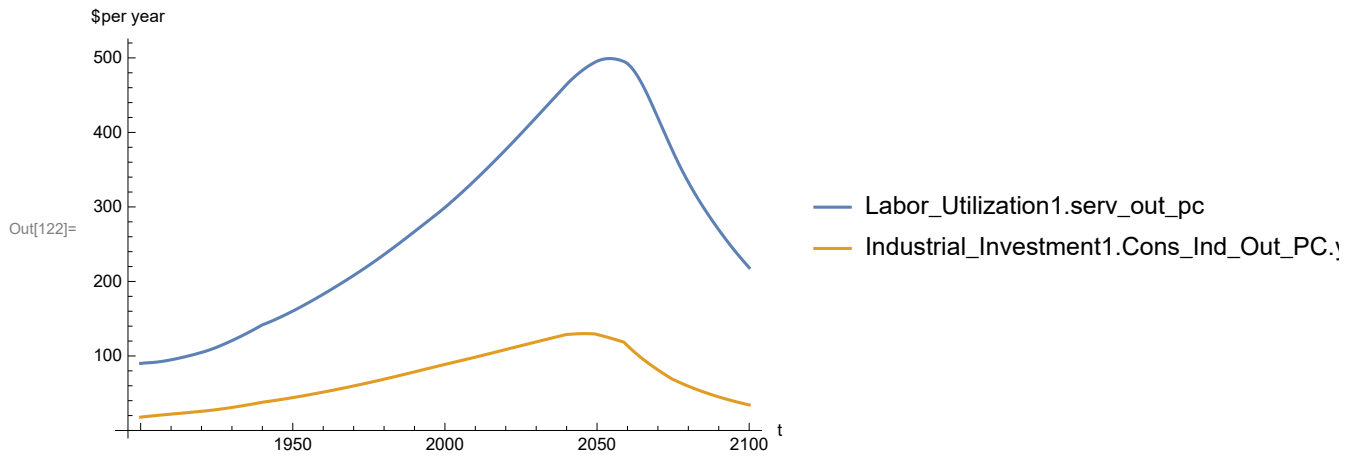
```
In[121]:= MinAndMax[basesevsim[{"Industrial_Investment1.Industrial_Output.industrial_output"}]]
```

Maximum is 1.89904×10^{12}

Minimum is 6.65×10^{10}

Plot consolidated industrial output per capita (dollars/year).

```
In[122]:= SystemModelPlot[basesevsim,
  {"Labor_Utilization1.serv_out_pc", "Industrial_Investment1.Cons_Ind_Out_PC.y"}]
```



Find max and min of y values.

```
In[123]:= MinAndMax[basesevsim[{"Labor_Utilization1.serv_out_pc"}]]
```

Maximum is 499.113

Minimum is 90.

Find max and min of y values.

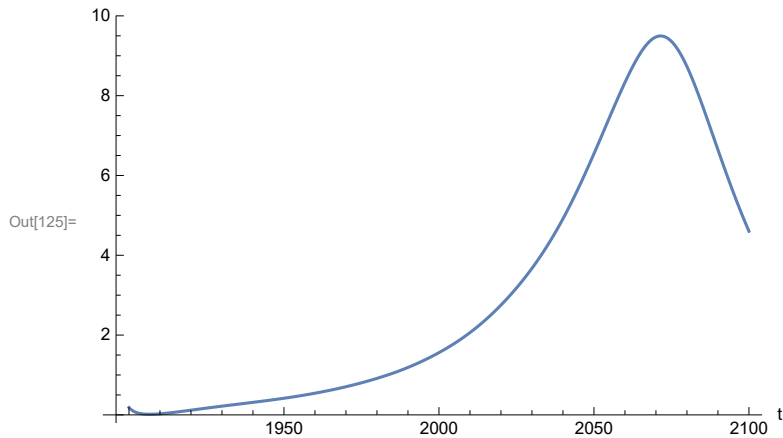
```
In[124]:= MinAndMax[basesevsim[{"Industrial_Investment1.Cons_Ind_Out_PC.y"}]]
```

Maximum is 129.961

Minimum is 17.8719

Plot persistent pollution index (normalized to 1970 value).

```
In[125]:= SystemModelPlot[basesevsim, {"Pollution_Dynamics1.PPoll_Index.y"}]
```



Find max and min of y values.

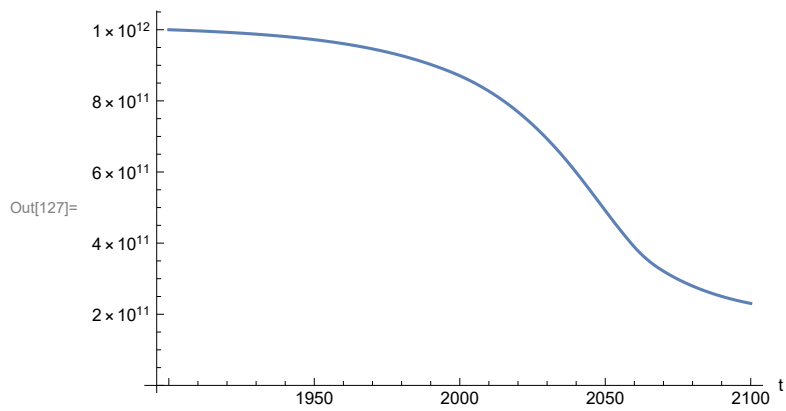
```
In[126]:= MinAndMax[basesevsim[{"Pollution_Dynamics1.PPoll_Index.y"}]]
```

Maximum is 9.49608

Minimum is 0.0157849

Plot non-renewable resources remaining.

```
In[127]:= SystemModelPlot[basesevsim, {"NR_Resource_Utilization1.NR_Resources.y"}]
```



APPENDIX 6. BENCHMARK SCENARIO 2 SIMULATIONS, Experiment 1

Define a function that extracts range data from scenario data. (The right-hand-side of this definition is specific to a *World3* data structure and assumes that the function whose range is being extracted is globally (i.e., not piecewise) defined.)

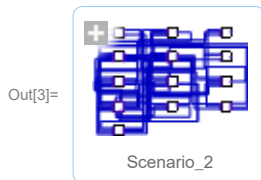
```
In[1]:= RangeData[data_] := data[[1]][[4]][[3]];
```

Define a procedure to determine and print minimum and maximum of “y” values.

```
In[2]:= MinAndMax[data_] := (myscenseries = RangeData[data];  
    Print["Maximum is ", Max[myscenseries]]; Print["Minimum is ", Min[myscenseries]])
```

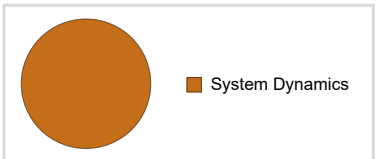
Here are some high-level properties of Benchmark Scenario 2.

```
In[3]:= mysim = SystemModel["SystemDynamics.WorldDynamics.World3.Scenario_2"]
```



```
In[4]:= mysummary = mysim["Summary"]
```

Out[4]=

ModelName	SystemDynamics.WorldDynamics.World3.Scenario_2
Description	More abundant non-recoverable natural resources
SimulationModel	True
Plots	0
Components	106
Balanced	True
SystemEquations	1583
SystemVariables	1583
Domain	

Show the value of `t_air_poll_time`.

```
In[5]= SystemModel[mysim][{"ParameterValues", "t_air_poll_time"}]
```

```
Out[5]= {t_air_poll_time → 4000}
```

Show Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals.

```
In[6]= SystemModel[mysim][
  {"ParameterValues", "Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[1]"}]
```

```
Out[6]= {Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[1] → 1}
```

```
In[7]= SystemModel[mysim][
  {"ParameterValues", "Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[2]"}]
```

```
Out[7]= {Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[2] → 1}
```

```
In[8]= SystemModel[mysim][
  {"ParameterValues", "Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[3]"}]
```

```
Out[8]= {Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[3] → 0.7}
```

```
In[9]= SystemModel[mysim][
  {"ParameterValues", "Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[4]"}]
```

```
Out[9]= {Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[4] → 0.4}
```

Show Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_2.y_vals.

```
In[10]= SystemModel[mysim][
  {"ParameterValues", "Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_2.y_vals[1]"}]
```

```
Out[10]= {Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_2.y_vals[1] → 1}
```

```
In[11]= SystemModel[mysim][
  {"ParameterValues", "Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_2.y_vals[2]"}]
```

```
Out[11]= {Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_2.y_vals[2] → 1}
```

```
In[12]= SystemModel[mysim][
  {"ParameterValues", "Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_2.y_vals[3]"}]
```

```
Out[12]= {Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_2.y_vals[3] → 0.98}
```

```
In[13]= SystemModel[mysim][
  {"ParameterValues", "Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_2.y_vals[4]"}]
```

```
Out[13]= {Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_2.y_vals[4] → 0.95}
```

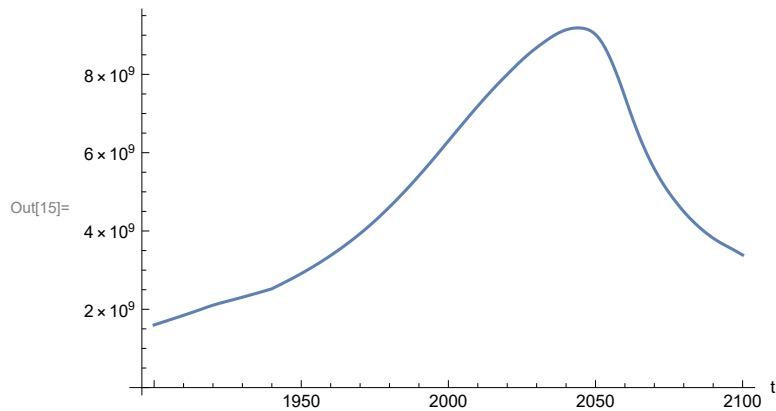
Execute Benchmark Scenario 2 and plot the variables shown in Figure 2.

In[14]:= **basesim = SystemModelSimulate[mysim]**

Out[14]= SystemModelSimulationData [ Model: Scenario_2
Time: 1.90×10^3 to 2.10×10^3]

Plot total population, people.

In[15]:= **SystemModelPlot[basesim, {"Population_Dynamics1.Birth_Rate.pop"}]**



Find max and min of population values.

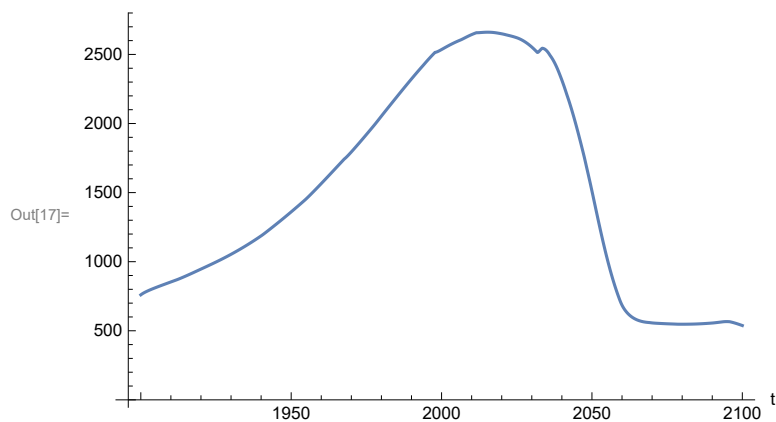
In[16]:= **MinAndMax[basesim[{"Population_Dynamics1.Birth_Rate.pop"}]]**

Maximum is 9.18617×10^9

Minimum is 1.6×10^9

Plot land yield.

In[17]:= **SystemModelPlot[basesim, {"Food_Production1.Land_Yield.y"}]**



Find max and min of y values.

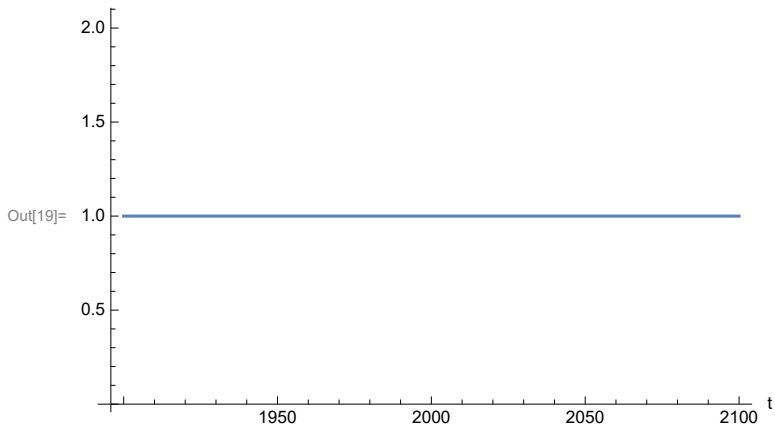
```
In[18]:= MinAndMax[basesim[{"Food_Production1.Land_Yield.y"}]]
```

Maximum is 2660.86

Minimum is 537.946

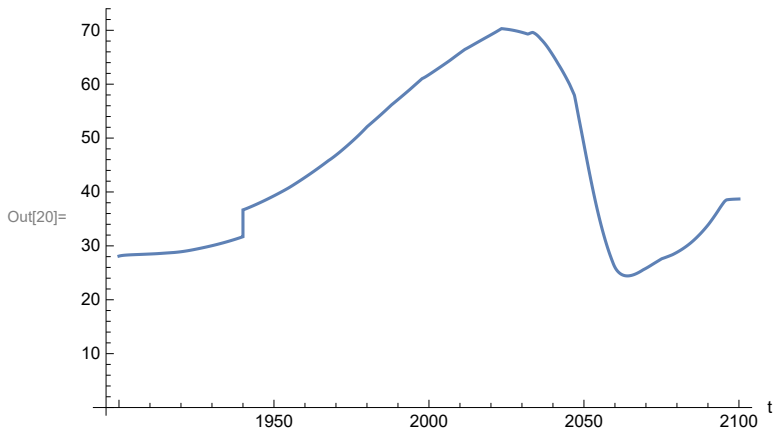
Plot multiplier of air pollution on land yield.

```
In[19]:= SystemModelPlot[basesim, {"Food_Production1.s_yield_mlt_air_poll"}]
```



Plot life expectancy, years.

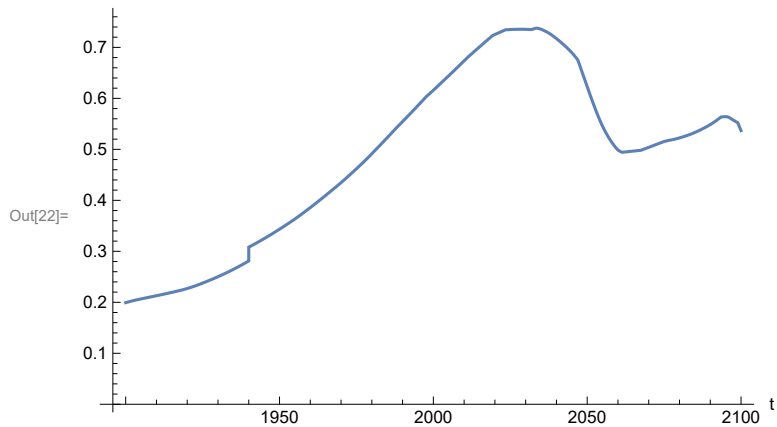
```
In[20]:= SystemModelPlot[basesim, {"Life_Expectancy1.Life_Expectancy.y"}]
```



```
In[21]:=
```

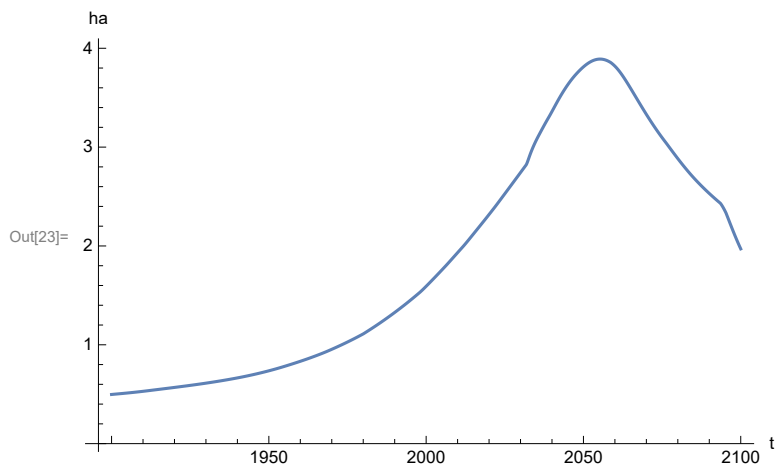
Plot human welfare index.


```
In[22]:= SystemModelPlot[basesim,
  {"Human_Welfare_Index1.HWI_Human_Welfare_Index.hwi_human_welfare_index"}]
```



Plot per capita ecological footprint, hectares.

```
In[23]:= SystemModelPlot[basesim,
  {"Human_Ecological_Footprint1.HEF_Human_Ecological_Footprint.hef_human_ecological_footprint"}]
```



Find max and min of y values.

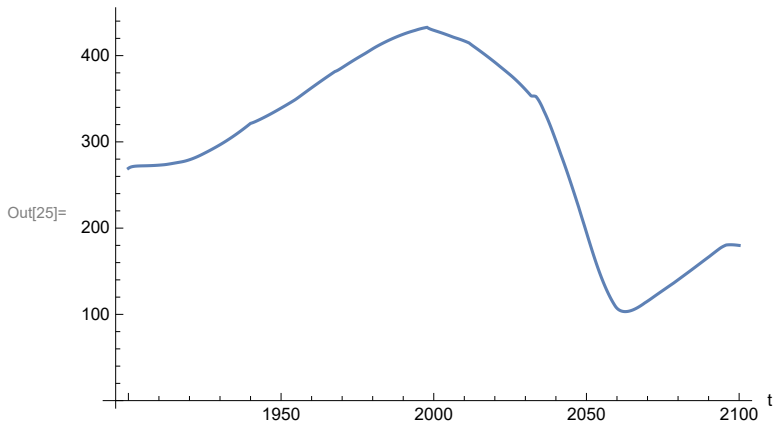
```
In[24]:= MinAndMax[basesim[
  {"Human_Ecological_Footprint1.HEF_Human_Ecological_Footprint.hef_human_ecological_footprint"}]]
```

Maximum is 3.89061

Minimum is 0.497387

Plot food production per capita (kg/year).

```
In[25]:= SystemModelPlot[basesim, {"Food_Production1.Food_PC.y"}]
```



Find max and min of y values.

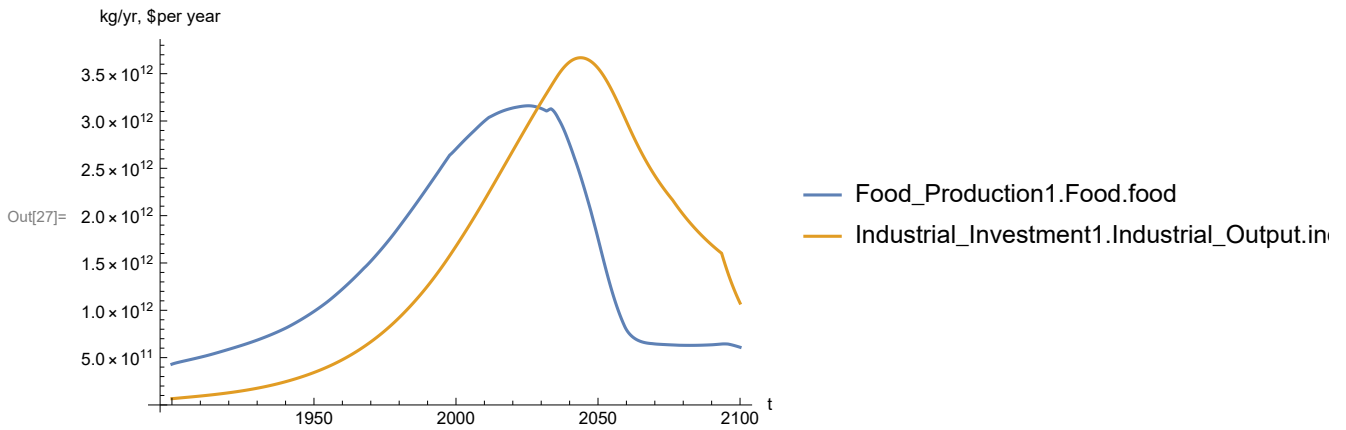
```
In[26]:= MinAndMax[basesim[{"Food_Production1.Food_PC.y"}]]
```

Maximum is 432.786

Minimum is 103.214

Plot total food production (kg/year), and industrial output (dollars/year).

```
In[27]:= SystemModelPlot[basesim, {"Food_Production1.Food.food",
    "Industrial_Investment1.Industrial_Output.industrial_output"}]
```



Find max and min of y values.

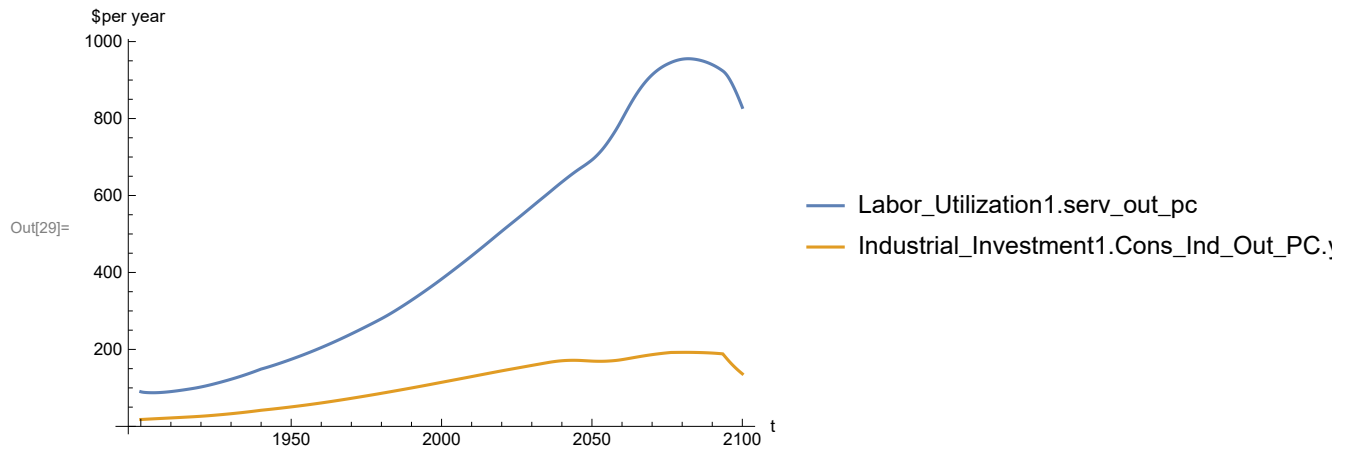
```
In[28]:= MinAndMax[basesim[{"Industrial_Investment1.Industrial_Output.industrial_output"}]]
```

Maximum is 3.66844×10^{12}

Minimum is 6.65×10^{10}

Plot labor utilization per capita (dollars/year), and consolidated industrial output per capita (dollars/year)

```
In[29]:= SystemModelPlot[basesim,
  {"Labor_Utilization1.serv_out_pc", "Industrial_Investment1.Cons_Ind_Out_PC.y"}]
```



Find max and min of y values.

```
In[30]:= MinAndMax[basesim[{"Labor_Utilization1.serv_out_pc"}]]
```

Maximum is 955.429

Minimum is 87.4451

Find max and min of y values.

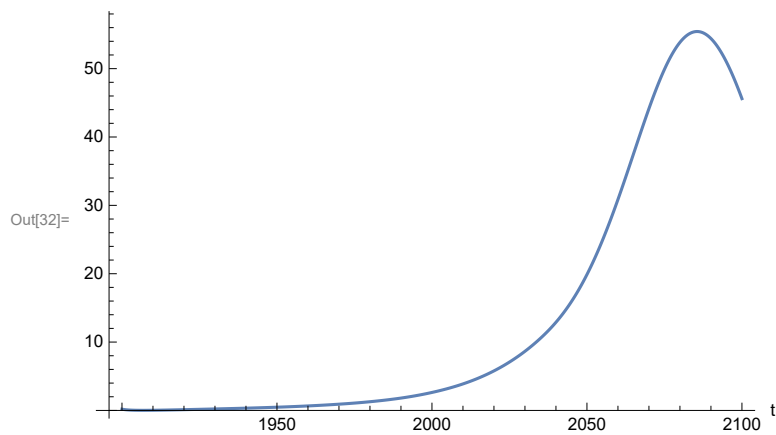
```
In[31]:= MinAndMax[basesim[{"Industrial_Investment1.Cons_Ind_Out_PC.y"}]]
```

Maximum is 192.383

Minimum is 17.8719

Plot persistent pollution index.

```
In[32]:= SystemModelPlot[basesim, {"Pollution_Dynamics1.PPoll_Index.y"}]
```



Find max and min of y values.

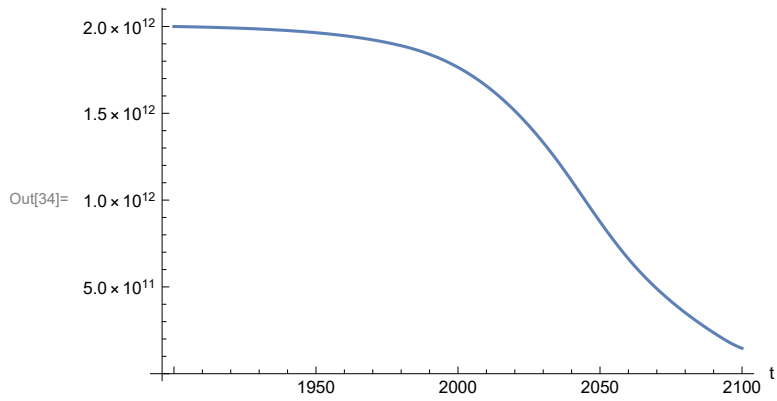
```
In[33]:= MinAndMax[basesim[{"Pollution_Dynamics1.PPoll_Index.y"}]]
```

Maximum is 55.4312

Minimum is 0.0150765

Plot non-renewable resources remaining.

```
In[34]:= SystemModelPlot[basesim, {"NR_Resource_Utilization1.NR_Resources.y"}]
```





APPENDIX 7. Effects of mitigating the impact of air pollution on agricultural land yield, beginning calendar year 2020, Benchmark Scenario 2, Experiment 2

Change the value of the air pollution effect multiplier switch time `t_air_poll_time`, to calendar year 2020, and execute the resulting scenario, plotting the variables shown in Figure 2.

```
In[35]:= newmysim = SystemModel[mysim, <|"ParameterValues" → {"t_air_poll_time" → 2020}|>]
```



```
In[36]:= testsim = SystemModelSimulate[newmysim]
```

Out[36]= SystemModelSimulationData [  Model: W76b38d4409574481b472c18e2e3b4f0b
Time: 1.90×10^3 to 2.10×10^3]

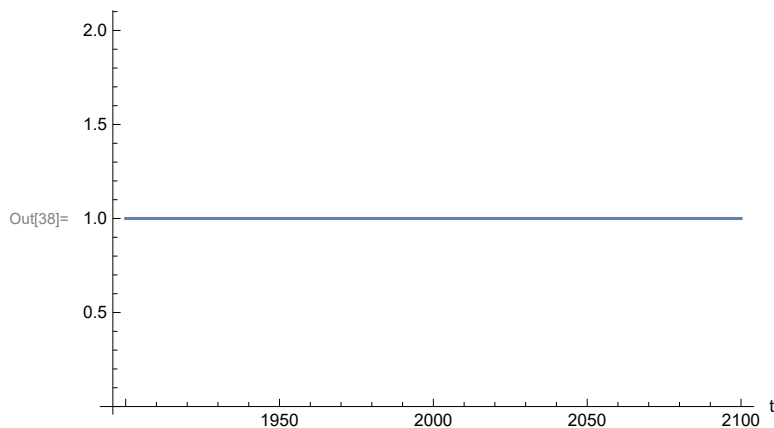
Show the value of `t_air_poll_time` (calendar year).

```
In[37]:= SystemModel[newmysim][{"ParameterValues", "t_air_poll_time"}]
```

Out[37]= {t_air_poll_time → 2020}

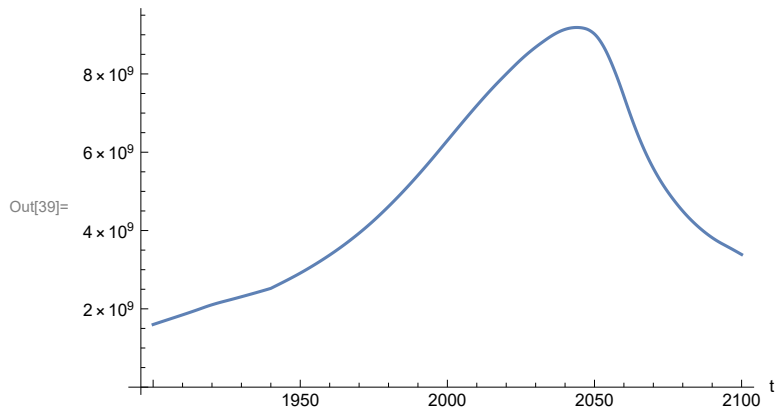
Plot air pollution multiplier of land yield.

```
In[38]:= SystemModelPlot[testsim, {"Food_Production1.s_yield_mlt_air_poll"}]
```



Plot the world population, people.

```
In[39]:= SystemModelPlot[testsim, {"Population_Dynamics1.Birth_Rate.pop"}]
```



Find max and min of y values.

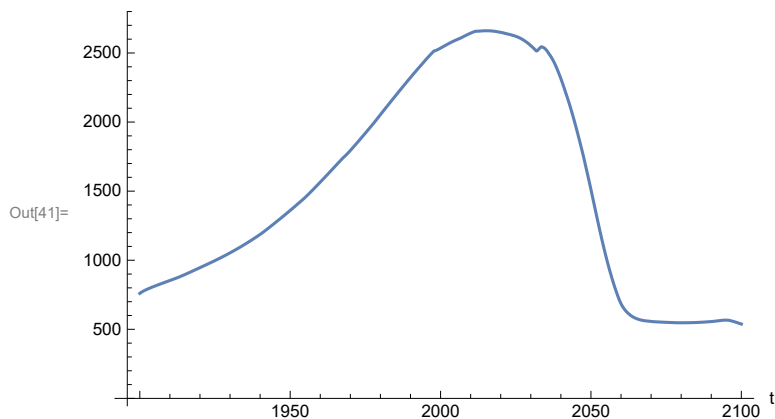
```
In[40]:= MinAndMax[testsim[{"Population_Dynamics1.Birth_Rate.pop"}]]
```

Maximum is 9.18617×10^9

Minimum is 1.6×10^9

Plot land yield.

```
In[41]:= SystemModelPlot[testsim, {"Food_Production1.Land_Yield.y"}]
```



Find max and min of y values.

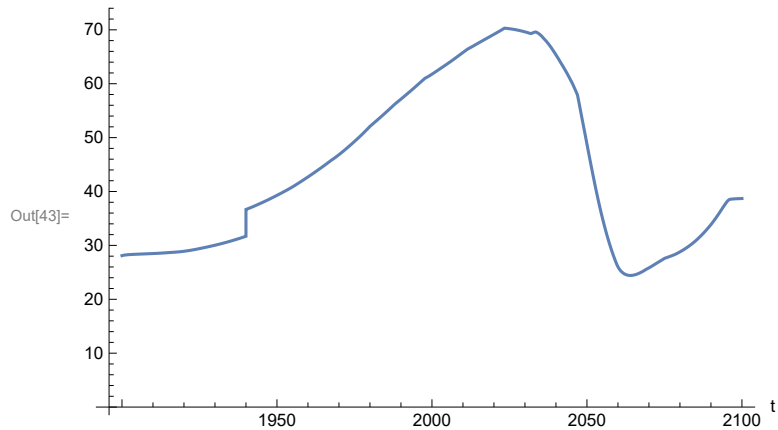
```
In[42]:= MinAndMax[testsim[{"Food_Production1.Land_Yield.y"}]]
```

Maximum is 2660.86

Minimum is 537.946

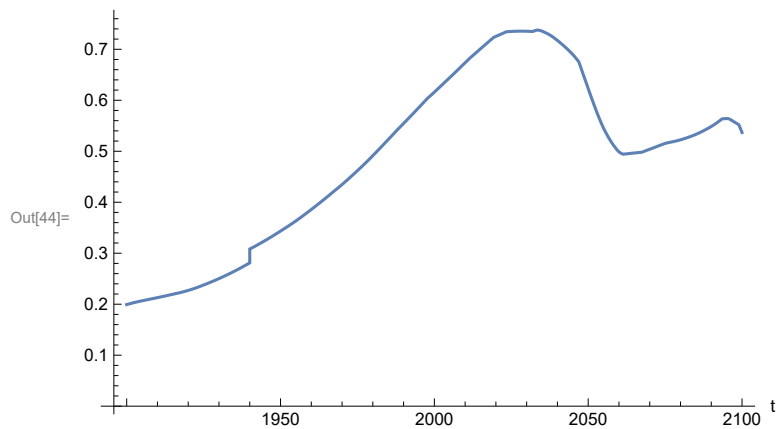
Plot life expectancy, in years.

```
In[43]:= SystemModelPlot[testsim, {"Life_Expectancy1.Life_Expectancy.y"}]
```



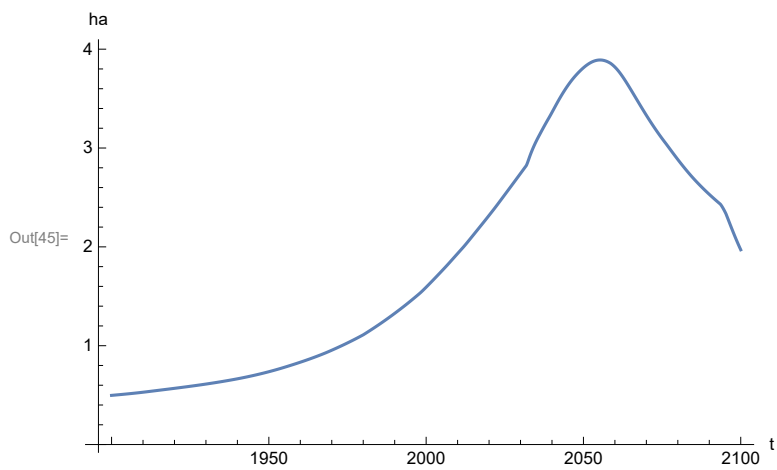
Plot the human welfare index.

```
In[44]:= SystemModelPlot[testsim, {"Human_Welfare_Index1.HWI_Human_Welfare_Index.hwi_human_welfare_index"}]
```



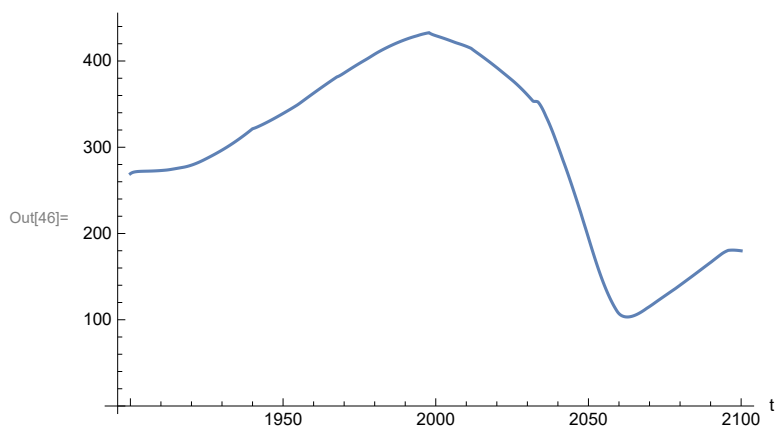
Plot the human ecological footprint, in hectares.

```
In[45]:= SystemModelPlot[testsim,
  {"Human_Ecological_Footprint1.HEF_Human_Ecological_Footprint.hef_human_ecological_
    _footprint"}]
```



Plot per capita food production, kg/year.

```
In[46]:= SystemModelPlot[testsim, {"Food_Production1.Food_PC.y"}]
```



Find max and min of y values.

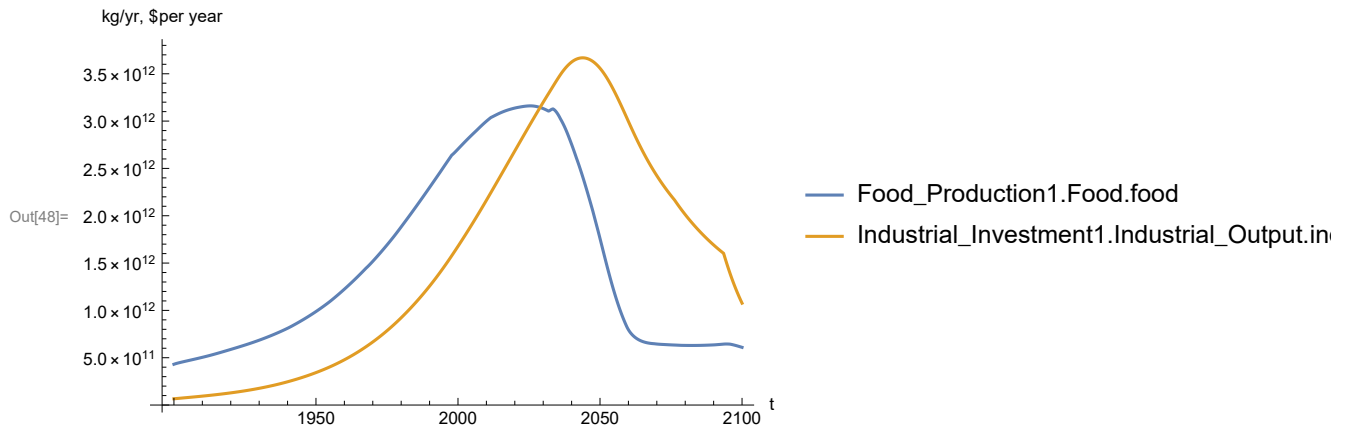
```
In[47]:= MinAndMax[testsim[{"Food_Production1.Food_PC.y"}]]
```

Maximum is 432.786

Minimum is 103.214

Plot total food production (kg/yr) and industrial output (in dollars).


```
In[48]:= SystemModelPlot[testsim, {"Food_Production1.Food.food",
  "Industrial_Investment1.Industrial_Output.industrial_output"}]
```



Find max and min of y values.

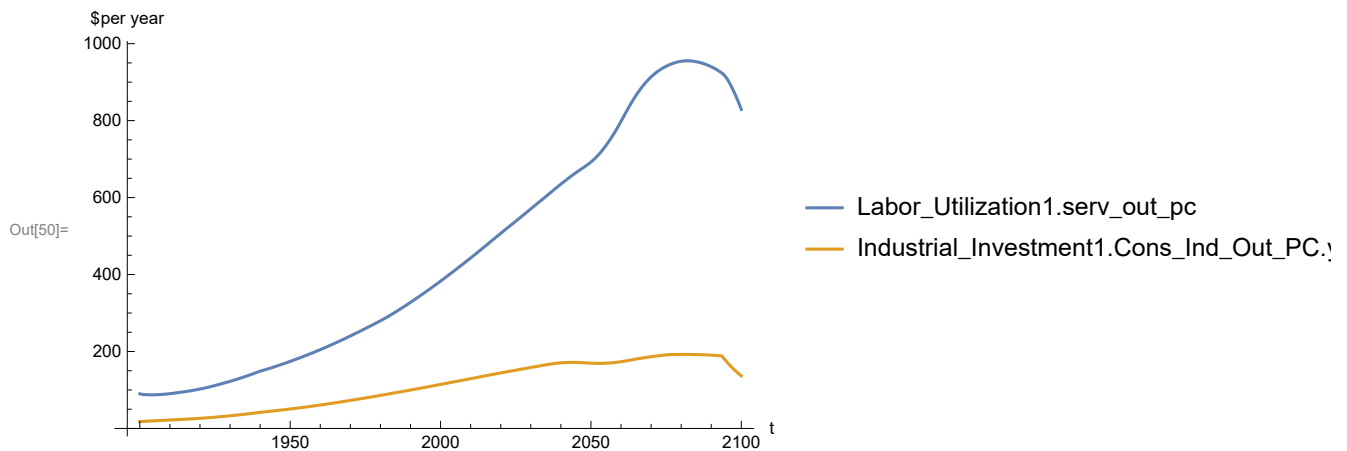
```
In[49]:= MinAndMax[testsim[{"Industrial_Investment1.Industrial_Output.industrial_output"}]]
```

Maximum is 3.66844×10^{12}

Minimum is 6.65×10^{10}

Plot consolidated industrial output per capita (dollars/year).

```
In[50]:= SystemModelPlot[testsim,
  {"Labor_Utilization1.serv_out_pc", "Industrial_Investment1.Cons_Ind_Out_PC.y"}]
```



Find max and min of y values.

```
In[51]:= MinAndMax[testsim[{"Labor_Utilization1.serv_out_pc"}]]
```

Maximum is 955.429

Minimum is 87.4451

Find max and min of y values.

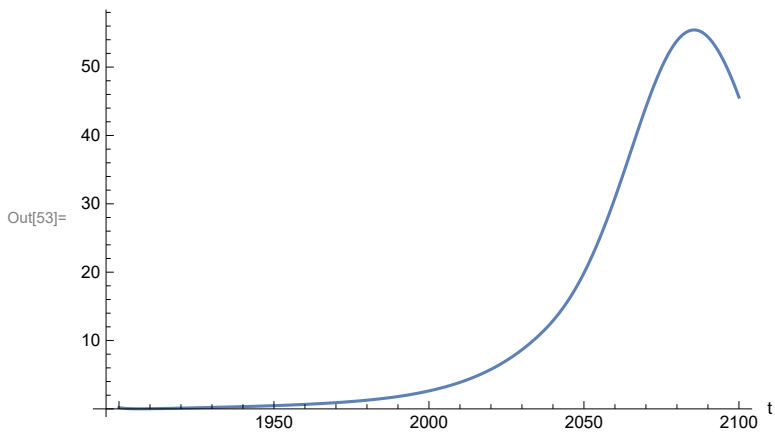
```
In[52]:= MinAndMax[testsim[{"Industrial_Investment1.Cons_Ind_Out_PC.y"}]]
```

Maximum is 192.383

Minimum is 17.8719

Plot persistent pollution index (normalized to 1970 value).

```
In[53]:= SystemModelPlot[testsim, {"Pollution_Dynamics1.PPoll_Index.y"}]
```



Find max and min of y values.

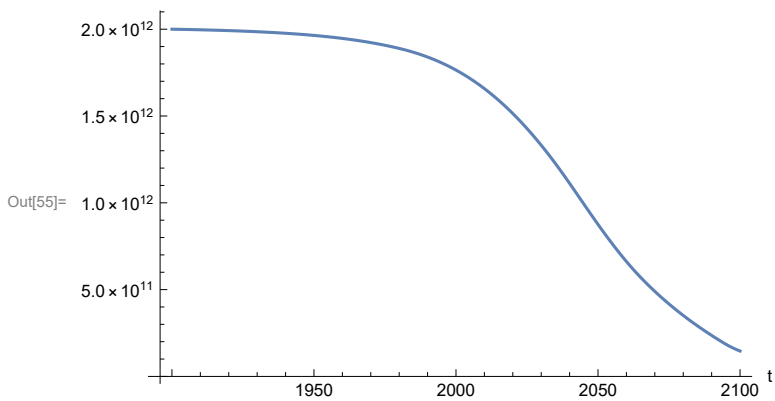
```
In[54]:= MinAndMax[testsim[{"Pollution_Dynamics1.PPoll_Index.y"}]]
```

Maximum is 55.4312

Minimum is 0.0150765

Plot non-renewable resources remaining.

```
In[55]:= SystemModelPlot[testsim, {"NR_Resource_Utilization1.NR_Resources.y"}]
```



APPENDIX 8. Effects of mitigating the impact of air pollution on agricultural land yield, beginning calendar year 1970, Benchmark Scenario 2, Experiment 3

Change the value of the air pollution effect multiplier switch time `t_air_poll_time`, to calendar year 1970, and execute the resulting scenario, plotting the variables shown in Figure 2.

```
In[56]:= newmysim1970 = SystemModel[mysim, <|"ParameterValues" → {"t_air_poll_time" → 1970} |>]
```



```
In[57]:= testsim1970 = SystemModelSimulate[newmysim1970]
```

Out[57]= SystemModelSimulationData [ Model: Wfb2583bf614446c7b1b83d1e062cef05
Time: 1.90×10^3 to 2.10×10^3]

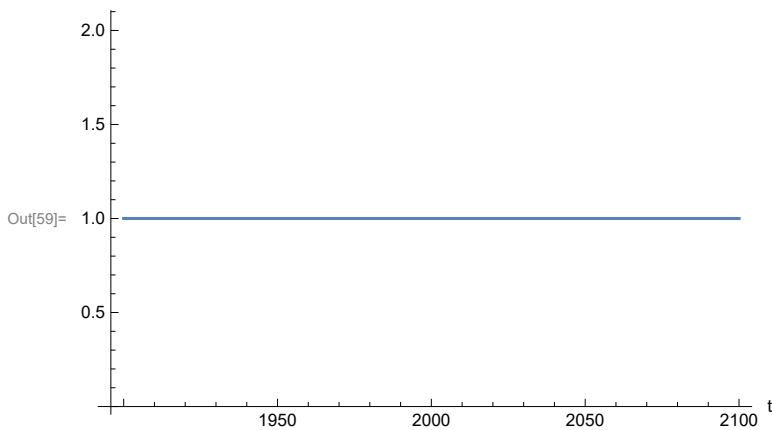
Show the value of `t_air_poll_time` (calendar year).

```
In[58]:= SystemModel[newmysim1970][{"ParameterValues", "t_air_poll_time"}]
```

Out[58]= {t_air_poll_time → 1970}

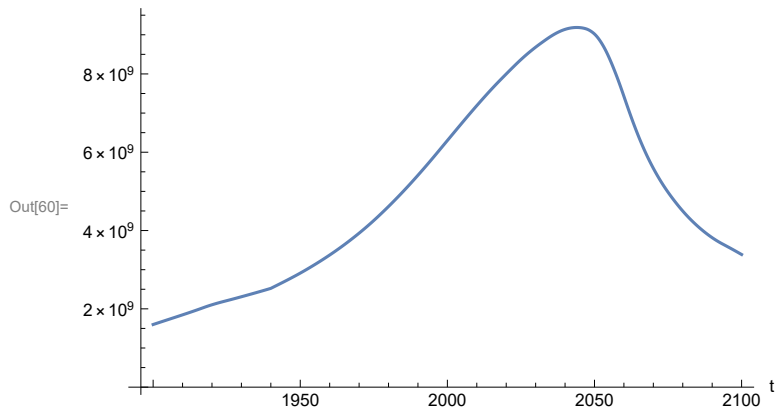
Plot air pollution multiplier of land yield.

```
In[59]:= SystemModelPlot[testsim1970, {"Food_Production1.s_yield_mlt_air_poll"}]
```



Plot the world population, people.

```
In[60]:= SystemModelPlot[testsim1970, {"Population_Dynamics1.Birth_Rate.pop"}]
```



Find max and min of y values.

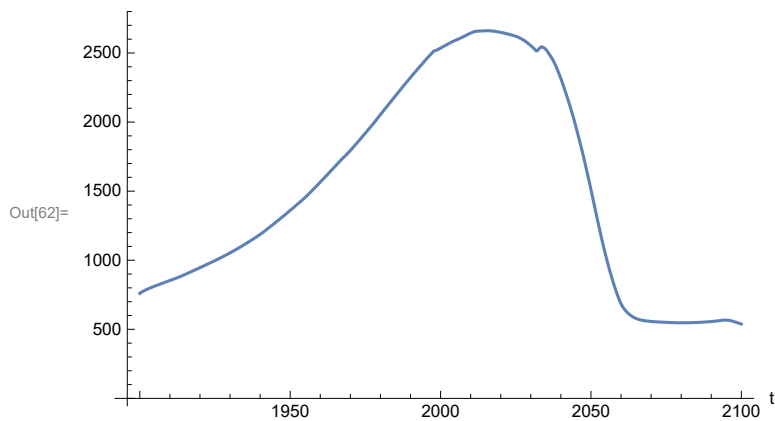
```
In[61]:= MinAndMax[testsim1970[{"Population_Dynamics1.Birth_Rate.pop"}]]
```

Maximum is 9.18617×10^9

Minimum is 1.6×10^9

Plot land yield.

```
In[62]:= SystemModelPlot[testsim1970, {"Food_Production1.Land_Yield.y"}]
```



Find max and min of y values.

```
In[63]:= MinAndMax[testsim1970[{"Food_Production1.Land_Yield.y"}]]
```

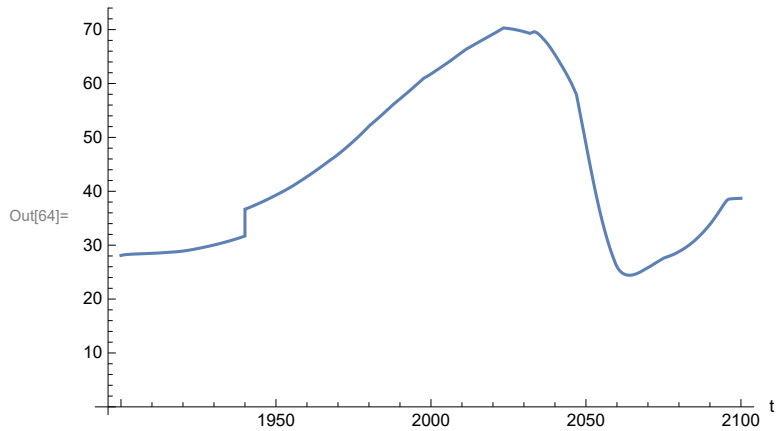
Maximum is 2660.86

Minimum is 537.946

Plot life expectancy, years.

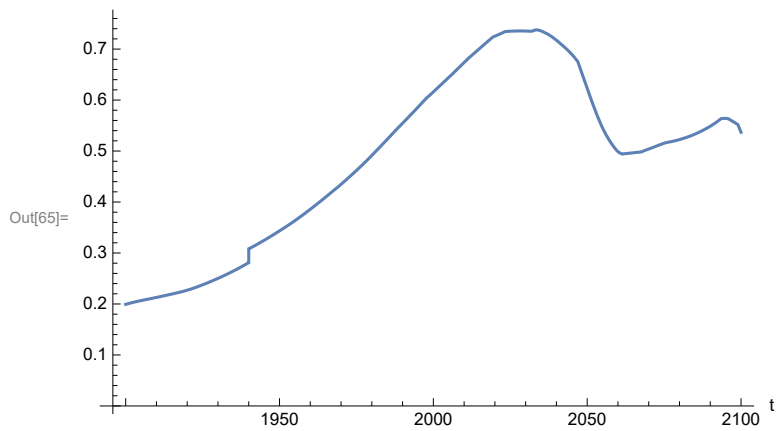
Plot life expectancy, in years.

```
In[64]:= SystemModelPlot[testsim1970, {"Life_Expectancy1.Life_Expectancy.y"}]
```



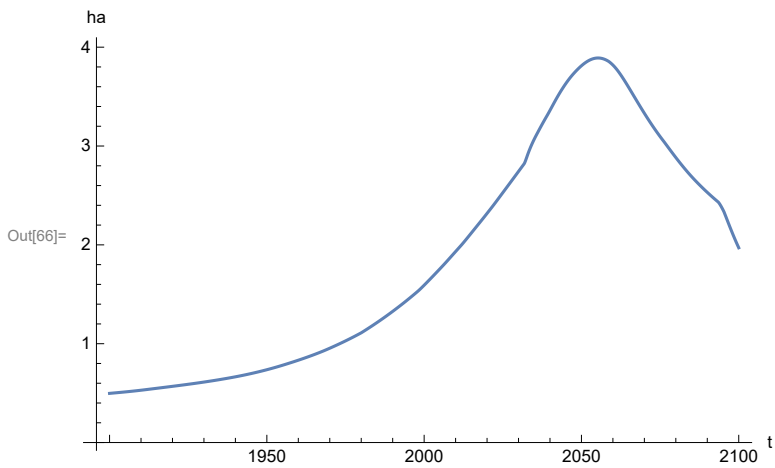
Plot the human welfare index.

```
In[65]:= SystemModelPlot[testsim1970, {"Human_Welfare_Index1.HWI_Human_Welfare_Index.hwi_human_welfare_index"}]
```



Plot the human ecological footprint, in hectares.

```
In[66]:= SystemModelPlot[testsim1970,
  {"Human_Ecological_Footprint1.HEF_Human_Ecological_Footprint.hef_human_ecological_
    _footprint"}]
```



Find max and min of y values.

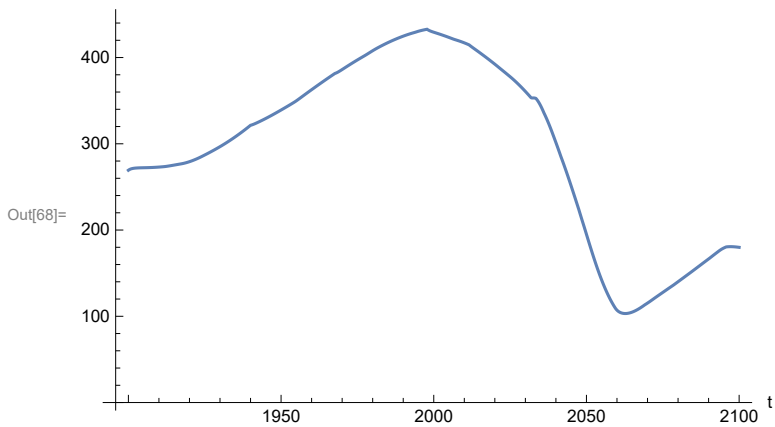
```
In[67]:= MinAndMax[testsim1970[
  {"Human_Ecological_Footprint1.HEF_Human_Ecological_Footprint.hef_human_ecological_
    _footprint"}]]
```

Maximum is 3.89061

Minimum is 0.497387

Plot per capita food production, kg/year.

```
In[68]:= SystemModelPlot[testsim1970, {"Food_Production1.Food_PC.y"}]
```



Find max and min of y values.

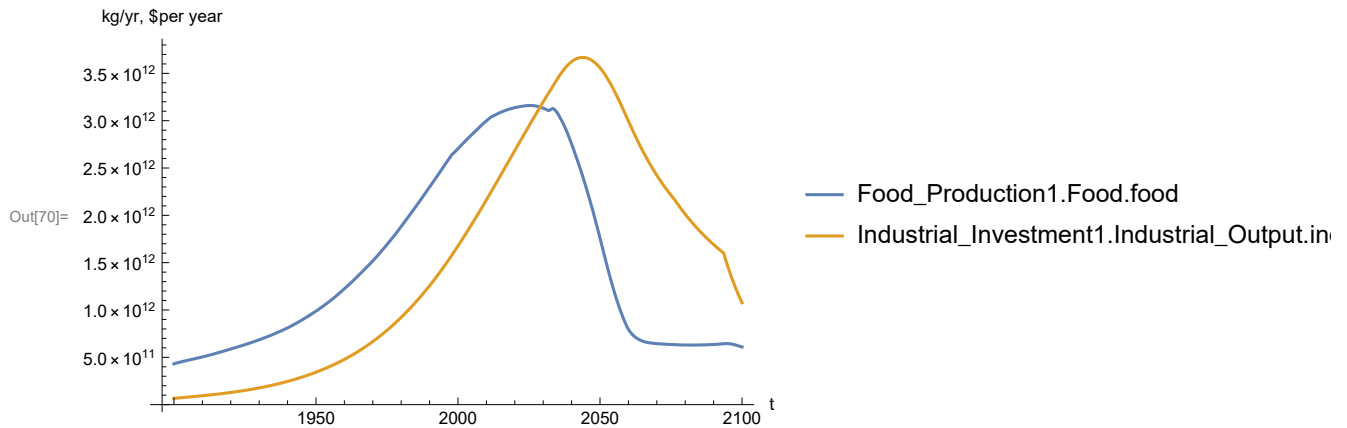
```
In[69]:= MinAndMax[testsim1970[{"Food_Production1.Food_PC.y"}]]
```

Maximum is 432.786

Minimum is 103.214

Plot total food production (kg/yr) and industrial output (in dollars).

```
In[70]:= SystemModelPlot[testsim1970, {"Food_Production1.Food.food",
  "Industrial_Investment1.Industrial_Output.industrial_output"}]
```



Find max and min of y values.

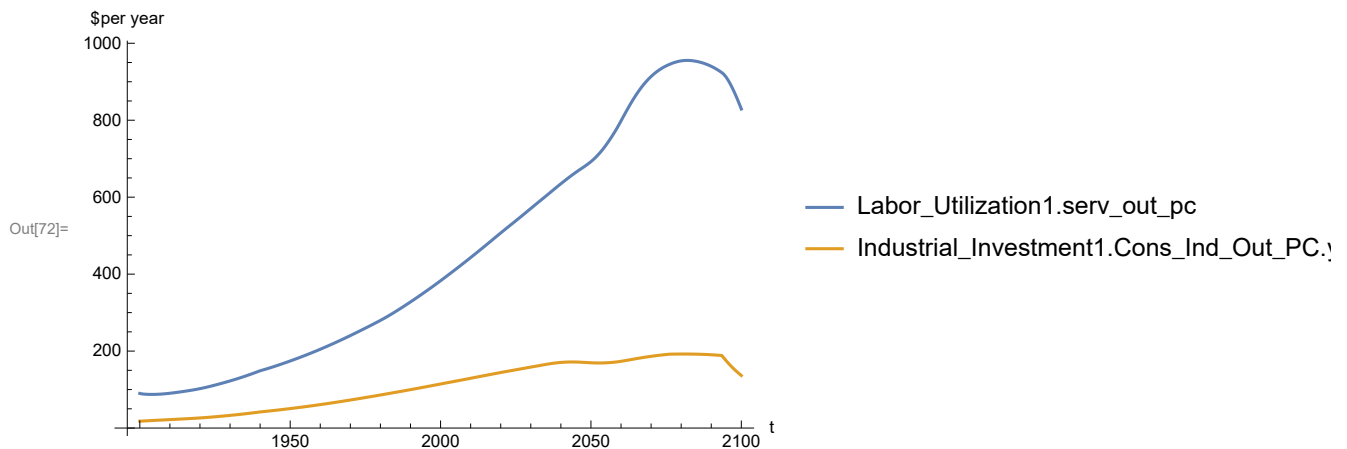
```
In[71]:= MinAndMax[testsim1970[{"Industrial_Investment1.Industrial_Output.industrial_output"}]]
```

Maximum is 3.66844×10^{12}

Minimum is 6.65×10^{10}

Plot consolidated industrial output per capita (dollars/year).

```
In[72]:= SystemModelPlot[testsim1970,
  {"Labor_Utilization1.serv_out_pc", "Industrial_Investment1.Cons_Ind_Out_PC.y"}]
```



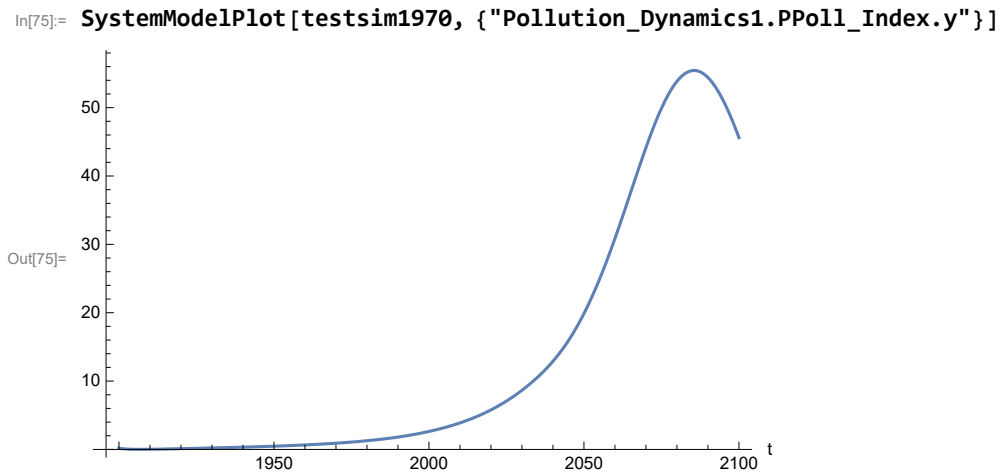
Find max and min of y values.

```
In[73]:= MinAndMax[testsim1970[{"Labor_Utilization1.serv_out_pc"}]]
Maximum is 955.429
Minimum is 87.4451
```

Find max and min of y values.

```
In[74]:= MinAndMax[testsim1970[{"Industrial_Investment1.Cons_Ind_Out_PC.y"}]]
Maximum is 192.383
Minimum is 17.8719
```

Plot persistent pollution index (normalized to 1970 value).

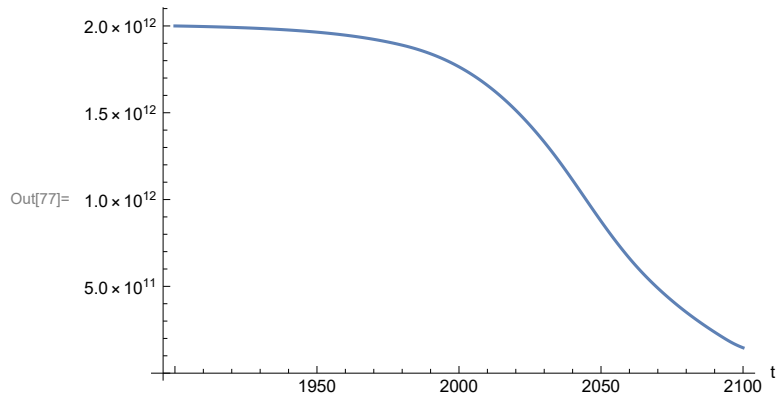


Find max and min of y values.

```
In[76]:= MinAndMax[testsim1970[{"Pollution_Dynamics1.PPoll_Index.y"}]]
Maximum is 55.4312
Minimum is 0.0150765
```

Plot non-renewable resources remaining.


```
In[77]:= SystemModelPlot[testsim1970, {"NR_Resource_Utilization1.NR_Resources.y"}]
```



APPENDIX 9. "STRONG AIR POLLUTION" EFFECTS SCENARIO, Benchmark Scenario 2, Experiment 4

Scenario 2 with air pollution effect on land yield changed as noted.

```
In[78]:= strsim = SystemModel[mysim, <|"ParameterValues" ->
      {"Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals" -> {0.7, 0.5, 0.3, 0.1}}|>]
```



```
In[79]:= basestrsim = SystemModelSimulate[strsim]
```

Out[79]= SystemModelSimulationData [ Model: Wc698029143f54692979b2a23b500ca56
Time: 1.90×10^3 to 2.10×10^3]

Show Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals.

```
In[80]:= SystemModel[strsim] [
      {"ParameterValues", "Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[1]"}]
```

Out[80]= {Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[1] → 0.7}

```
In[81]:= SystemModel[strsim] [
      {"ParameterValues", "Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[2]"}]
```

Out[81]= {Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[2] → 0.5}

```
In[82]:= SystemModel[strsim] [
      {"ParameterValues", "Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[3]"}]
```

Out[82]= {Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[3] → 0.3}

```
In[83]:= SystemModel[strsim] [
      {"ParameterValues", "Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[4]"}]
```

Out[83]= {Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[4] → 0.1}

Show the value of t_air_poll_time (calendar year).

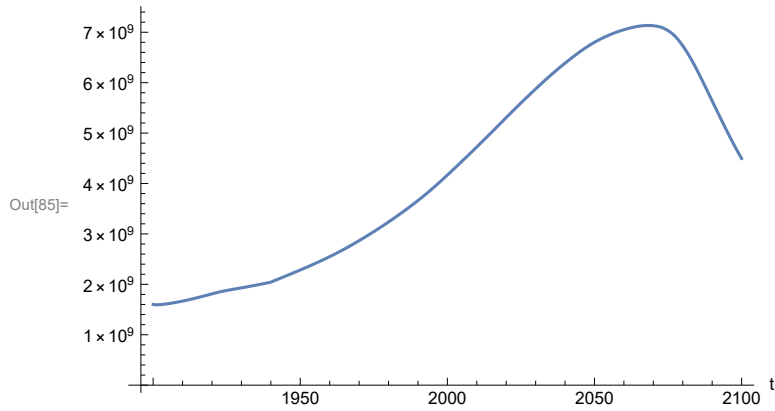
```
In[84]:= SystemModel[strsim] [{"ParameterValues", "t_air_poll_time"}]
```

Out[84]= {t_air_poll_time → 4000}

Plot the world population, people. Note that the peak population is about one billion less, and about

20 years later, than the peak population forecast by Experiments 1-3.

```
In[85]:= SystemModelPlot[basestransim, {"Population_Dynamics1.Birth_Rate.pop"}]
```



Find max and min of y values.

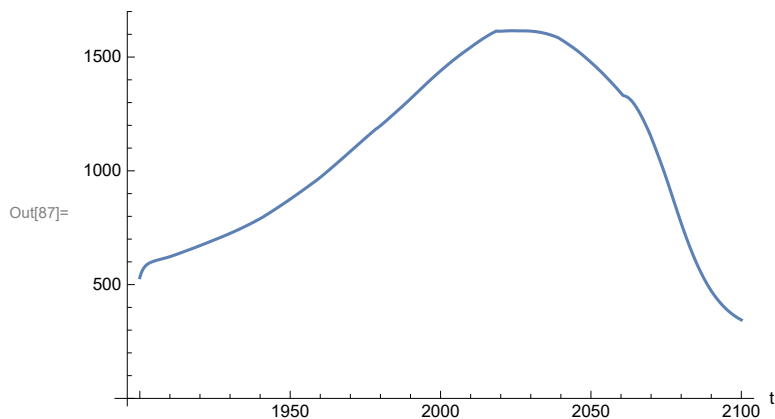
```
In[86]:= MinAndMax[basestransim[{"Population_Dynamics1.Birth_Rate.pop"}]]
```

Maximum is 7.13448×10^9

Minimum is 1.59431×10^9

Plot land yield.

```
In[87]:= SystemModelPlot[basestransim, {"Food_Production1.Land_Yield.y"}]
```



Find max and min of y values.

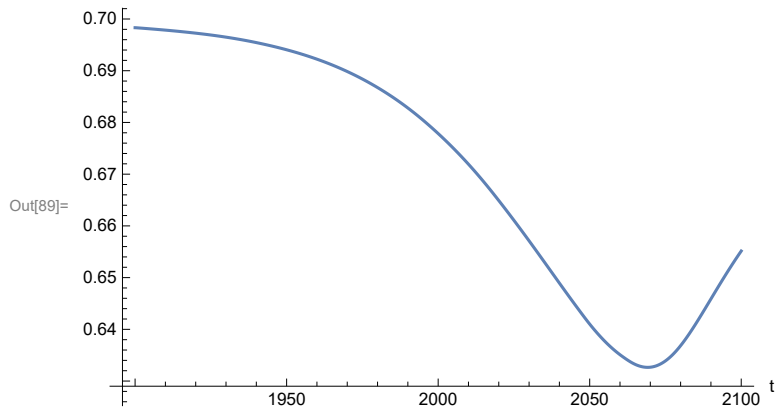
```
In[88]:= MinAndMax[basestransim[{"Food_Production1.Land_Yield.y"}]]
```

Maximum is 1615.65

Minimum is 344.902

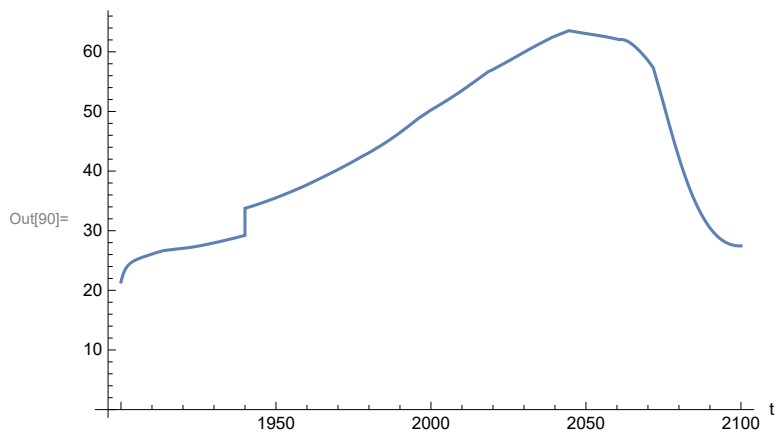
Plot multiplier of air pollution on land yield.

```
In[89]:= SystemModelPlot[basestransim, {"Food_Production1.s_yield_mlt_air_poll"}]
```



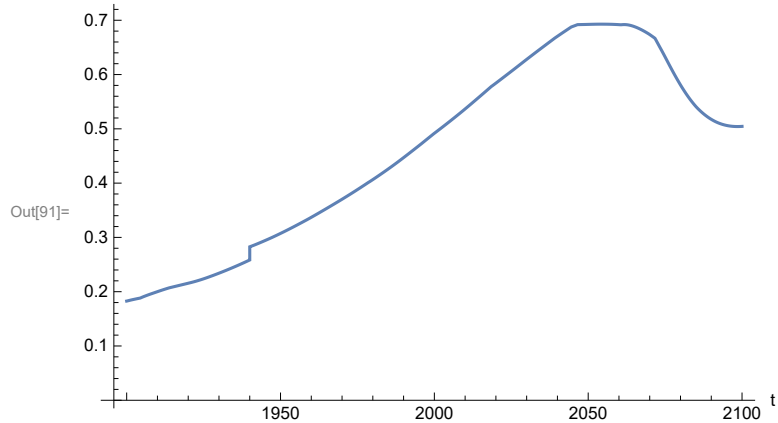
Plot life expectancy, in years.

```
In[90]:= SystemModelPlot[basestransim, {"Life_Expectancy1.Life_Expectancy.y"}]
```



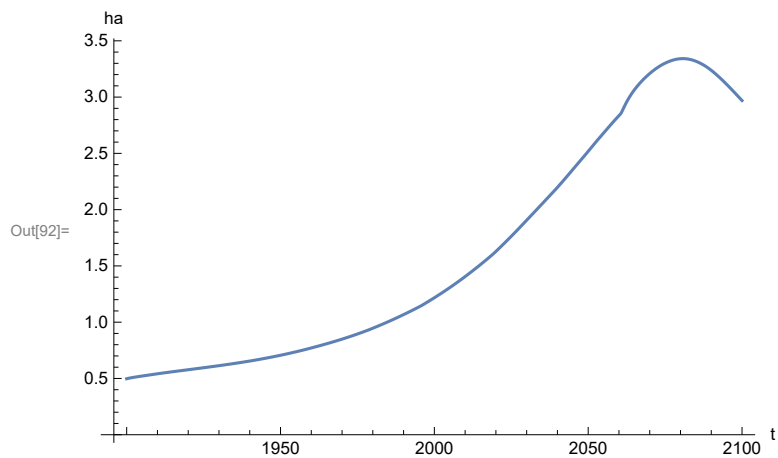
Plot the human welfare index.

```
In[91]:= SystemModelPlot[basestrsim,
  {"Human_Welfare_Index1.HWI_Human_Welfare_Index.hwi_human_welfare_index"}]
```



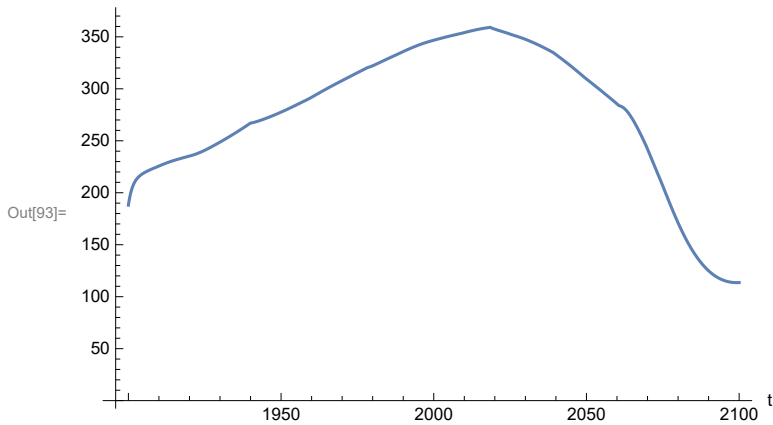
Plot the human ecological footprint, in hectares.

```
In[92]:= SystemModelPlot[basestrsim,
  {"Human_Ecological_Footprint1.HEF_Human_Ecological_Footprint.hef_human_ecological_
    _footprint"}]
```



Plot per capita food production, kg/year.

In[93]:= **SystemModelPlot**[basestrsim, {"Food_Production1.Food_PC.y"}]



Find max and min of y values.

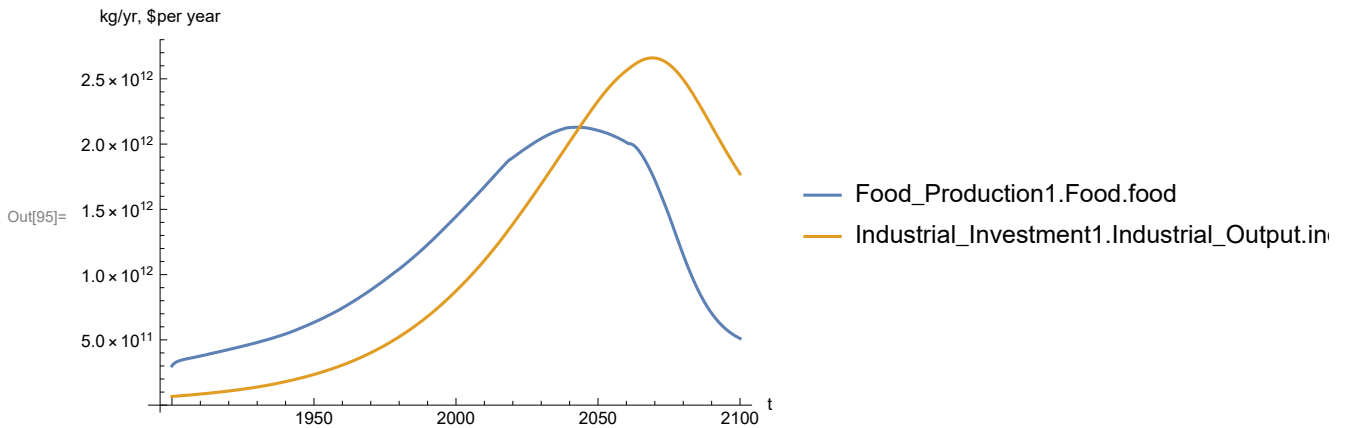
In[94]:= **MinAndMax**[basestrsim[{"Food_Production1.Food_PC.y"}]]

Maximum is 359.129

Minimum is 113.524

Plot total food production (kg/yr) and industrial output (in dollars).

In[95]:= **SystemModelPlot**[basestrsim, {"Food_Production1.Food.food", "Industrial_Investment1.Industrial_Output.industrial_output"}]



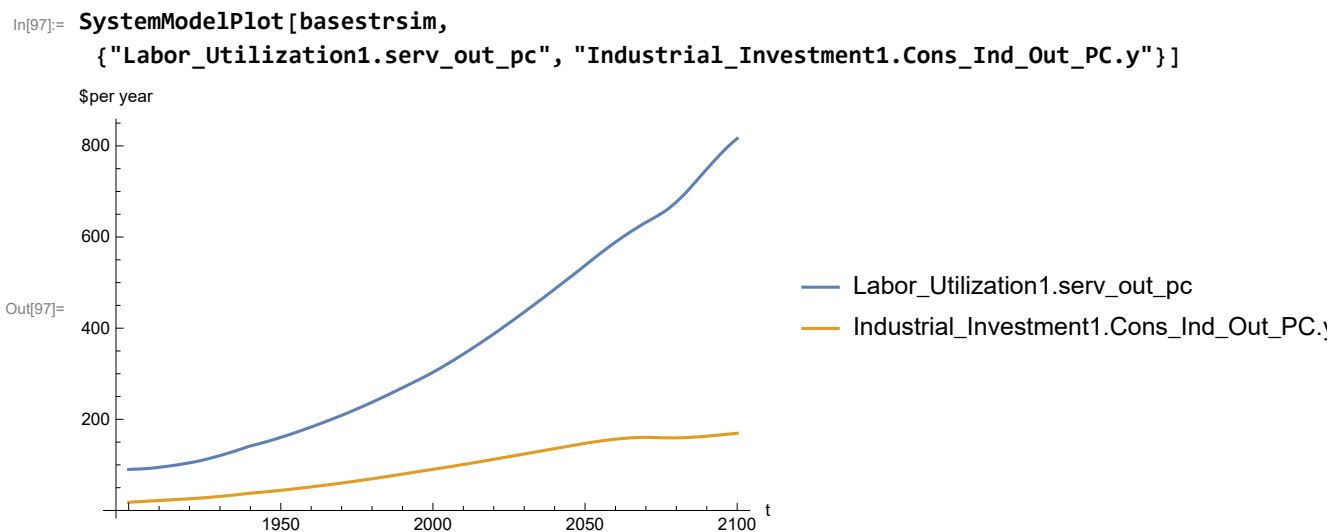
Find max and min of y values.

In[96]:= **MinAndMax**[basestrsim[{"Industrial_Investment1.Industrial_Output.industrial_output"}]]

Maximum is 2.66026×10^{12}

Minimum is 6.65×10^{10}

Plot consolidated industrial output per capita (dollars/year).



Find max and min of y values.

```
In[98]:= MinAndMax[basestransim[{"Labor_Utilization1.serv_out_pc"}]]
```

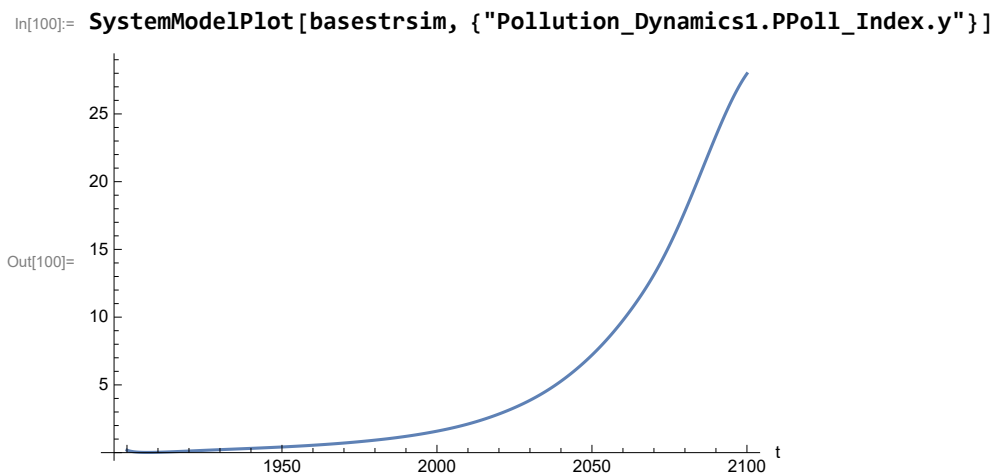
Maximum is 816.107
Minimum is 89.9974

Find max and min of y values.

```
In[99]:= MinAndMax[basestransim[{"Industrial_Investment1.Cons_Ind_Out_PC.y"}]]
```

Maximum is 169.456
Minimum is 17.8719

Plot persistent pollution index (normalized to 1970 value).



Find max and min of y values.

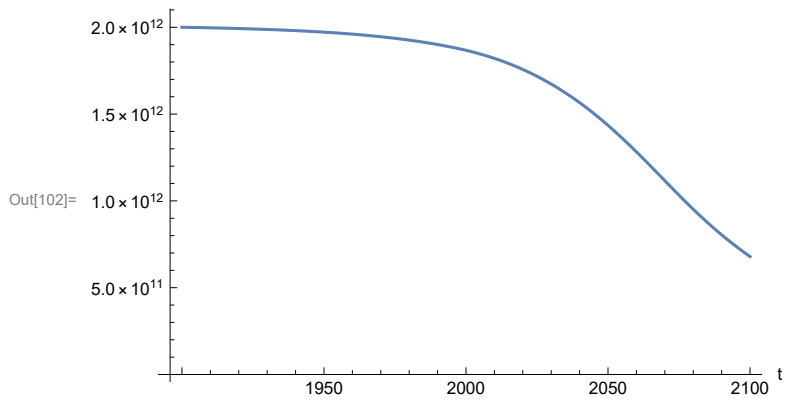
```
In[101]:= MinAndMax[basestrsim[{"Pollution_Dynamics1.PPoll_Index.y"}]]
```

Maximum is 27.9674

Minimum is 0.0157768

Plot non-renewable resources remaining.

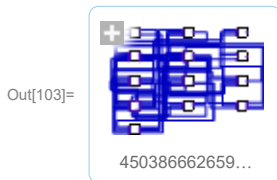
```
In[102]:= SystemModelPlot[basestrsim, {"NR_Resource_Utilization1.NR_Resources.y"}]
```




APPENDIX 10. SEVERE LAND LOSS DUE TO AIR POLLUTION, Benchmark Scenario 2, Experiment 5

Scenario 2 with air pollution effect on land yield changed as noted.

```
In[103]:= sevsim = SystemModel[mysim, <|"ParameterValues" ->
  {"Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals" -> {0.7, 0.1, 0.1, 0.1}}|>]
```



```
In[104]:= basesevsim = SystemModelSimulate[sevsim]
```

Out[104]= SystemModelSimulationData [ Model: W4503866626594a308ecfdcc6917a47d9
Time: 1.90×10^3 to 2.10×10^3]

Show Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals.

```
In[105]:= SystemModel[sevsim] [
  {"ParameterValues", "Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[1]"}]
```

Out[105]= {Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[1] → 0.7}

```
In[106]:= SystemModel[sevsim] [
  {"ParameterValues", "Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[2]"}]
```

Out[106]= {Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[2] → 0.1}

```
In[107]:= SystemModel[sevsim] [
  {"ParameterValues", "Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[3]"}]
```

Out[107]= {Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[3] → 0.1}

```
In[108]:= SystemModel[sevsim] [
  {"ParameterValues", "Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[4]"}]
```

Out[108]= {Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[4] → 0.1}

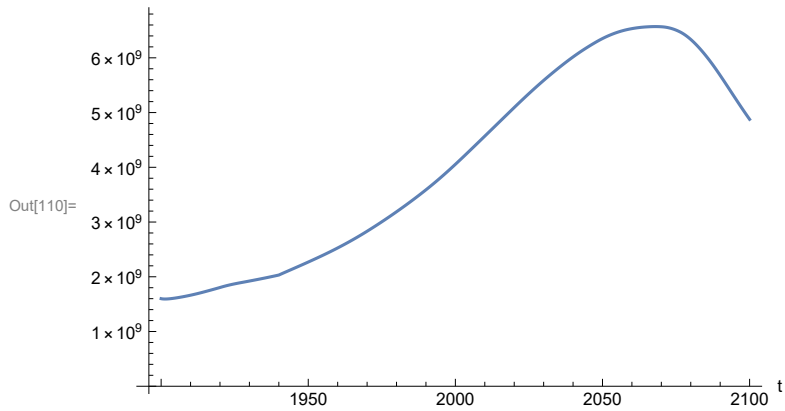
Show the value of t_air_poll_time (calendar year).

```
In[109]:= SystemModel[sevsim][{"ParameterValues", "t_air_poll_time"}]
```

```
Out[109]:= {t_air_poll_time → 4000}
```

Plot the world population, people.

```
In[110]:= SystemModelPlot[basesevsim, {"Population_Dynamics1.Birth_Rate.pop"}]
```



Find max and min of y values.

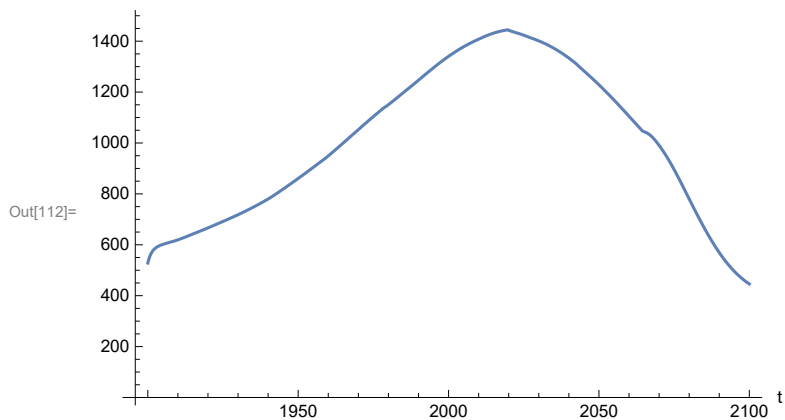
```
In[111]:= MinAndMax[basesevsim[{"Population_Dynamics1.Birth_Rate.pop"}]]
```

```
Maximum is 6.57091 × 109
```

```
Minimum is 1.59367 × 109
```

Plot land yield.

```
In[112]:= SystemModelPlot[basesevsim, {"Food_Production1.Land_Yield.y"}]
```



Find max and min of y values.

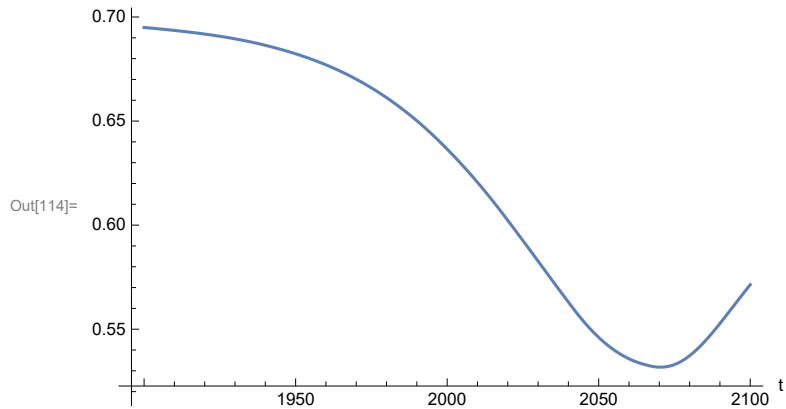
```
In[113]:= MinAndMax[basesevsim[{"Food_Production1.Land_Yield.y"}]]
```

Maximum is 1444.56

Minimum is 446.149

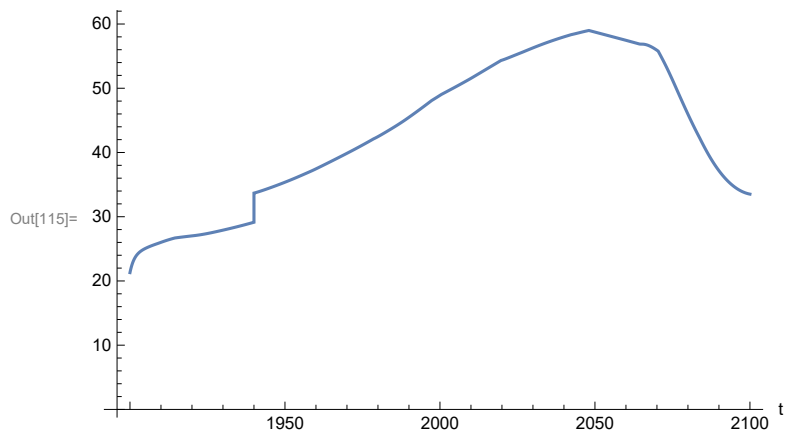
Plot multiplier of air pollution on land yield.

```
In[114]:= SystemModelPlot[basesevsim, {"Food_Production1.s_yield_mlt_air_poll"}]
```



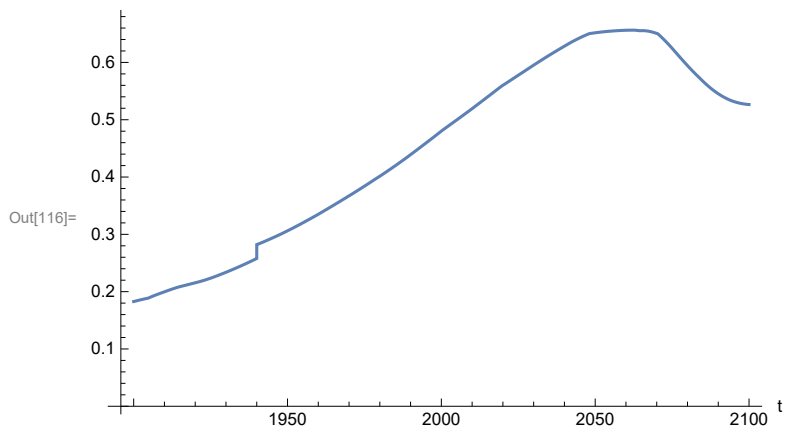
Plot life expectancy, in years.

```
In[115]:= SystemModelPlot[basesevsim, {"Life_Expectancy1.Life_Expectancy.y"}]
```



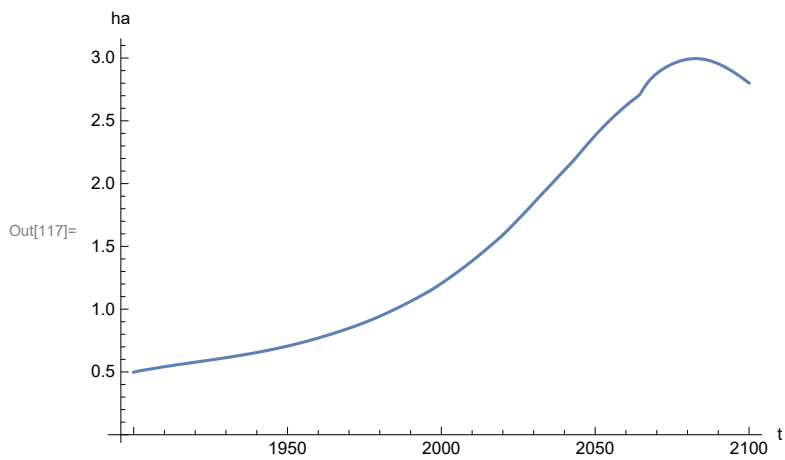
Plot the human welfare index.

```
In[116]:= SystemModelPlot[basesevsim,
  {"Human_Welfare_Index1.HWI_Human_Welfare_Index.hwi_human_welfare_index"}]
```



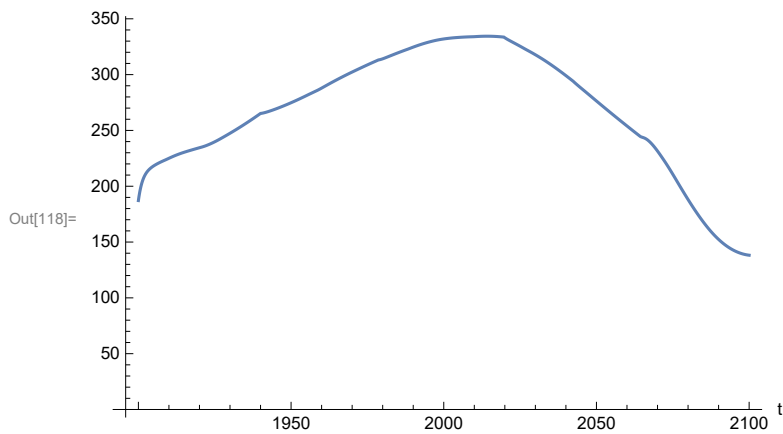
Plot the human ecological footprint, in hectares.

```
In[117]:= SystemModelPlot[basesevsim,
  {"Human_Ecological_Footprint1.HEF_Human_Ecological_Footprint.hef_human_ecological_
    _footprint"}]
```



Plot per capita food production, kg/year.

```
In[118]:= SystemModelPlot[basesevsim, {"Food_Production1.Food_PC.y"}]
```



Find max and min of y values.

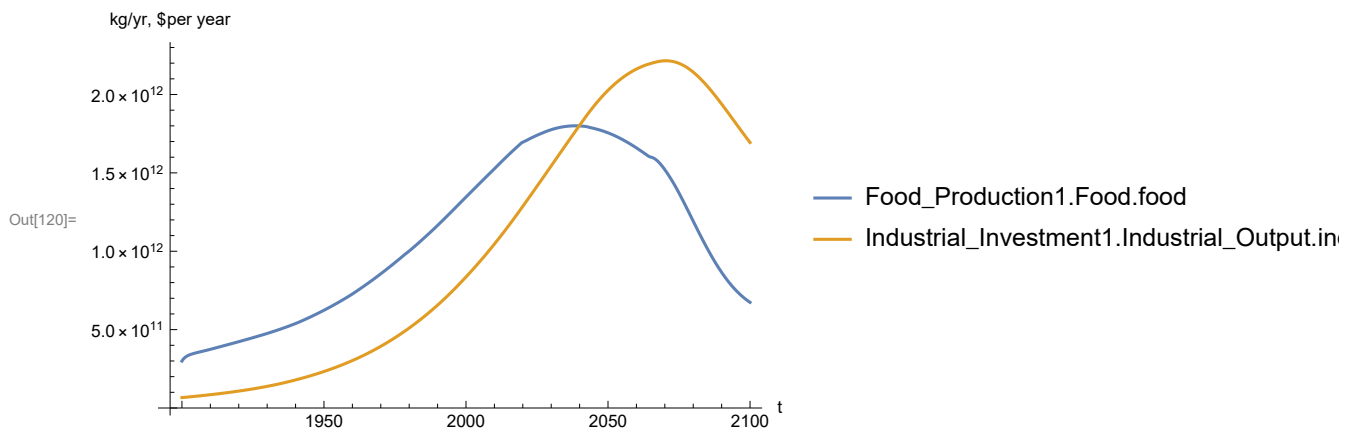
```
In[119]:= MinAndMax[basesevsim[{"Food_Production1.Food_PC.y"}]]
```

Maximum is 334.399

Minimum is 138.21

Plot total food production (kg/yr) and industrial output (in dollars).

```
In[120]:= SystemModelPlot[basesevsim, {"Food_Production1.Food.food",
  "Industrial_Investment1.Industrial_Output.industrial_output"}]
```



Find max and min of y values.

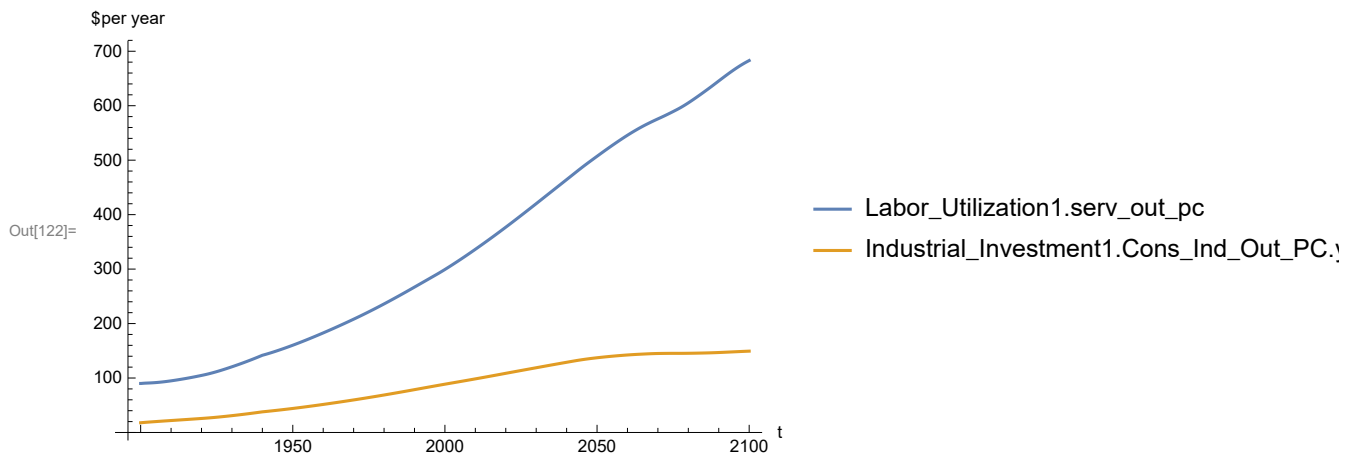
```
In[121]:= MinAndMax[basesevsim[{"Industrial_Investment1.Industrial_Output.industrial_output"}]]
```

Maximum is 2.21513×10^{12}

Minimum is 6.65×10^{10}

Plot consolidated industrial output per capita (dollars/year).

```
In[122]:= SystemModelPlot[basesevsim,
  {"Labor_Utilization1.serv_out_pc", "Industrial_Investment1.Cons_Ind_Out_PC.y"}]
```



Find max and min of y values.

```
In[123]:= MinAndMax[basesevsim[{"Labor_Utilization1.serv_out_pc"}]]
```

Maximum is 682.905

Minimum is 90.

Find max and min of y values.

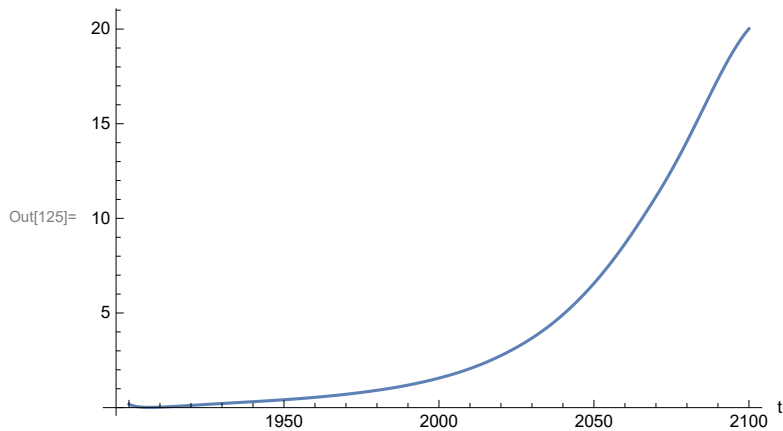
```
In[124]:= MinAndMax[basesevsim[{"Industrial_Investment1.Cons_Ind_Out_PC.y"}]]
```

Maximum is 149.342

Minimum is 17.8719

Plot persistent pollution index (normalized to 1970 value).

```
In[125]:= SystemModelPlot[basesevsim, {"Pollution_Dynamics1.PPoll_Index.y"}]
```



Find max and min of y values.

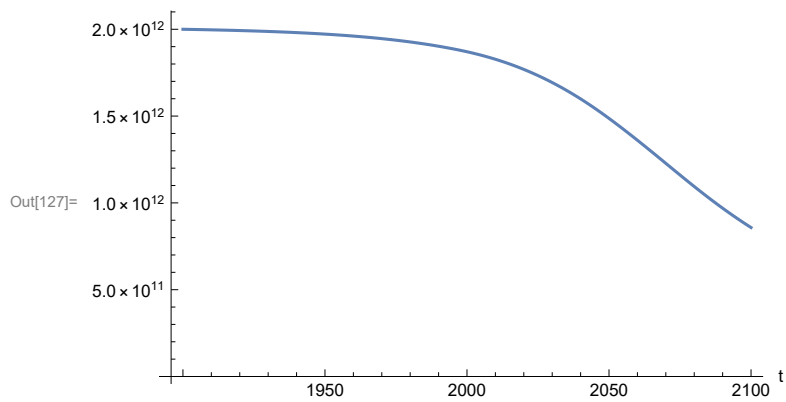
```
In[126]:= MinAndMax[basesevsim[{"Pollution_Dynamics1.PPoll_Index.y"}]]
```

Maximum is 20.0195

Minimum is 0.0157849

Plot non-renewable resources remaining.

```
In[127]:= SystemModelPlot[basesevsim, {"NR_Resource_Utilization1.NR_Resources.y"}]
```



APPENDIX 11. BENCHMARK SCENARIO 3 SIMULATIONS, Scenario 3, Experiment 1

Define a function that extracts range data from scenario data. (The right-hand-side of this definition is specific to a *World3* data structure and assumes that the function whose range is being extracted is globally (i.e., not piecewise) defined.)

```
In[1]:= RangeData[data_] := data[[1]][[4]][[3]];
```

Define a procedure to determine and print minimum and maximum of “y” values.

```
In[2]:= MinAndMax[data_] := (myscenseries = RangeData[data];  
Print["Maximum is ", Max[myscenseries]]; Print["Minimum is ", Min[myscenseries]])
```

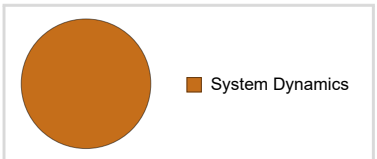
Here are some high-level properties of Benchmark Scenario 3.

```
In[3]:= mysim = SystemModel["SystemDynamics.WorldDynamics.World3.Scenario_3"]
```



```
In[4]:= mysummary = mysim["Summary"]
```

Out[4]=

ModelName	SystemDynamics.WorldDynamics.World3.Scenario_3
Description	More accessible non-recoverable natural resources and pollution control
SimulationModel	True
Plots	0
Components	106
Balanced	True
SystemEquations	1583
SystemVariables	1583
Domain	

Show the value of `t_air_poll_time`.


```
In[5]= SystemModel[mysim][{"ParameterValues", "t_air_poll_time"}]
```

```
Out[5]= {t_air_poll_time → 4000}
```

Show Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals.

```
In[6]= SystemModel[mysim][
  {"ParameterValues", "Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[1]"}]
```

```
Out[6]= {Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[1] → 1}
```

```
In[7]= SystemModel[mysim][
  {"ParameterValues", "Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[2]"}]
```

```
Out[7]= {Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[2] → 1}
```

```
In[8]= SystemModel[mysim][
  {"ParameterValues", "Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[3]"}]
```

```
Out[8]= {Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[3] → 0.7}
```

```
In[9]= SystemModel[mysim][
  {"ParameterValues", "Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[4]"}]
```

```
Out[9]= {Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[4] → 0.4}
```

Show Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_2.y_vals.

```
In[10]= SystemModel[mysim][
  {"ParameterValues", "Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_2.y_vals[1]"}]
```

```
Out[10]= {Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_2.y_vals[1] → 1}
```

```
In[11]= SystemModel[mysim][
  {"ParameterValues", "Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_2.y_vals[2]"}]
```

```
Out[11]= {Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_2.y_vals[2] → 1}
```

```
In[12]= SystemModel[mysim][
  {"ParameterValues", "Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_2.y_vals[3]"}]
```

```
Out[12]= {Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_2.y_vals[3] → 0.98}
```

```
In[13]= SystemModel[mysim][
  {"ParameterValues", "Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_2.y_vals[4]"}]
```

```
Out[13]= {Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_2.y_vals[4] → 0.95}
```

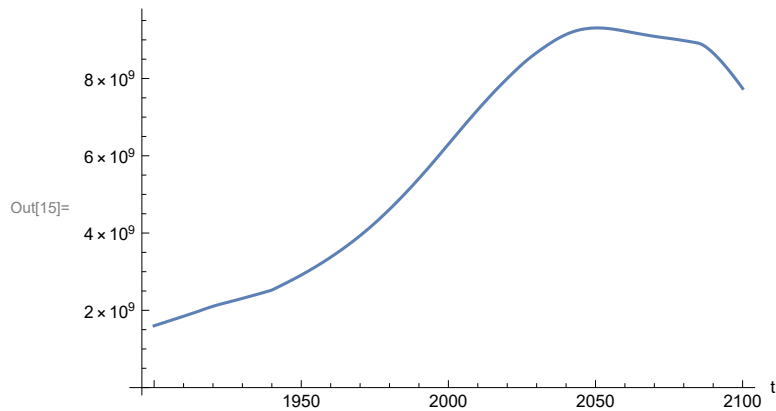
Execute Benchmark Simulation 3 and plot the variables shown in Figure 2.

In[14]:= **basesim = SystemModelSimulate[mysim]**

Out[14]= SystemModelSimulationData [  Model: Scenario_3
Time: 1.90×10^3 to 2.10×10^3]

Plot total population, people.

In[15]:= **SystemModelPlot[basesim, {"Population_Dynamics1.Birth_Rate.pop"}]**



Find max and min of population values.

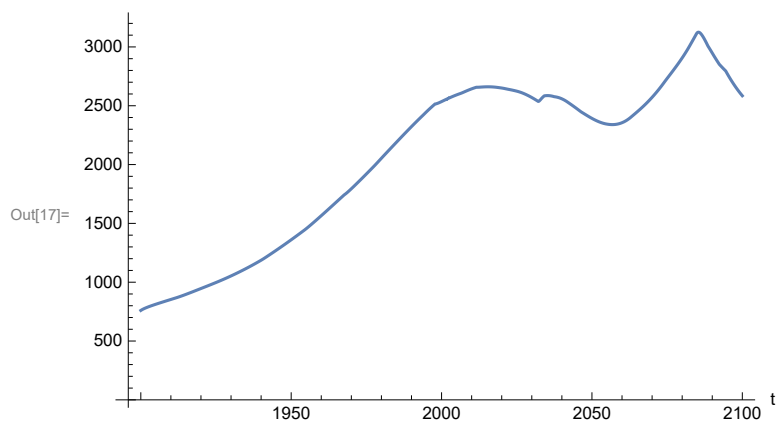
In[16]:= **MinAndMax[basesim[{"Population_Dynamics1.Birth_Rate.pop"}]]**

Maximum is 9.30865×10^9

Minimum is 1.6×10^9

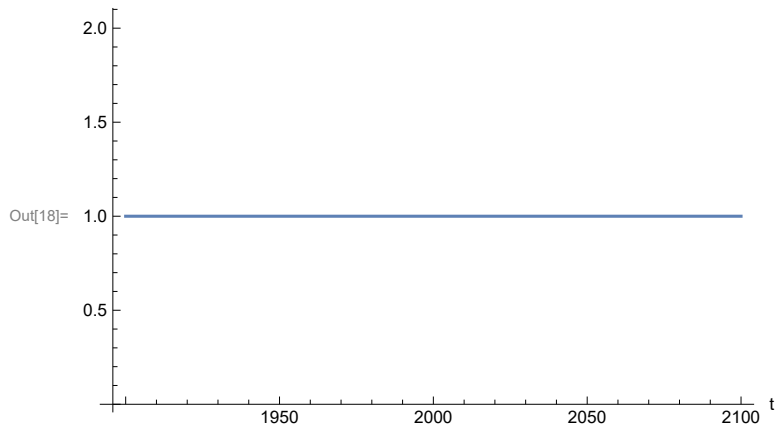
Plot land yield.

In[17]:= **SystemModelPlot[basesim, {"Food_Production1.Land_Yield.y"}]**



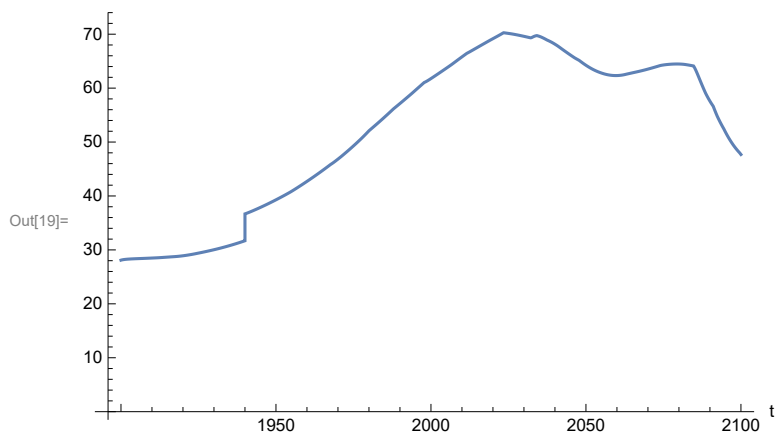
Plot multiplier of air pollution on land yield.

```
In[18]:= SystemModelPlot[basesim, {"Food_Production1.s_yield_mlt_air_poll"}]
```



Plot life expectancy, years.

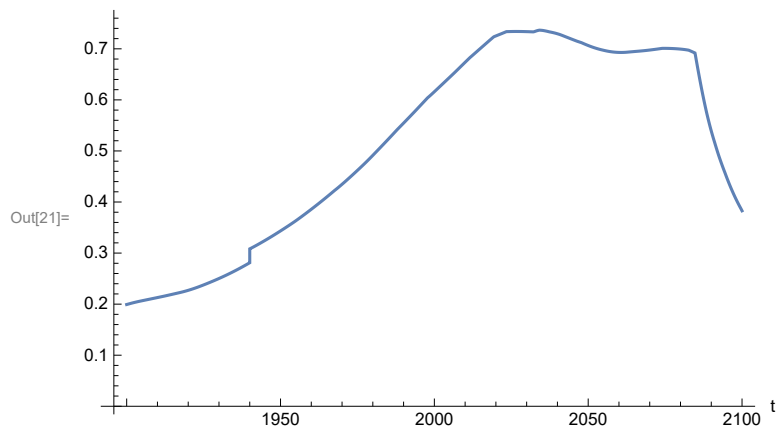
```
In[19]:= SystemModelPlot[basesim, {"Life_Expectancy1.Life_Expectancy.y"}]
```



```
In[20]:=
```

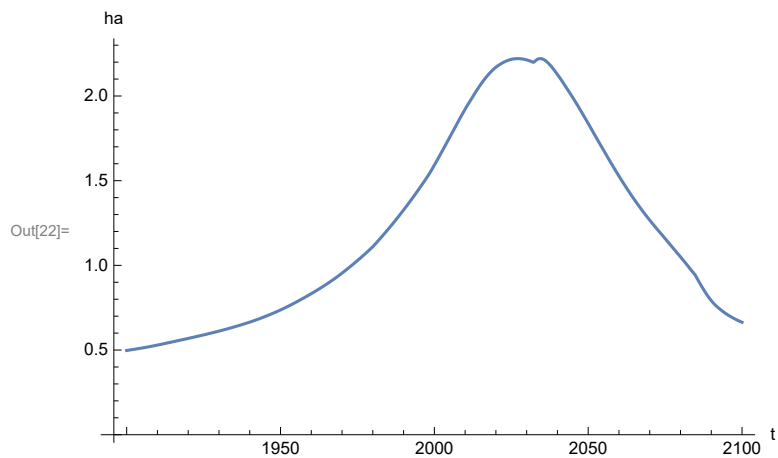
Plot human welfare index.

```
In[21]:= SystemModelPlot[basesim,
  {"Human_Welfare_Index1.HWI_Human_Welfare_Index.hwi_human_welfare_index"}]
```



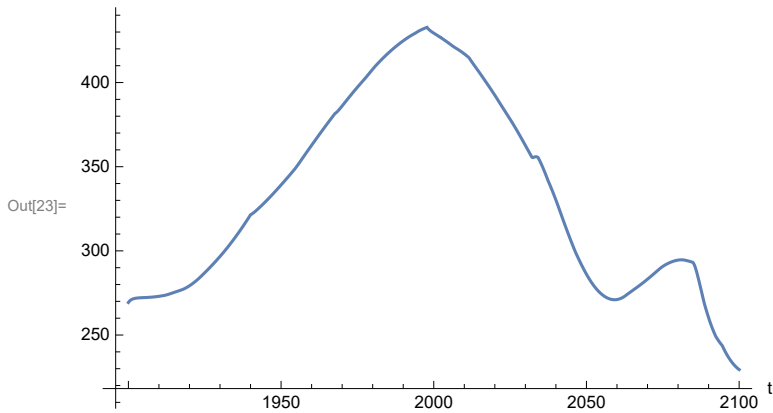
Plot per capita ecological footprint, hectares.

```
In[22]:= SystemModelPlot[basesim,
  {"Human_Ecological_Footprint1.HEF_Human_Ecological_Footprint.hef_human_ecological_footprint"}]
```



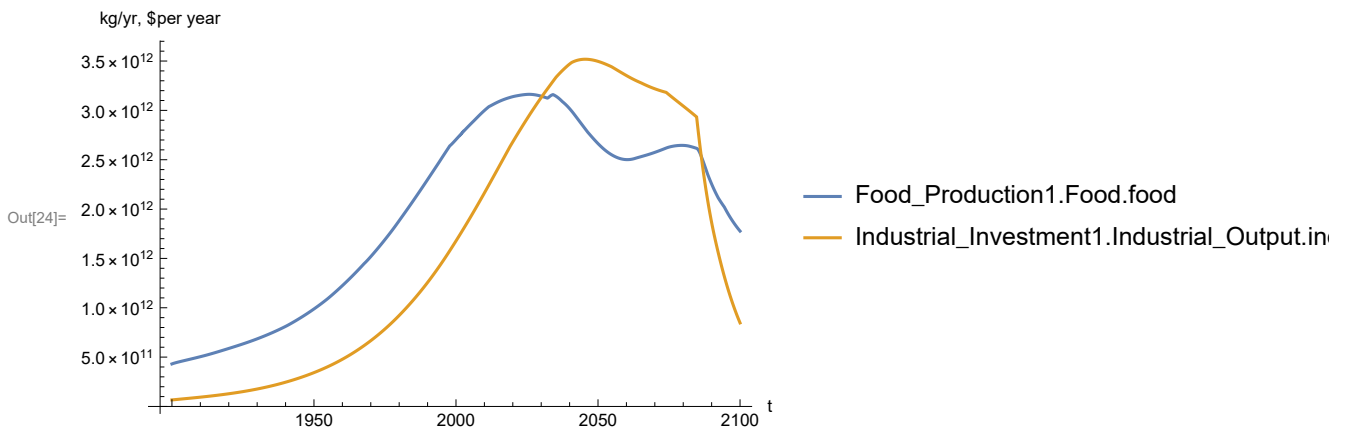
Plot food production per capita (kg/year).

In[23]= `SystemModelPlot[basesim, {"Food_Production1.Food_PC.y"}]`



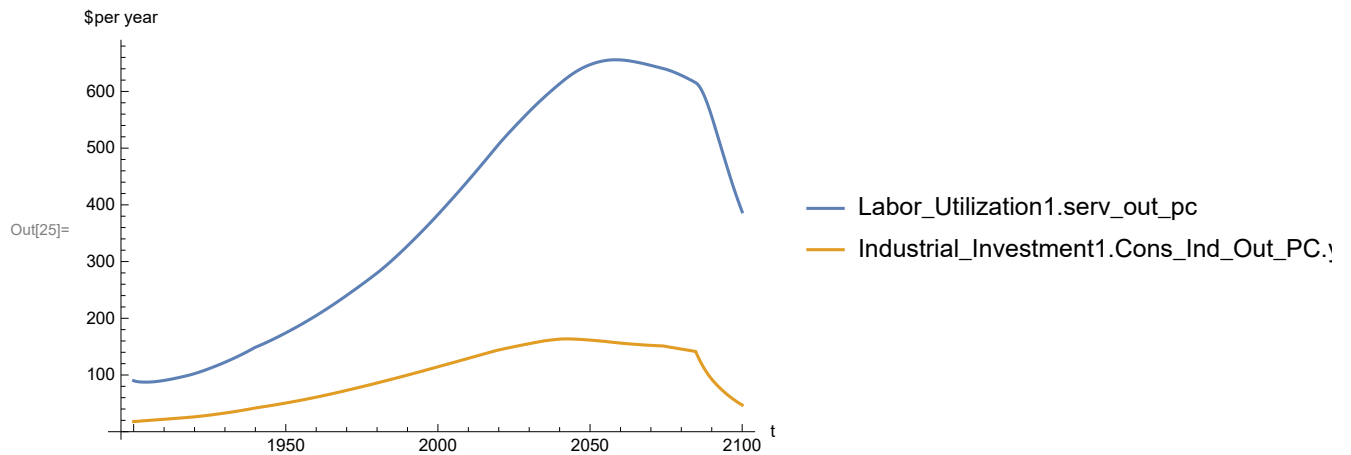
Plot total food production (kg/year), and industrial output (dollars/year).

In[24]= `SystemModelPlot[basesim, {"Food_Production1.Food.food", "Industrial_Investment1.Industrial_Output.industrial_output"}]`



Plot labor utilization per capita (dollars/year), and consolidated industrial output per capita (dollars/year)

```
In[25]:= SystemModelPlot[basesim,
  {"Labor_Utilization1.serv_out_pc", "Industrial_Investment1.Cons_Ind_Out_PC.y"}]
```



Find max and min of y values.

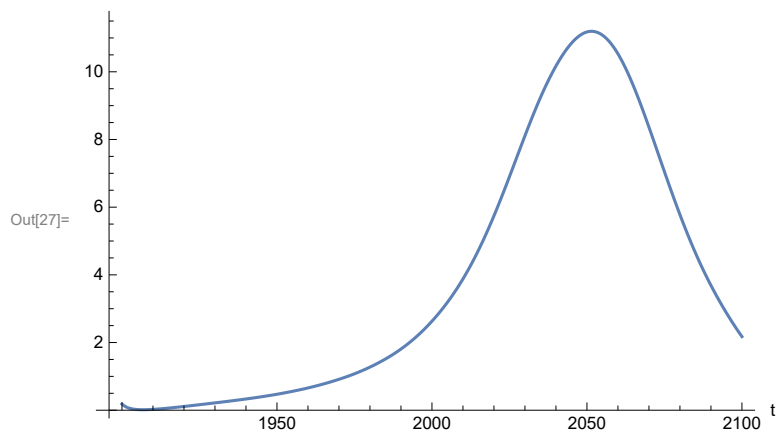
```
In[26]:= MinAndMax[basesim[{"Labor_Utilization1.serv_out_pc"}]]
```

Maximum is 655.832

Minimum is 87.4451

Plot persistent pollution index.

```
In[27]:= SystemModelPlot[basesim, {"Pollution_Dynamics1.PPoll_Index.y"}]
```



Find max and min of y values.

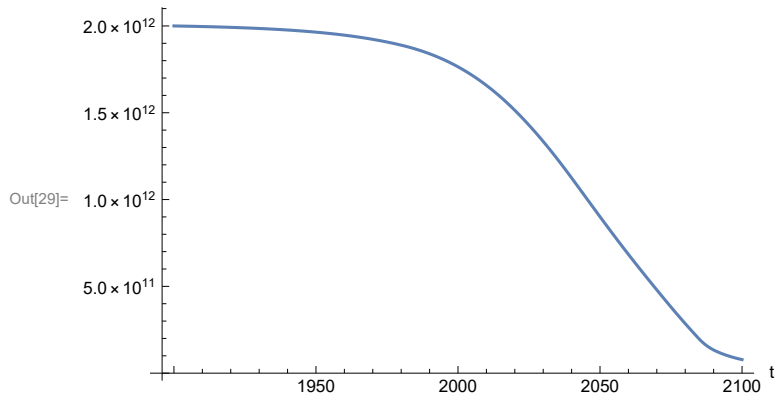
```
In[28]:= MinAndMax[basesim[{"Pollution_Dynamics1.PPoll_Index.y"}]]
```

Maximum is 11.1964

Minimum is 0.0150765

Plot non-renewable resources remaining.

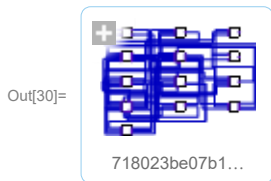
In[29]:= SystemModelPlot[basesim, {"NR_Resource_Utilization1.NR_Resources.y"}]





APPENDIX 12. Effects of mitigating the impact of air pollution on agricultural land yield, beginning calendar year 2020, Scenario 3, Experiment 2

Change the value of the air pollution effect multiplier switch time `t_air_poll_time`, to calendar year 2020, and execute the resulting scenario, plotting the variables shown in Figure 2.

```
In[30]:= newmysim = SystemModel[mysim, <|"ParameterValues" → {"t_air_poll_time" → 2020}|>]
```



```
In[31]:= testsim = SystemModelSimulate[newmysim]
```

Out[31]= SystemModelSimulationData [  Model: W718023be07b1433b8c8eeb866cdf87a2
Time: 1.90×10^3 to 2.10×10^3]

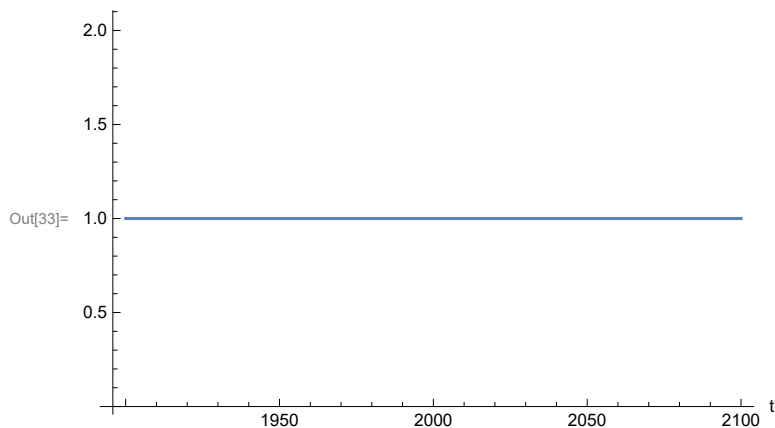
Show the value of `t_air_poll_time` (calendar year).

```
In[32]:= SystemModel[newmysim][{"ParameterValues", "t_air_poll_time"}]
```

Out[32]= {t_air_poll_time → 2020}

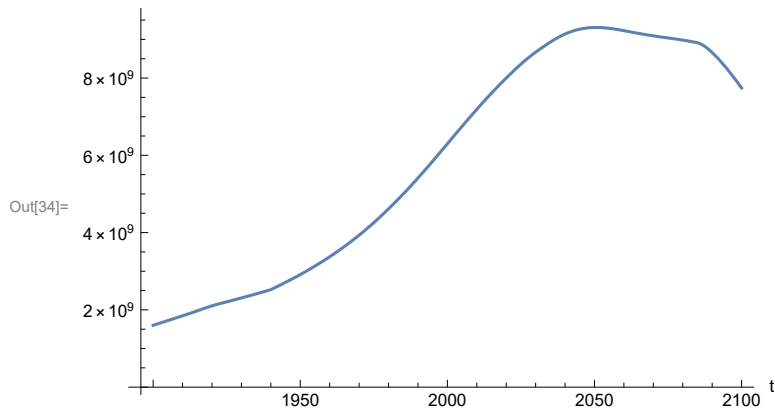
Plot air pollution multiplier of land yield.

```
In[33]:= SystemModelPlot[testsim, {"Food_Production1.s_yield_mlt_air_poll"}]
```



Plot the world population, people.

```
In[34]:= SystemModelPlot[testsim, {"Population_Dynamics1.Birth_Rate.pop"}]
```



Find max and min of y values.

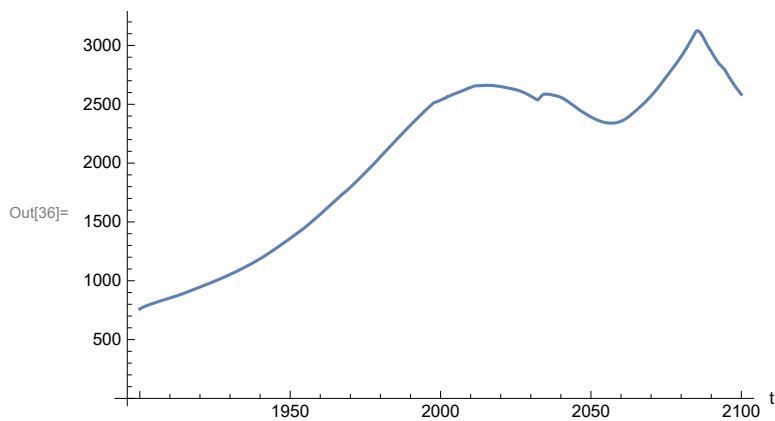
```
In[35]:= MinAndMax[testsim[{"Population_Dynamics1.Birth_Rate.pop"}]]
```

Maximum is 9.30865×10^9

Minimum is 1.6×10^9

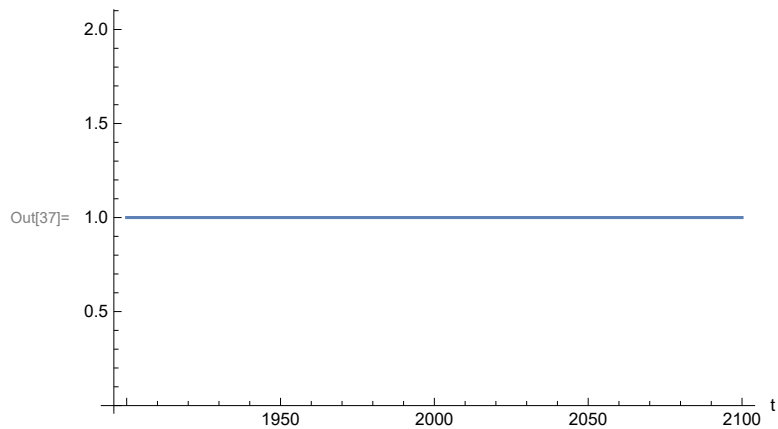
Plot land yield.

```
In[36]:= SystemModelPlot[testsim, {"Food_Production1.Land_Yield.y"}]
```



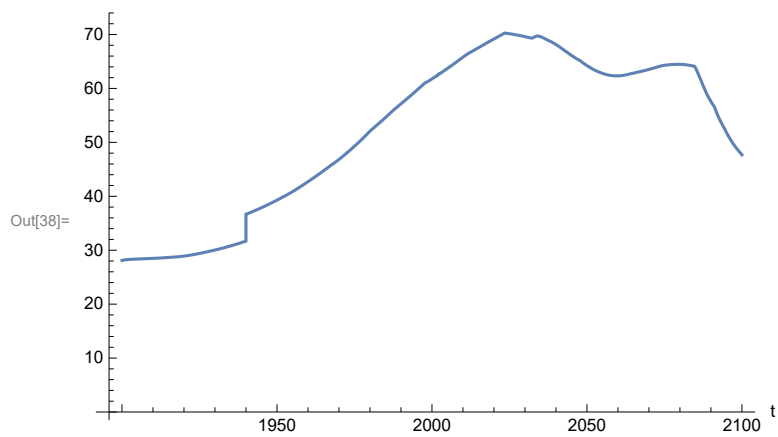
Plot multiplier of air pollution on land yield.

```
In[37]:= SystemModelPlot[testsim, {"Food_Production1.s_yield_mlt_air_poll"}]
```



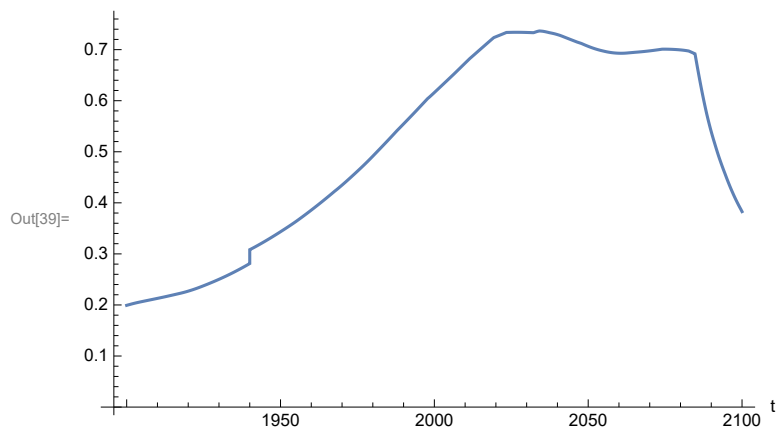
Plot life expectancy, in years.

```
In[38]:= SystemModelPlot[testsim, {"Life_Expectancy1.Life_Expectancy.y"}]
```



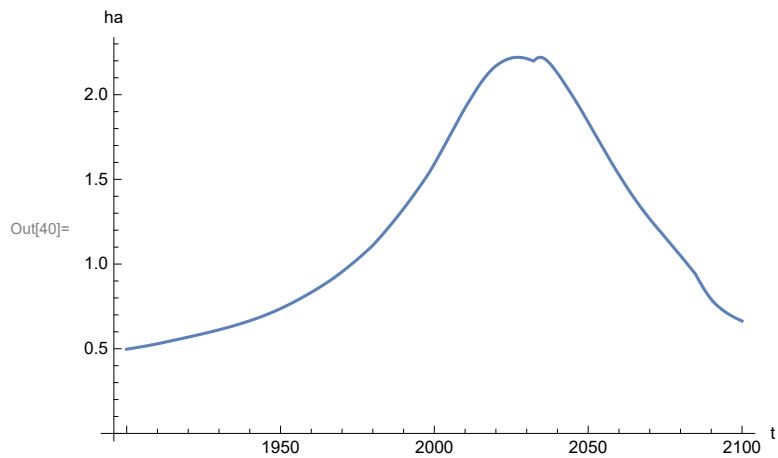
Plot the human welfare index.

```
In[39]:= SystemModelPlot[testsim, {"Human_Welfare_Index1.HWI_Human_Welfare_Index.hwi_human_welfare_index"}]
```



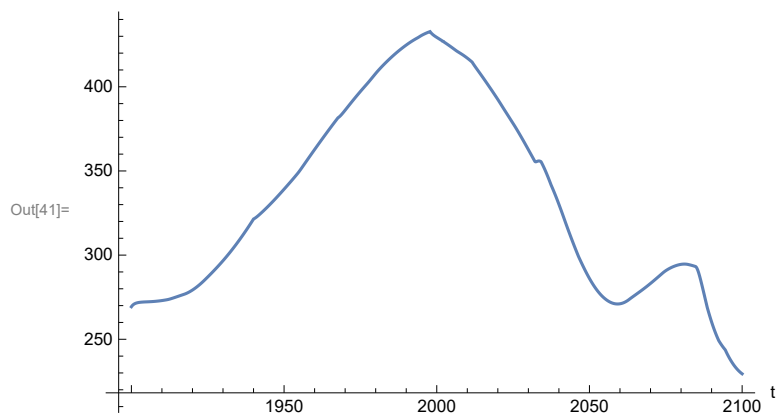
Plot the human ecological footprint, in hectares.

```
In[40]:= SystemModelPlot[testsim,
  {"Human_Ecological_Footprint1.HEF_Human_Ecological_Footprint.hef_human_ecological_
    _footprint"}]
```



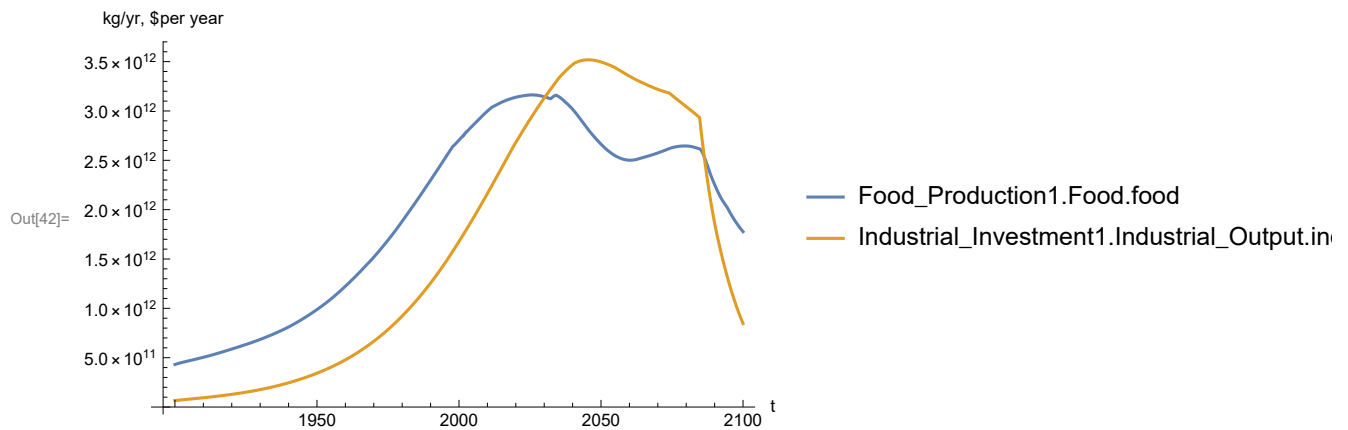
Plot per capita food production, kg/year.

```
In[41]:= SystemModelPlot[testsim, {"Food_Production1.Food_PC.y"}]
```



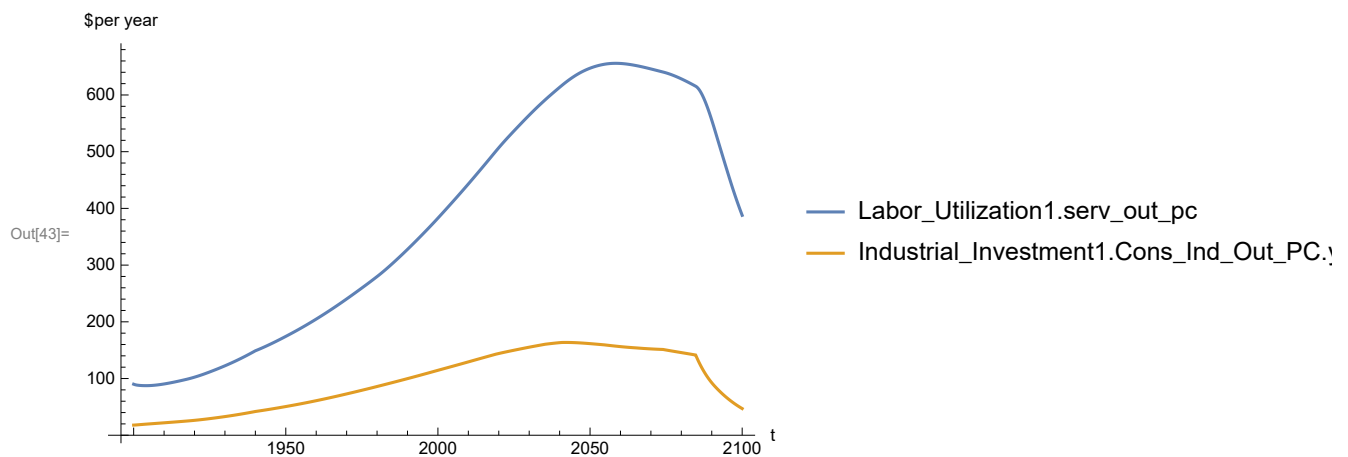
Plot total food production (kg/yr) and industrial output (in dollars).

```
In[42]:= SystemModelPlot[testsim, {"Food_Production1.Food.food",
  "Industrial_Investment1.Industrial_Output.industrial_output"}]
```



Plot labor utilization per capita and consolidated industrial output per capita (dollars/year).

```
In[43]:= SystemModelPlot[testsim,
  {"Labor_Utilization1.serv_out_pc", "Industrial_Investment1.Cons_Ind_Out_PC.y"}]
```



Find max and min of y values.

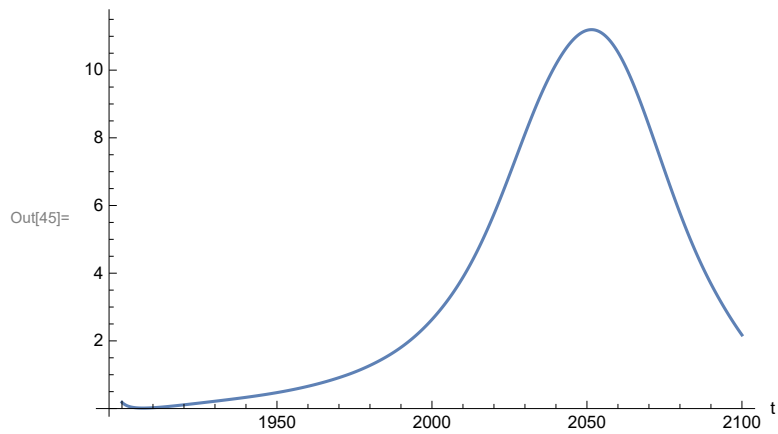
```
In[44]:= MinAndMax[testsim[{"Labor_Utilization1.serv_out_pc"}]]
```

Maximum is 655.832

Minimum is 87.4451

Plot persistent pollution index (normalized to 1970 value).

```
In[45]:= SystemModelPlot[testsim, {"Pollution_Dynamics1.PPoll_Index.y"}]
```



Find max and min of y values.

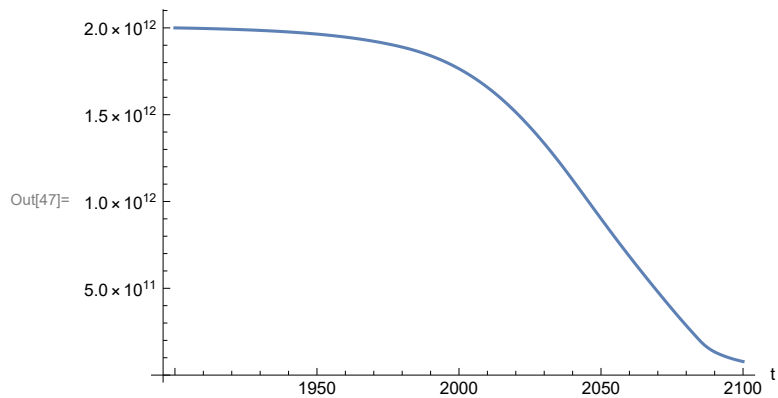
```
In[46]:= MinAndMax[testsim[{"Pollution_Dynamics1.PPoll_Index.y"}]]
```

Maximum is 11.1964

Minimum is 0.0150765

Plot non-renewable resources remaining.

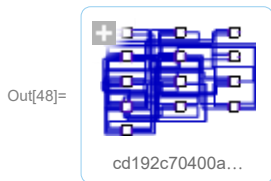
```
In[47]:= SystemModelPlot[testsim, {"NR_Resource_Utilization1.NR_Resources.y"}]
```



APPENDIX 13. Effects of mitigating the impact of air pollution on agricultural land yield, beginning calendar year 1970, Scenario 3, Experiment 3

Change the value of the air pollution effect multiplier switch time `t_air_poll_time`, to calendar year 1970, and execute the resulting scenario, plotting the variables shown in Figure 2.

```
In[48]:= newmysim1970 = SystemModel[mysim, <|"ParameterValues" → {"t_air_poll_time" → 1970} |>]
```



```
In[49]:= testsim1970 = SystemModelSimulate[newmysim1970]
```

Out[49]= SystemModelSimulationData [ Model: Wcd192c70400a42939da31568a3d8a226
Time: 1.90×10^3 to 2.10×10^3]

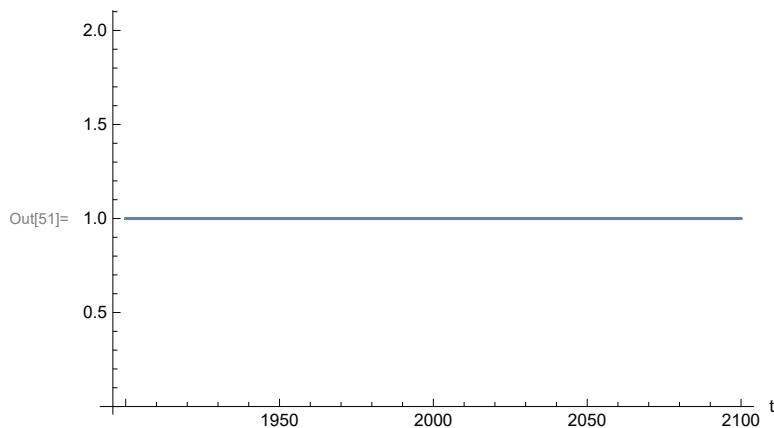
Show the value of `t_air_poll_time` (calendar year).

```
In[50]:= SystemModel[newmysim1970][{"ParameterValues", "t_air_poll_time"}]
```

Out[50]= {t_air_poll_time → 1970}

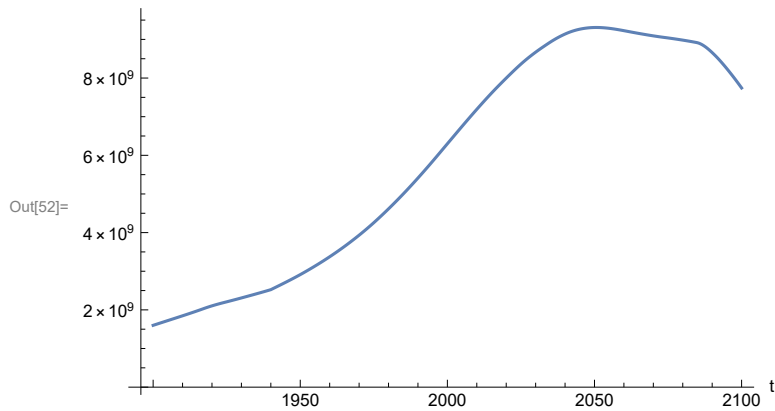
Plot air pollution multiplier of land yield.

```
In[51]:= SystemModelPlot[testsim1970, {"Food_Production1.s_yield_mlt_air_poll"}]
```



Plot the world population, people.

```
In[52]:= SystemModelPlot[testsim1970, {"Population_Dynamics1.Birth_Rate.pop"}]
```



Find max and min of y values.

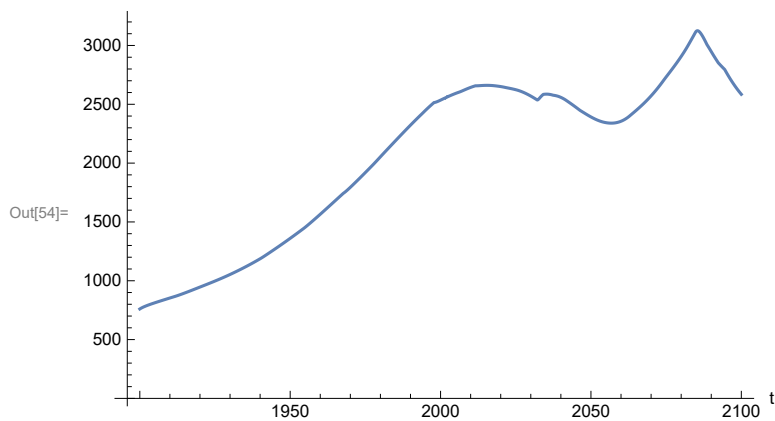
```
In[53]:= MinAndMax[testsim1970[{"Population_Dynamics1.Birth_Rate.pop"}]]
```

Maximum is 9.30865×10^9

Minimum is 1.6×10^9

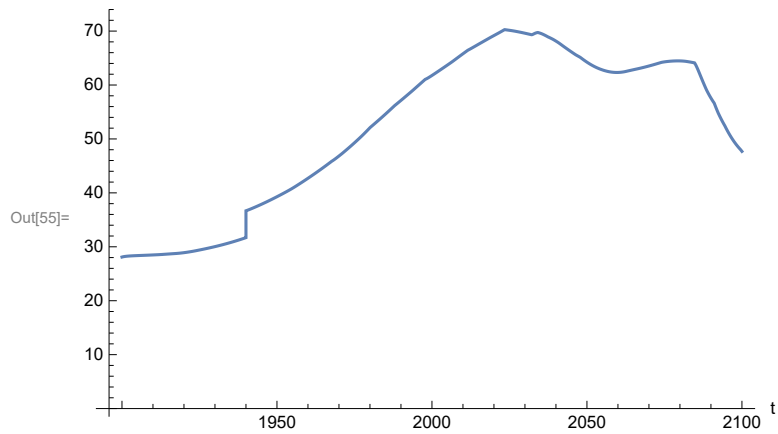
Plot land yield.

```
In[54]:= SystemModelPlot[testsim1970, {"Food_Production1.Land_Yield.y"}]
```



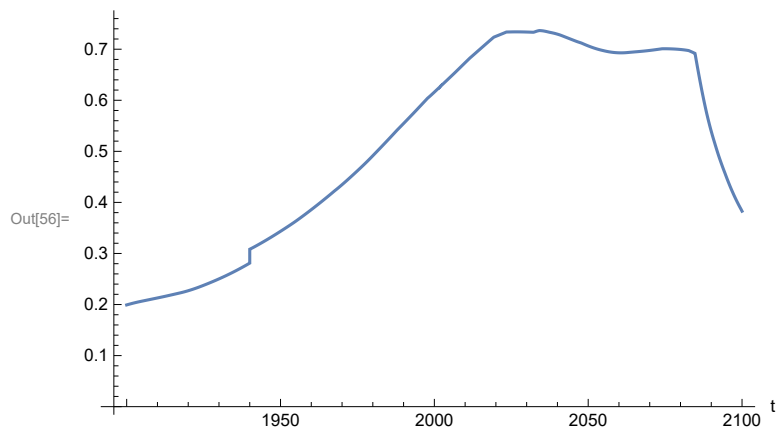
Plot life expectancy, in years.

```
In[55]:= SystemModelPlot[testsim1970, {"Life_Expectancy1.Life_Expectancy.y"}]
```



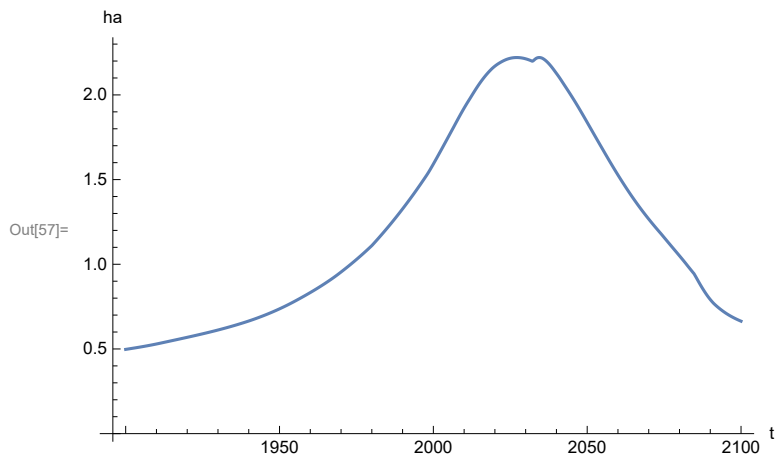
Plot the human welfare index.

```
In[56]:= SystemModelPlot[testsim1970, {"Human_Welfare_Index1.HWI_Human_Welfare_Index.hwi_human_welfare_index"}]
```



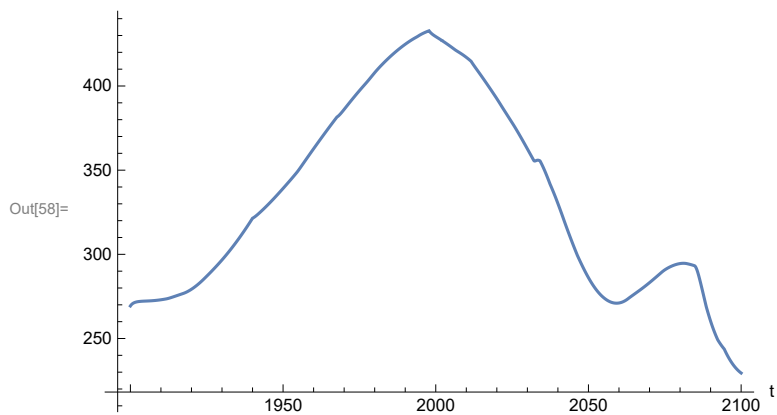
Plot the human ecological footprint, in hectares.


```
In[57]:= SystemModelPlot[testsim1970,
  {"Human_Ecological_Footprint1.HEF_Human_Ecological_Footprint.hef_human_ecological_
    _footprint"}]
```



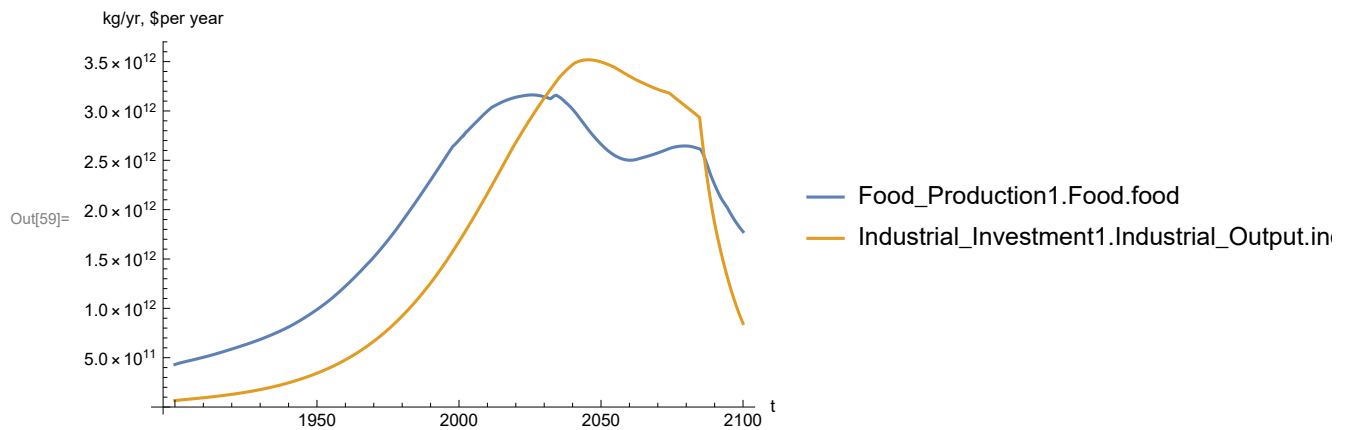
Plot per capita food production, kg/year.

```
In[58]:= SystemModelPlot[testsim1970, {"Food_Production1.Food_PC.y"}]
```



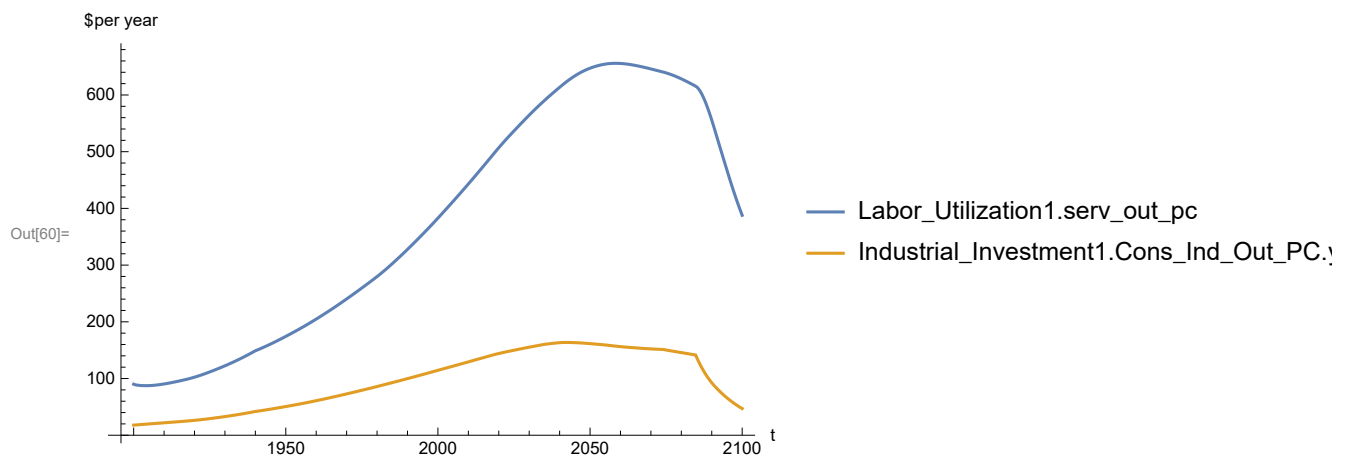
Plot total food production (kg/yr) and industrial output (in dollars).

```
In[59]:= SystemModelPlot[testsim1970, {"Food_Production1.Food.food",
  "Industrial_Investment1.Industrial_Output.industrial_output"}]
```



Plot consolidated industrial output per capita (dollars/year).

```
In[60]:= SystemModelPlot[testsim1970,
  {"Labor_Utilization1.serv_out_pc", "Industrial_Investment1.Cons_Ind_Out_PC.y"}]
```



Find max and min of y values.

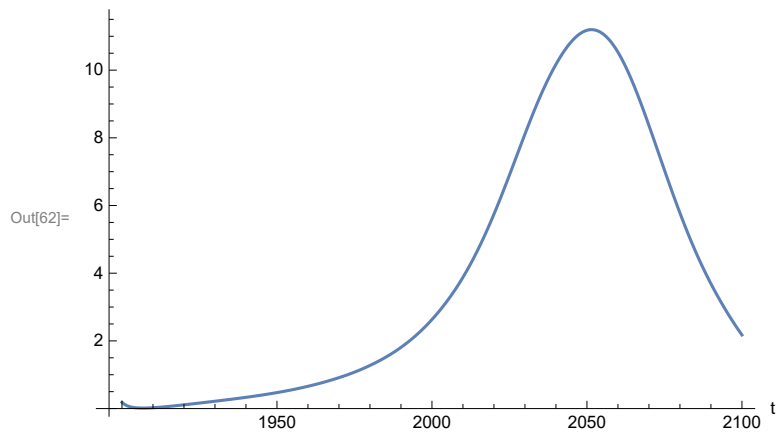
```
In[61]:= MinAndMax[testsim1970[{"Labor_Utilization1.serv_out_pc"}]]
```

Maximum is 655.832

Minimum is 87.4451

Plot persistent pollution index (normalized to 1970 value).

```
In[62]:= SystemModelPlot[testsim1970, {"Pollution_Dynamics1.PPoll_Index.y"}]
```



Find max and min of y values.

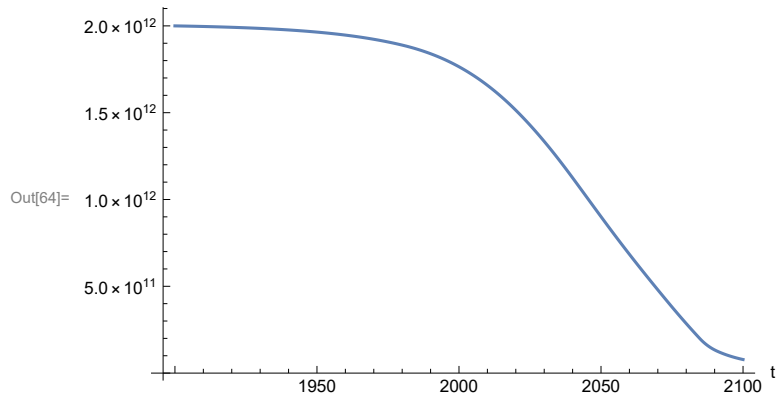
```
In[63]:= MinAndMax[testsim1970[{"Pollution_Dynamics1.PPoll_Index.y"}]]
```

Maximum is 11.1964

Minimum is 0.0150765

Plot non-renewable resources remaining.

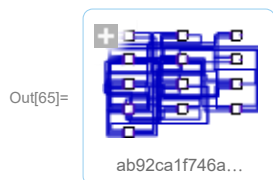
```
In[64]:= SystemModelPlot[testsim1970, {"NR_Resource_Utilization1.NR_Resources.y"}]
```



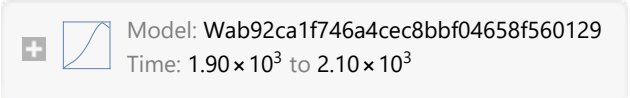
APPENDIX 14. “STRONG AIR POLLUTION” EFFECTS SCENARIO, Scenario 3, Experiment 4

Scenario 2 with air pollution effect on land yield changed as noted.

```
In[65]:= strsim = SystemModel[mysim, <|"ParameterValues" ->
      {"Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals" -> {0.7, 0.5, 0.3, 0.1}}|>]
```



```
In[66]:= basestrsim = SystemModelSimulate[strsim]
```

Out[66]= SystemModelSimulationData []

Show Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals.

```
In[67]:= SystemModel[strsim] [
      {"ParameterValues", "Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[1]"}]
```

Out[67]= {Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[1] → 0.7}

```
In[68]:= SystemModel[strsim] [
      {"ParameterValues", "Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[2]"}]
```

Out[68]= {Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[2] → 0.5}

```
In[69]:= SystemModel[strsim] [
      {"ParameterValues", "Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[3]"}]
```

Out[69]= {Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[3] → 0.3}

```
In[70]:= SystemModel[strsim] [
      {"ParameterValues", "Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[4]"}]
```

Out[70]= {Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[4] → 0.1}

Show the value of t_air_poll_time (calendar year).

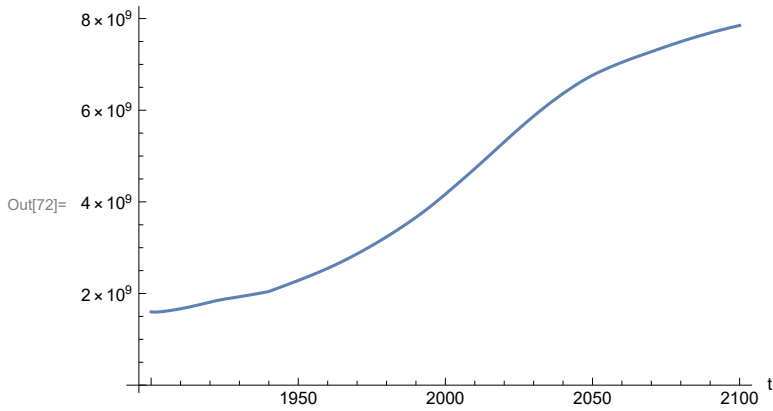
```
In[71]:= SystemModel[strsim] [{"ParameterValues", "t_air_poll_time"}]
```

Out[71]= {t_air_poll_time → 4000}

Plot the world population, people. Note that the peak population is about one billion less, and about

20 years later, than the peak population forecast by Experiments 1-3.

```
In[72]:= SystemModelPlot[basestransim, {"Population_Dynamics1.Birth_Rate.pop"}]
```

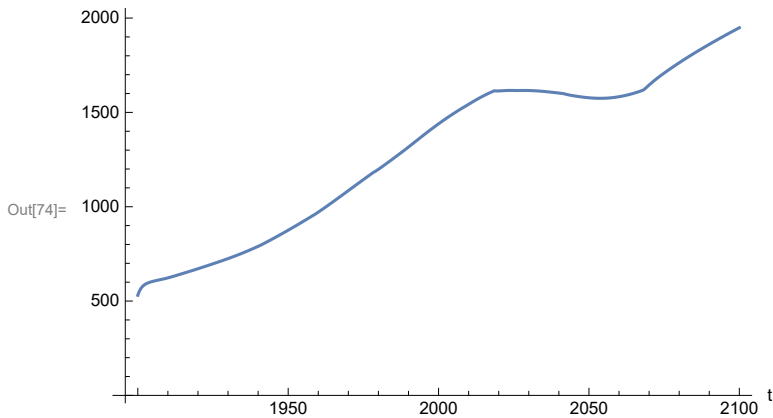


Find max and min of y values.

```
In[73]:= MinAndMax[basestransim[{"Population_Dynamics1.Birth_Rate.pop"}]]
Maximum is 7.84949 × 109
Minimum is 1.59431 × 109
```

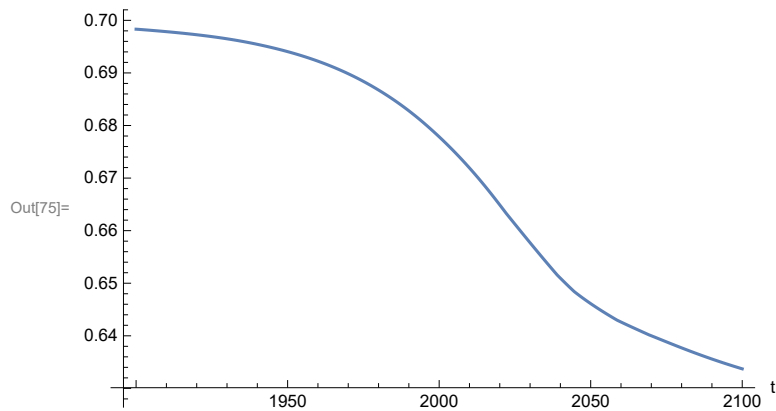
Plot land yield.

```
In[74]:= SystemModelPlot[basestransim, {"Food_Production1.Land_Yield.y"}]
```



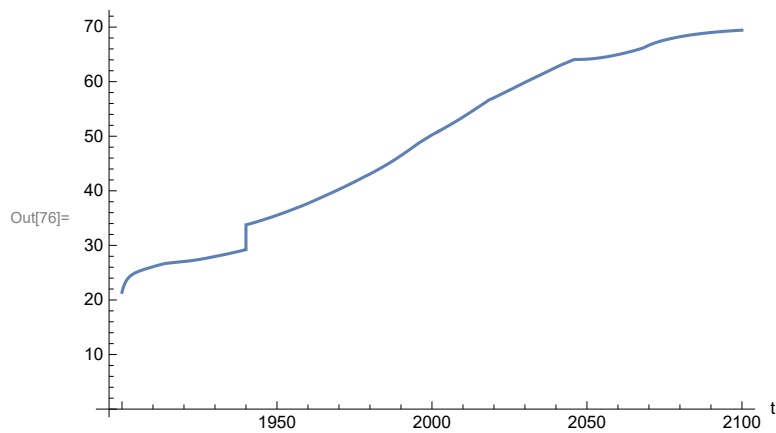
Plot multiplier of air pollution on land yield.

```
In[75]:= SystemModelPlot[basestransim, {"Food_Production1.s_yield_mlt_air_poll"}]
```



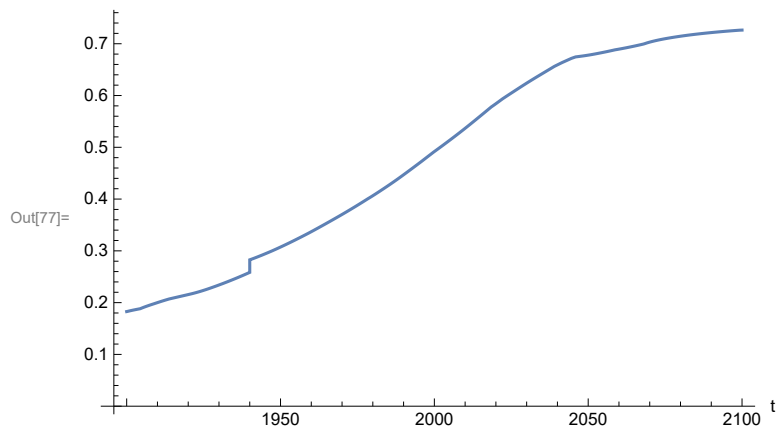
Plot life expectancy, in years.

```
In[76]:= SystemModelPlot[basestransim, {"Life_Expectancy1.Life_Expectancy.y"}]
```



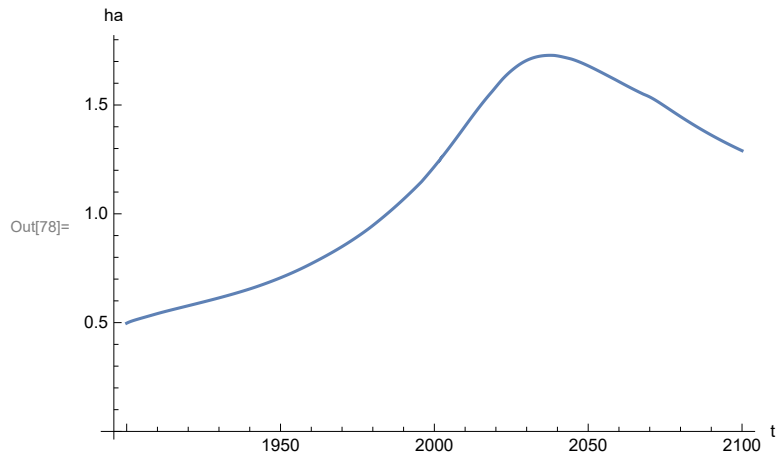
Plot the human welfare index.

```
In[77]:= SystemModelPlot[basestransim, {"Human_Welfare_Index1.HWI_Human_Welfare_Index.hwi_human_welfare_index"}]
```



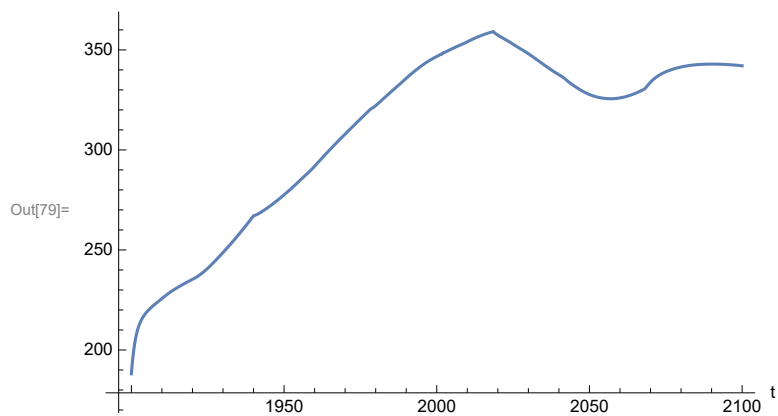
Plot the human ecological footprint, in hectares.

```
In[78]:= SystemModelPlot[basestrsim,
  {"Human_Ecological_Footprint1.HEF_Human_Ecological_Footprint.hef_human_ecological_
    _footprint"}]
```



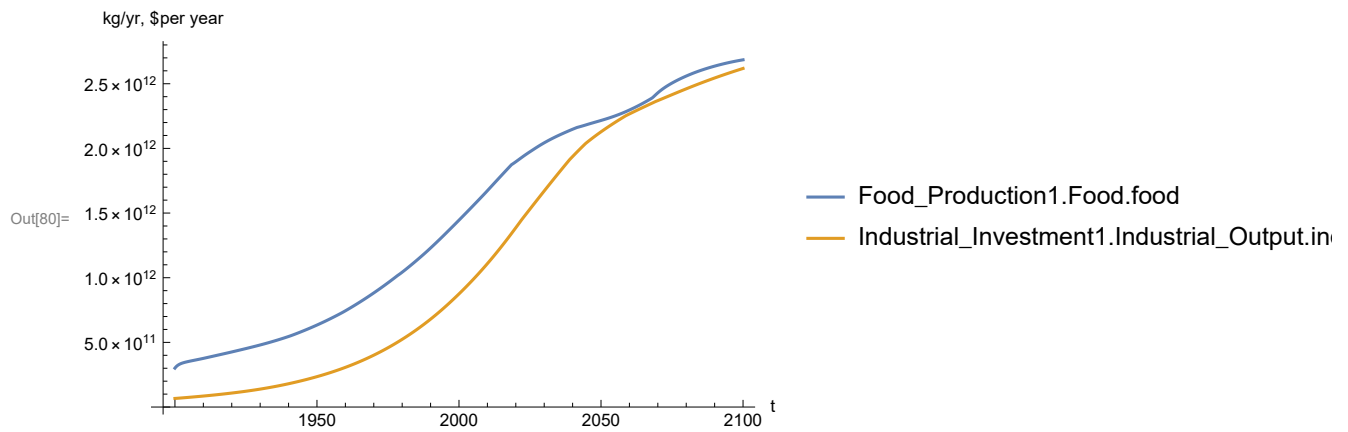
Plot per capita food production, kg/year.

```
In[79]:= SystemModelPlot[basestrsim, {"Food_Production1.Food_PC.y"}]
```



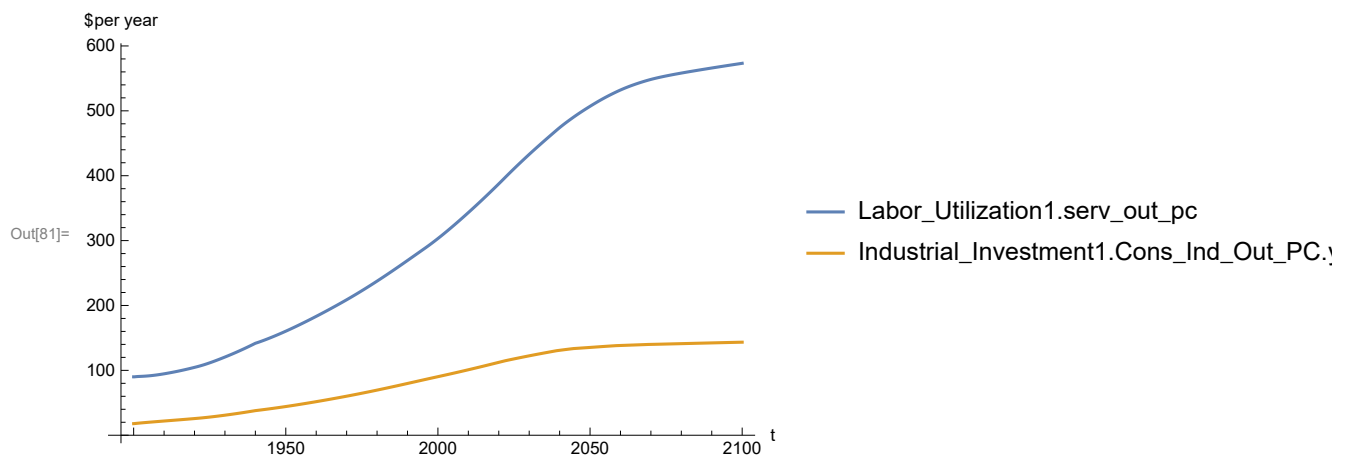
Plot total food production (kg/yr) and industrial output (in dollars).

```
In[80]:= SystemModelPlot[basestrsim, {"Food_Production1.Food.food",
  "Industrial_Investment1.Industrial_Output.industrial_output"}]
```



Plot consolidated industrial output per capita (dollars/year).

```
In[81]:= SystemModelPlot[basestrsim,
  {"Labor_Utilization1.serv_out_pc", "Industrial_Investment1.Cons_Ind_Out_PC.y"}]
```



Find max and min of y values.

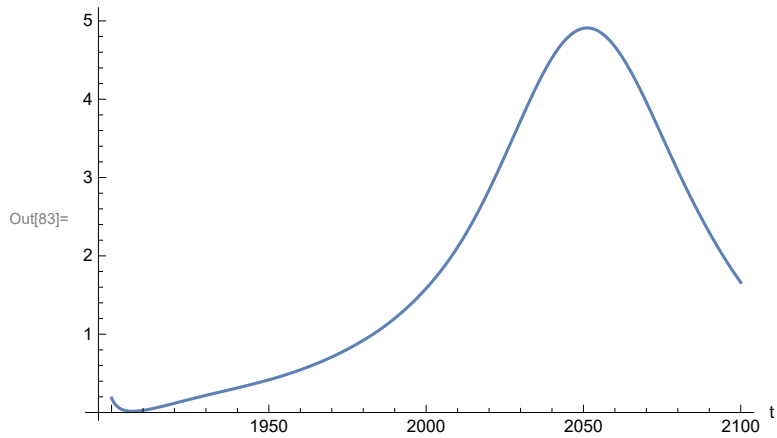
```
In[82]:= MinAndMax[basestrsim[{"Labor_Utilization1.serv_out_pc"}]]
```

Maximum is 573.228

Minimum is 89.9974

Plot persistent pollution index (normalized to 1970 value).


```
In[83]:= SystemModelPlot[basestransim, {"Pollution_Dynamics1.PPoll_Index.y"}]
```



Find max and min of y values.

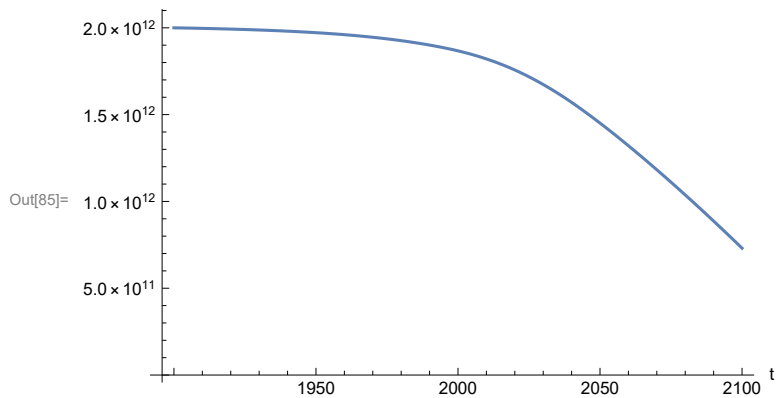
```
In[84]:= MinAndMax[basestransim[{"Pollution_Dynamics1.PPoll_Index.y"}]]
```

Maximum is 4.9102

Minimum is 0.0157768

Plot non-renewable resources remaining.

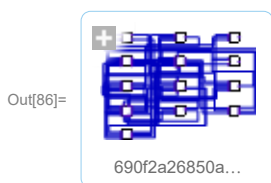
```
In[85]:= SystemModelPlot[basestransim, {"NR_Resource_Utilization1.NR_Resources.y"}]
```




APPENDIX 15. SEVERE LAND LOSS DUE TO AIR POLLUTION, Scenario 3, Experiment 5

Scenario 2 with air pollution effect on land yield changed as noted.

```
In[86]:= sevsim = SystemModel[mysim, <|"ParameterValues" ->
  {"Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals" -> {0.7, 0.1, 0.1, 0.1}}|>]
```



```
In[87]:= basesevsim = SystemModelSimulate[sevsim]
```

Out[87]= SystemModelSimulationData [ Model: W690f2a26850a4f2db3083e0e34c3b718
Time: 1.90×10^3 to 2.10×10^3]

Show Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals.

```
In[88]:= SystemModel[sevsim] [
  {"ParameterValues", "Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[1]"}]
```

Out[88]= {Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[1] → 0.7}

```
In[89]:= SystemModel[sevsim] [
  {"ParameterValues", "Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[2]"}]
```

Out[89]= {Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[2] → 0.1}

```
In[90]:= SystemModel[sevsim] [
  {"ParameterValues", "Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[3]"}]
```

Out[90]= {Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[3] → 0.1}

```
In[91]:= SystemModel[sevsim] [
  {"ParameterValues", "Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[4]"}]
```

Out[91]= {Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[4] → 0.1}

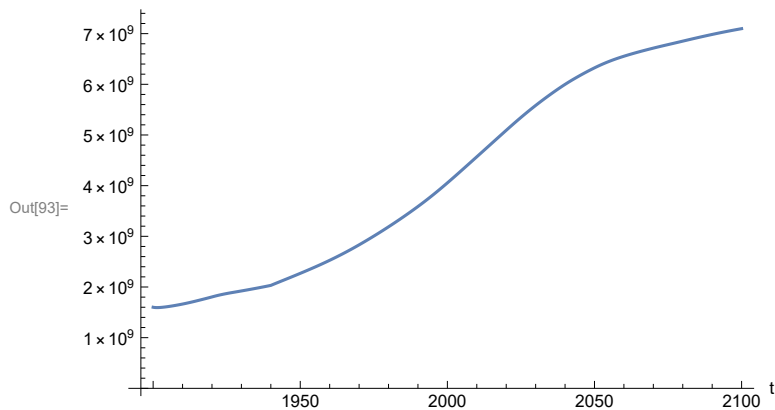
Show the value of t_air_poll_time (calendar year).

```
In[92]:= SystemModel[sevsim][{"ParameterValues", "t_air_poll_time"}]
```

```
Out[92]:= {t_air_poll_time → 4000}
```

Plot the world population, people. Note that the peak population is about one billion less, and about 20 years later, than the peak population forecast by Experiments 1-3.

```
In[93]:= SystemModelPlot[basesevsim, {"Population_Dynamics1.Birth_Rate.pop"}]
```



Find max and min of y values.

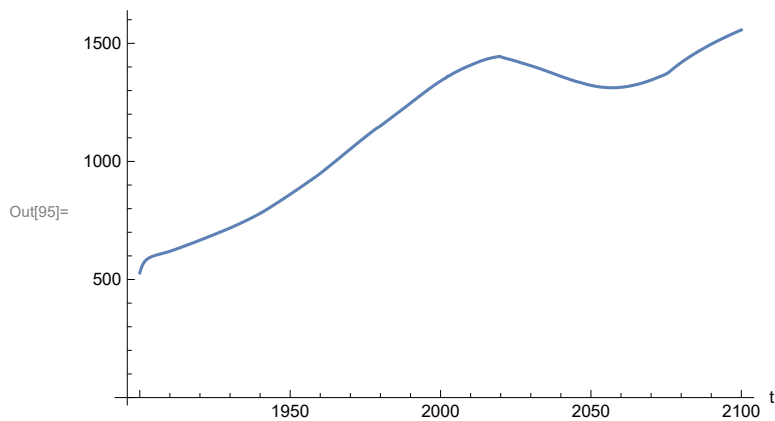
```
In[94]:= MinAndMax[basesevsim[{"Population_Dynamics1.Birth_Rate.pop"}]]
```

```
Maximum is 7.09802 × 109
```

```
Minimum is 1.59367 × 109
```

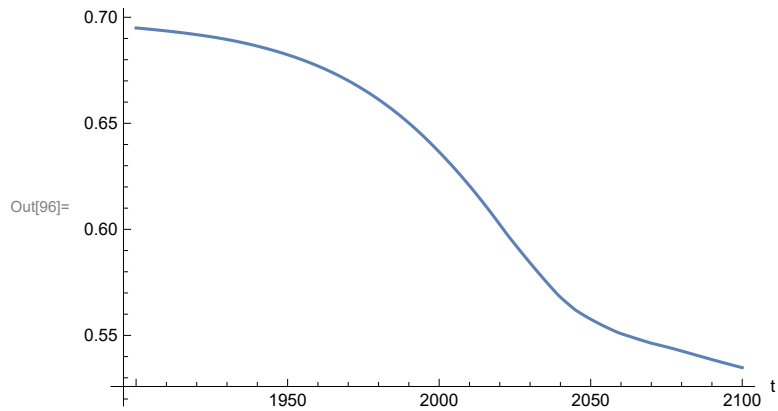
Plot land yield.

```
In[95]:= SystemModelPlot[basesevsim, {"Food_Production1.Land_Yield.y"}]
```



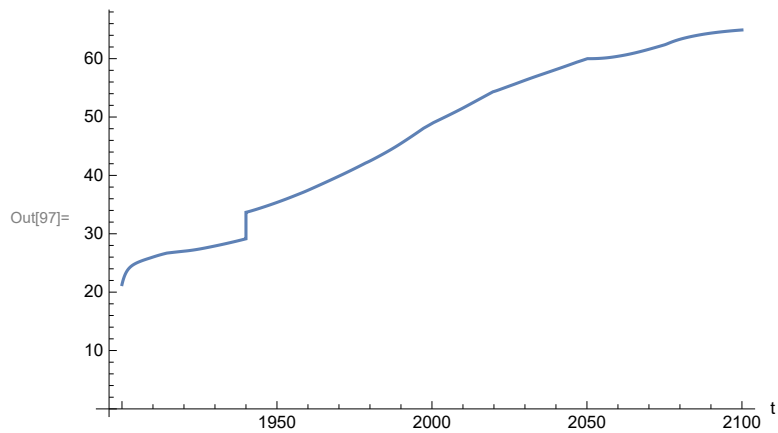
Plot multiplier of air pollution on land yield.

```
In[96]:= SystemModelPlot[basesevsim, {"Food_Production1.s_yield_mlt_air_poll"}]
```



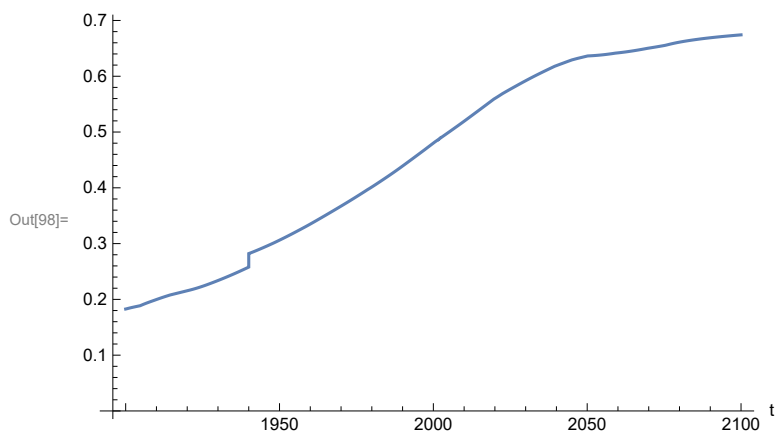
Plot life expectancy, in years.

```
In[97]:= SystemModelPlot[basesevsim, {"Life_Expectancy1.Life_Expectancy.y"}]
```



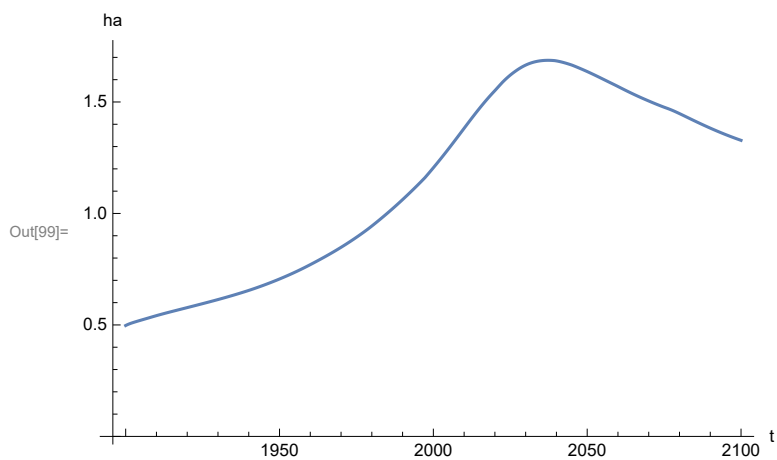
Plot the human welfare index.

```
In[98]:= SystemModelPlot[basesevsim,
  {"Human_Welfare_Index1.HWI_Human_Welfare_Index.hwi_human_welfare_index"}]
```



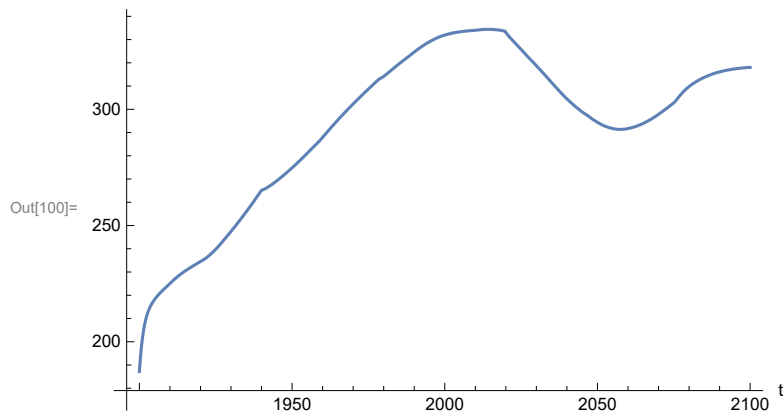
Plot the human ecological footprint, in hectares.

```
In[99]:= SystemModelPlot[basesevsim,
  {"Human_Ecological_Footprint1.HEF_Human_Ecological_Footprint.hef_human_ecological_footprint"}]
```



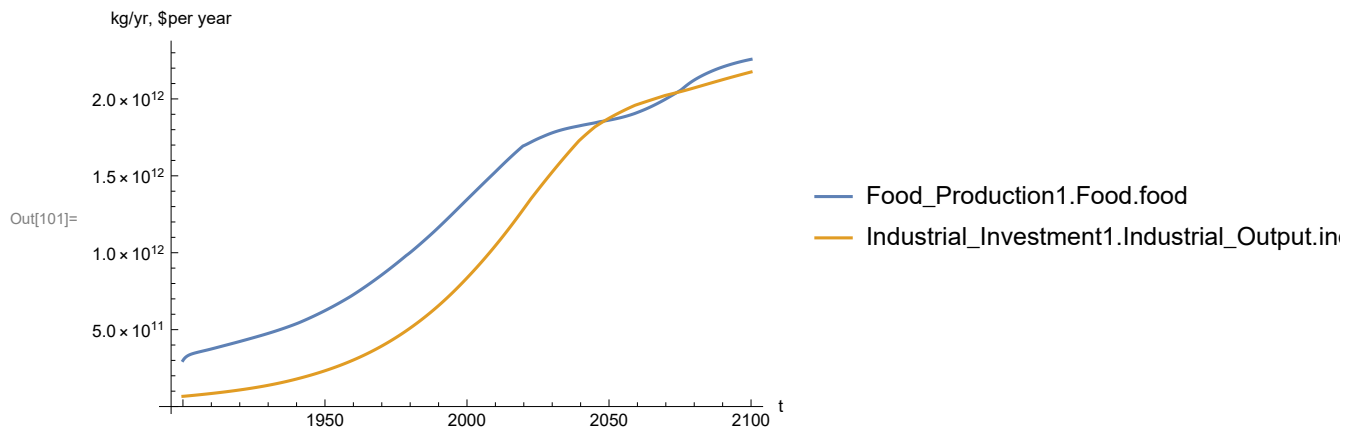
Plot per capita food production, kg/year. Note that food production per capita in 2100 has fallen to approximately the level it had in 1900 (before the rise of mechanized agriculture).

```
In[100]:= SystemModelPlot[basesevsim, {"Food_Production1.Food_PC.y"}]
```



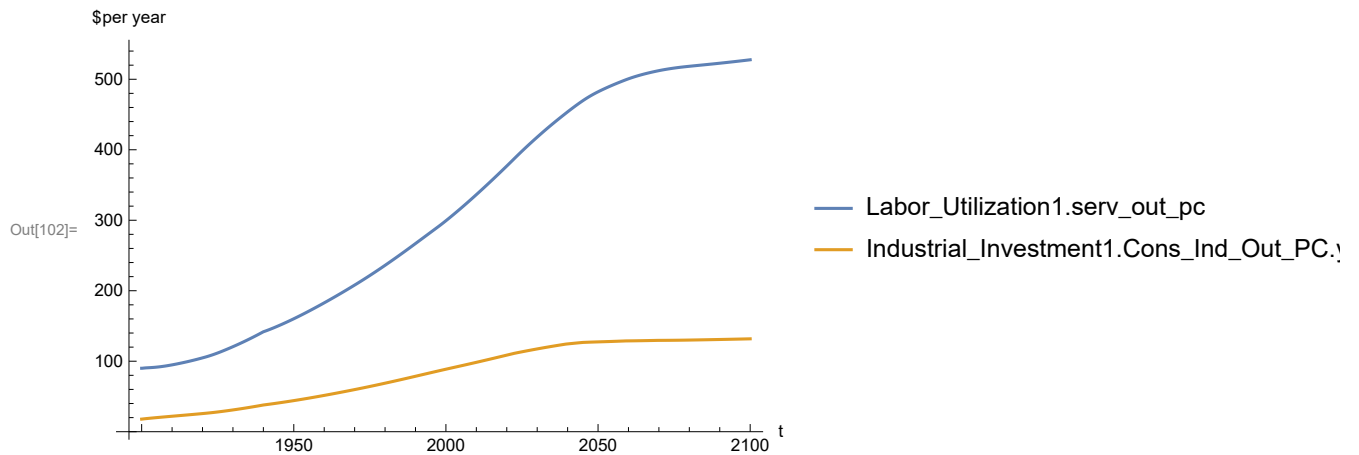
Plot total food production (kg/yr) and industrial output (in dollars).

```
In[101]:= SystemModelPlot[basesevsim, {"Food_Production1.Food.food",
  "Industrial_Investment1.Industrial_Output.industrial_output"}]
```



Plot consolidated industrial output per capita (dollars/year).

```
In[102]:= SystemModelPlot[basesevsim,
  {"Labor_Utilization1.serv_out_pc", "Industrial_Investment1.Cons_Ind_Out_PC.y"}]
```



Find max and min of y values.

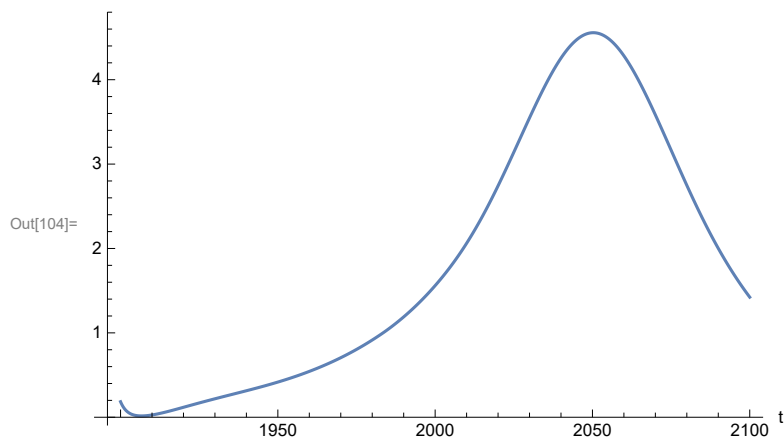
```
In[103]:= MinAndMax[basesevsim[{"Labor_Utilization1.serv_out_pc"}]]
```

Maximum is 527.647

Minimum is 90.

Plot persistent pollution index (normalized to 1970 value).

```
In[104]:= SystemModelPlot[basesevsim, {"Pollution_Dynamics1.PPoll_Index.y"}]
```



Find max and min of y values.

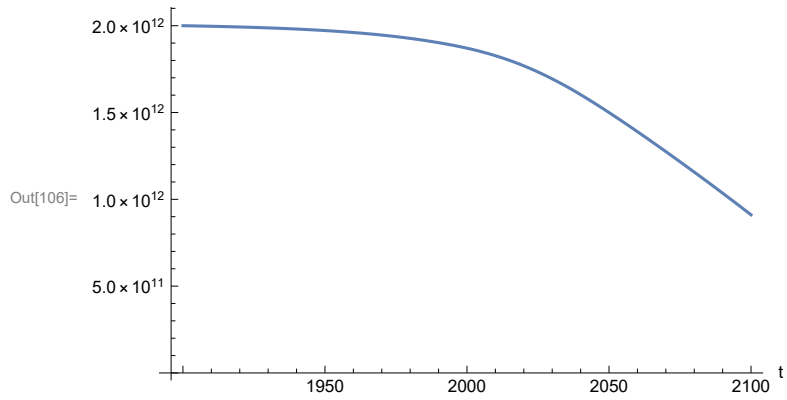
```
In[105]:= MinAndMax[basesevsim[{"Pollution_Dynamics1.PPoll_Index.y"}]]
```

Maximum is 4.55707

Minimum is 0.0157849

Plot non-renewable resources remaining.

```
In[106]:= SystemModelPlot[basesevsim, {"NR_Resource_Utilization1.NR_Resources.y"}]
```



APPENDIX 16. BENCHMARK SCENARIO 4 SIMULATIONS, Scenario 4, Experiment 1

Here are some high-level properties of Benchmark Scenario 4.

Define a function that extracts range data from scenario data. (The right-hand-side of this definition is specific to a *World3* data structure and assumes that the function whose range is being extracted is globally (i.e., not piecewise) defined.)

```
In[1]:= RangeData[data_] := data[[1]][[4]][[3]];
```

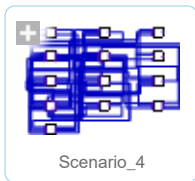
Define a procedure to determine and print minimum and maximum of “y” values.

```
In[2]:= MinAndMax[data_] := (myscenseries = RangeData[data];  
    Print["Maximum is ", Max[myscenseries]]; Print["Minimum is ", Min[myscenseries]])
```

```
In[3]:=
```

```
mysim = SystemModel["SystemDynamics.WorldDynamics.World3.Scenario_4"]
```

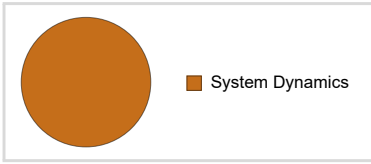
```
Out[3]=
```



```
In[4]:=
```

```
mysummary = mysim["Summary"]
```

```
Out[4]=
```

ModelName	SystemDynamics.WorldDynamics.World3.Scenario_4
Description	More accessible non-recoverable natural resources, pollution control, and land yield ent
SimulationModel	True
Plots	0
Components	106
Balanced	True
SystemEquations	1583
SystemVariables	1583
Domain	

Show the value of `t_air_poll_time`.

```
In[5]:= SystemModel[mysim][{"ParameterValues", "t_air_poll_time"}]
```

```
Out[5]= {t_air_poll_time → 4000}
```

Show Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals.

```
In[6]:= SystemModel[mysim][
  {"ParameterValues", "Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[1]"}]
```

```
Out[6]= {Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[1] → 1}
```

```
In[7]:= SystemModel[mysim][
  {"ParameterValues", "Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[2]"}]
```

```
Out[7]= {Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[2] → 1}
```

```
In[8]:= SystemModel[mysim][
  {"ParameterValues", "Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[3]"}]
```

```
Out[8]= {Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[3] → 0.7}
```

```
In[9]:= SystemModel[mysim][
  {"ParameterValues", "Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[4]"}]
```

```
Out[9]= {Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[4] → 0.4}
```

Show Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_2.y_vals.

```
In[10]:= SystemModel[mysim][
  {"ParameterValues", "Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_2.y_vals[1]"}]
```

```
Out[10]= {Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_2.y_vals[1] → 1}
```

```
In[11]:= SystemModel[mysim][
  {"ParameterValues", "Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_2.y_vals[2]"}]
```

```
Out[11]= {Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_2.y_vals[2] → 1}
```

```
In[12]:= SystemModel[mysim][
  {"ParameterValues", "Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_2.y_vals[3]"}]
```

```
Out[12]= {Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_2.y_vals[3] → 0.98}
```

```
In[13]:= SystemModel[mysim][
  {"ParameterValues", "Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_2.y_vals[4]"}]
```

```
Out[13]= {Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_2.y_vals[4] → 0.95}
```

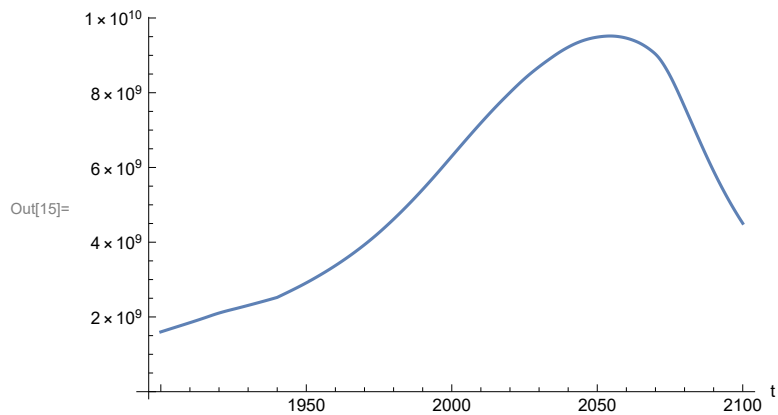
Execute Benchmark Simulation 4 and plot the variables shown in Figure 2.

In[14]:= **basesim = SystemModelSimulate[mysim]**

Out[14]= SystemModelSimulationData [  Model: Scenario_4
Time: 1.90×10^3 to 2.10×10^3]

Plot total population, people.

In[15]:= **SystemModelPlot[basesim, {"Population_Dynamics1.Birth_Rate.pop"}]**



Find max and min of population values.

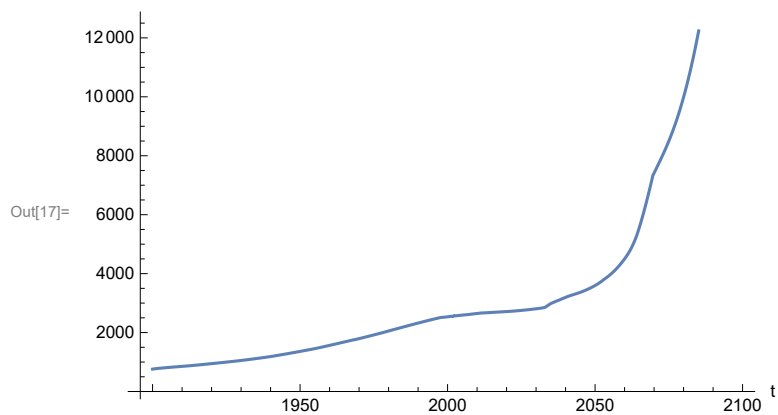
In[16]:= **MinAndMax[basesim[{"Population_Dynamics1.Birth_Rate.pop"}]]**

Maximum is 9.51746×10^9

Minimum is 1.6×10^9

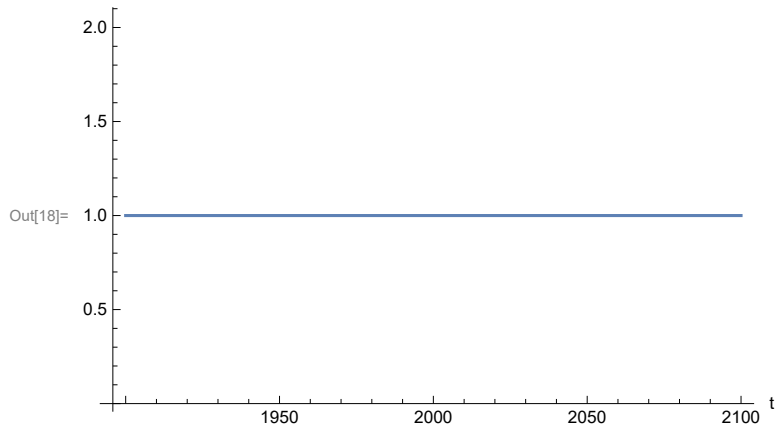
Plot land yield.

In[17]:= **SystemModelPlot[basesim, {"Food_Production1.Land_Yield.y"}]**



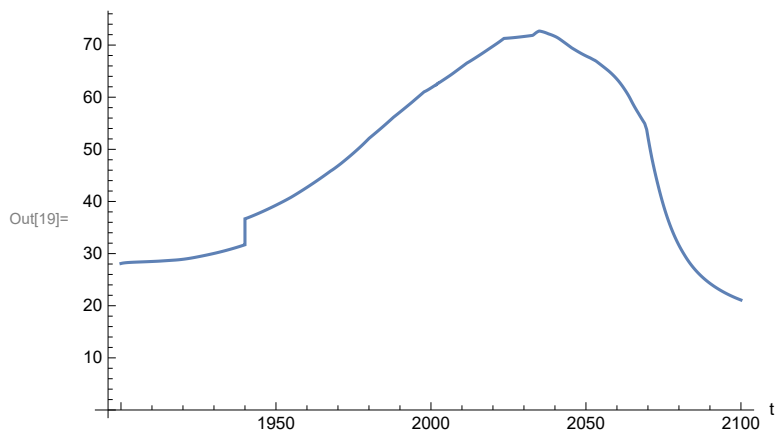
Plot multiplier of air pollution on land yield.

```
In[18]:= SystemModelPlot[basesim, {"Food_Production1.s_yield_mlt_air_poll"}]
```



Plot life expectancy, years.

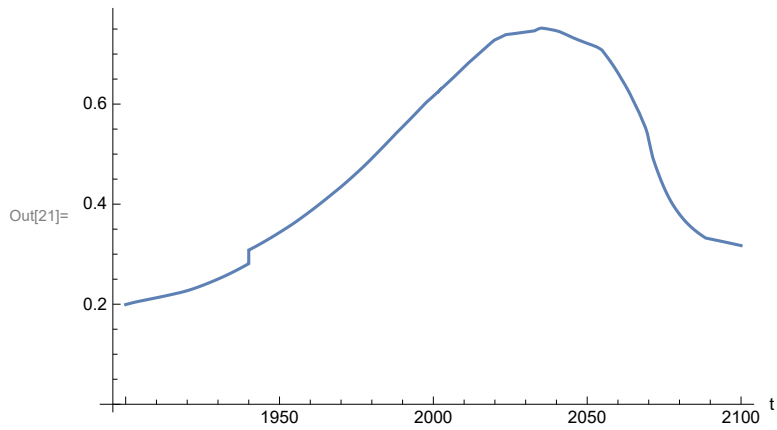
```
In[19]:= SystemModelPlot[basesim, {"Life_Expectancy1.Life_Expectancy.y"}]
```



```
In[20]:=
```

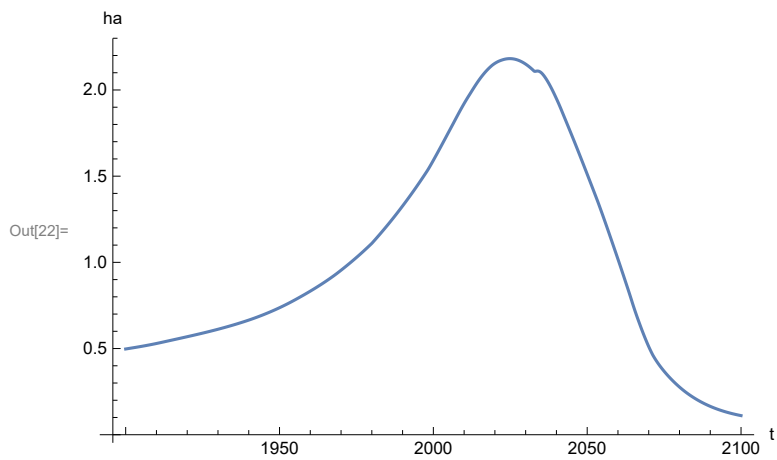
Plot human welfare index.

```
In[21]:= SystemModelPlot[basesim,
  {"Human_Welfare_Index1.HWI_Human_Welfare_Index.hwi_human_welfare_index"}]
```



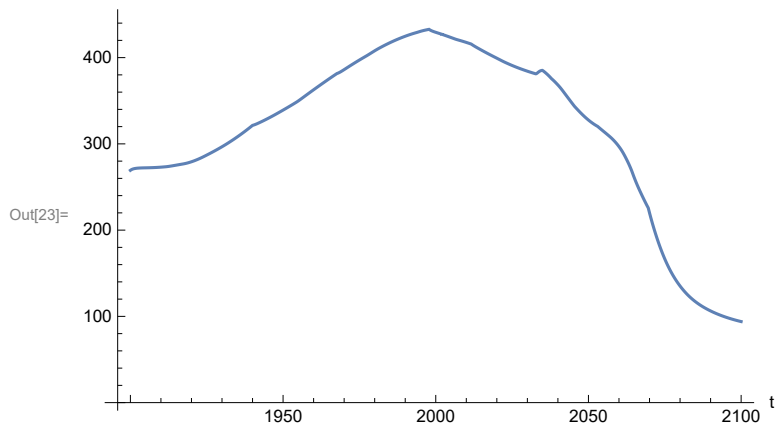
Plot per capita ecological footprint, hectares.

```
In[22]:= SystemModelPlot[basesim,
  {"Human_Ecological_Footprint1.HEF_Human_Ecological_Footprint.hef_human_ecological_footprint"}]
```



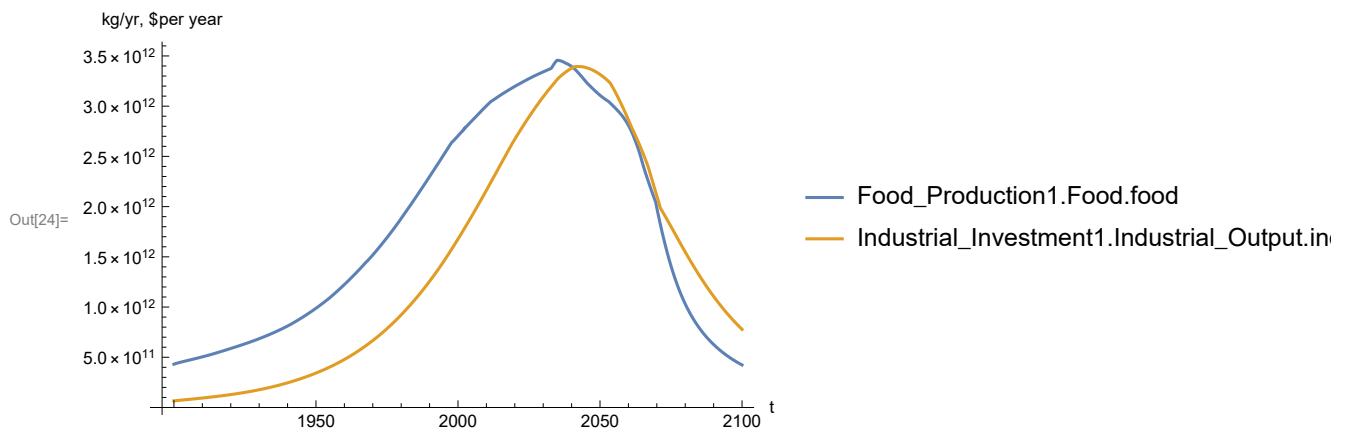
Plot food production per capita (kg/year).

```
In[23]:= SystemModelPlot[basesim, {"Food_Production1.Food_PC.y"}]
```



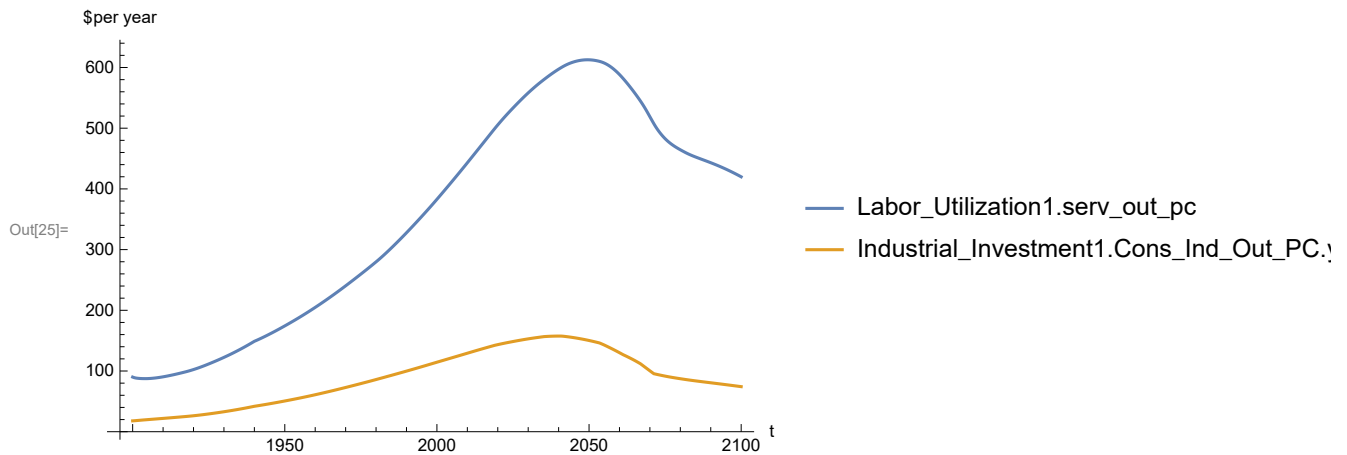
Plot total food production (kg/year), and industrial output (dollars/year).

```
In[24]:= SystemModelPlot[basesim, {"Food_Production1.Food.food",
    "Industrial_Investment1.Industrial_Output.industrial_output"}]
```



Plot labor utilization per capita (dollars/year), and consolidated industrial output per capita (dollars/year)

```
In[25]:= SystemModelPlot[basesim,
  {"Labor_Utilization1.serv_out_pc", "Industrial_Investment1.Cons_Ind_Out_PC.y"}]
```



Find max and min of y values.

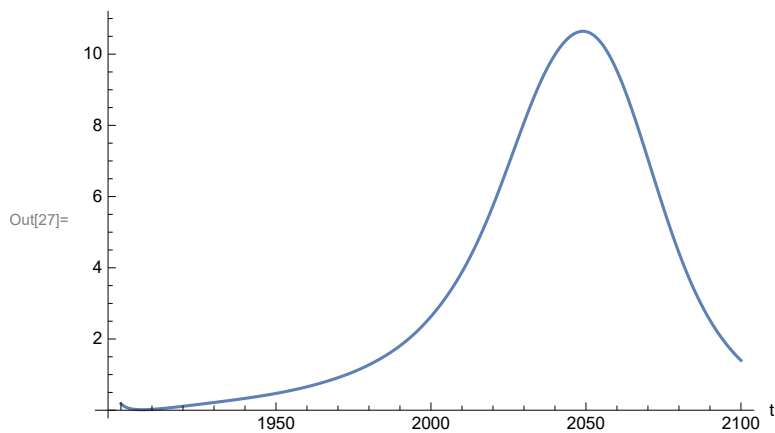
```
In[26]:= MinAndMax[basesim[{"Labor_Utilization1.serv_out_pc"}]]
```

Maximum is 612.714

Minimum is 87.4451

Plot persistent pollution index.

```
In[27]:= SystemModelPlot[basesim, {"Pollution_Dynamics1.PPoll_Index.y"}]
```



Find max and min of y values.

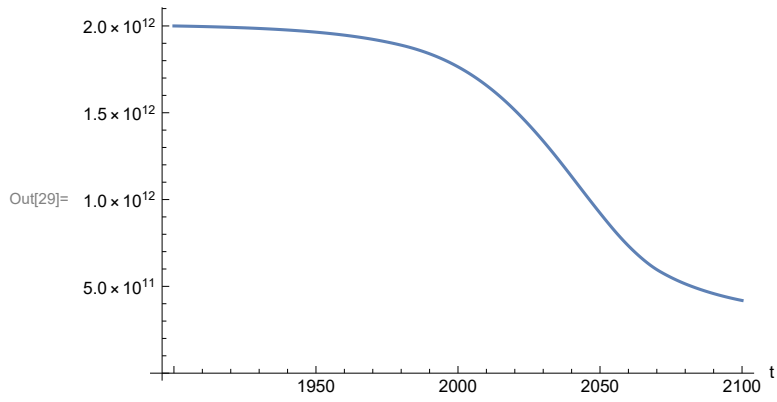
```
In[28]:= MinAndMax[basesim[{"Pollution_Dynamics1.PPoll_Index.y"}]]
```

Maximum is 10.6416

Minimum is 0.0150765

Plot non-renewable resources remaining.

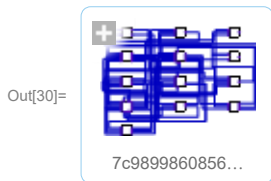
In[29]:= SystemModelPlot[basesim, {"NR_Resource_Utilization1.NR_Resources.y"}]



APPENDIX 17. Effects of mitigating the impact of air pollution on agricultural land yield, beginning calendar year 2020, Scenario 4, Experiment 2

Change the value of the air pollution effect multiplier switch time `t_air_poll_time`, to calendar year 2020, and execute the resulting scenario, plotting the variables shown in Figure 2.

```
In[30]:= newmysim = SystemModel[mysim, <|"ParameterValues" → {"t_air_poll_time" → 2020}|>]
```



```
In[31]:= testsim = SystemModelSimulate[newmysim]
```

Out[31]= SystemModelSimulationData [ Model: W7c989986085649cf9c0f5590660b1cc2
Time: 1.90×10^3 to 2.10×10^3]

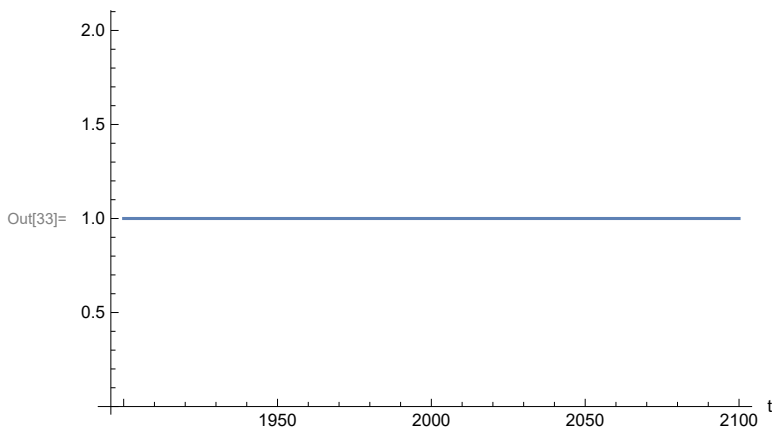
Show the value of `t_air_poll_time` (calendar year).

```
In[32]:= SystemModel[newmysim][{"ParameterValues", "t_air_poll_time"}]
```

Out[32]= {t_air_poll_time → 2020}

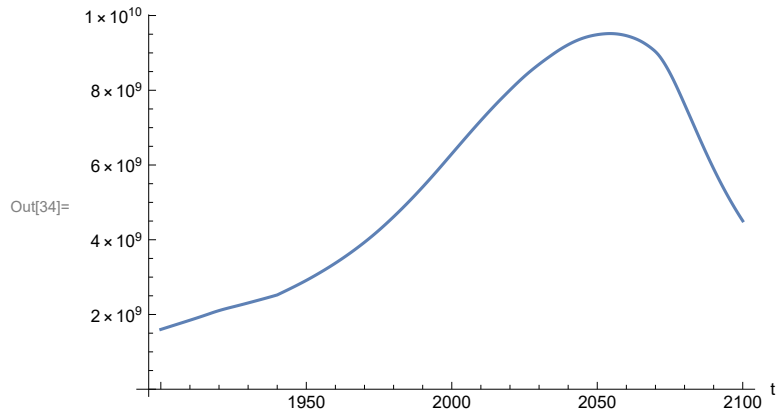
Plot air pollution multiplier of land yield.

```
In[33]:= SystemModelPlot[testsim, {"Food_Production1.s_yield_mlt_air_poll"}]
```



Plot the world population, people.

```
In[34]:= SystemModelPlot[testsim, {"Population_Dynamics1.Birth_Rate.pop"}]
```



Find max and min of y values.

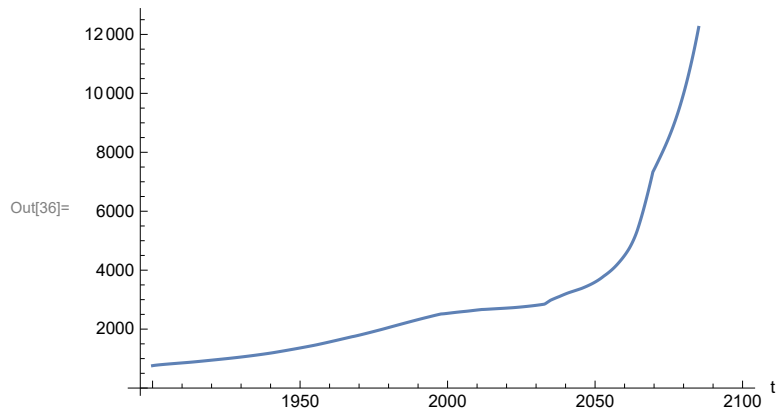
```
In[35]:= MinAndMax[testsim[{"Population_Dynamics1.Birth_Rate.pop"}]]
```

Maximum is 9.51746×10^9

Minimum is 1.6×10^9

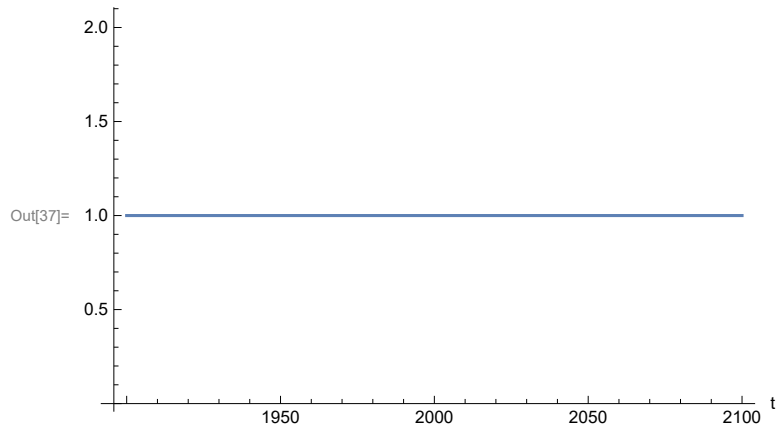
Plot land yield.

```
In[36]:= SystemModelPlot[testsim, {"Food_Production1.Land_Yield.y"}]
```



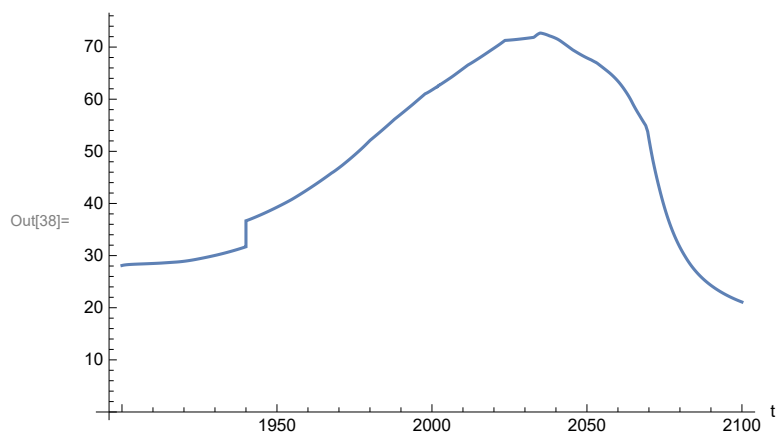
Plot multiplier of air pollution on land yield.

```
In[37]:= SystemModelPlot[testsim, {"Food_Production1.s_yield_mlt_air_poll"}]
```



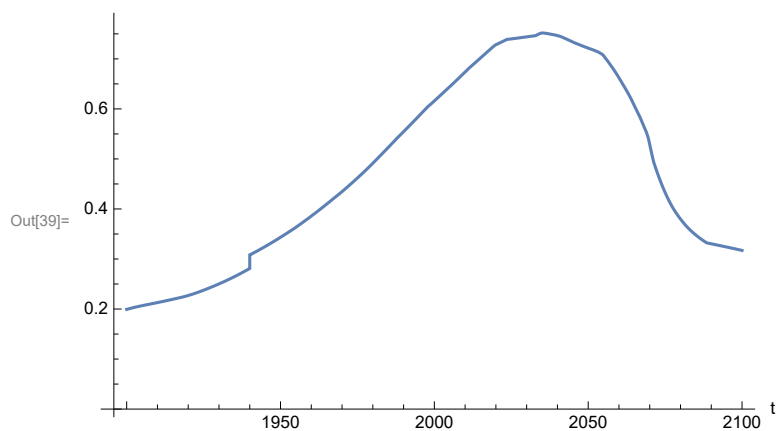
Plot life expectancy, in years.

```
In[38]:= SystemModelPlot[testsim, {"Life_Expectancy1.Life_Expectancy.y"}]
```



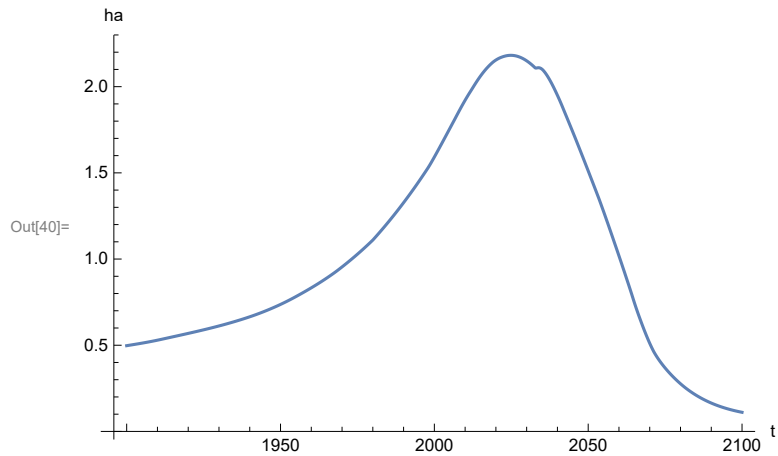
Plot the human welfare index.

```
In[39]:= SystemModelPlot[testsim, {"Human_Welfare_Index1.HWI_Human_Welfare_Index.hwi_human_welfare_index"}]
```



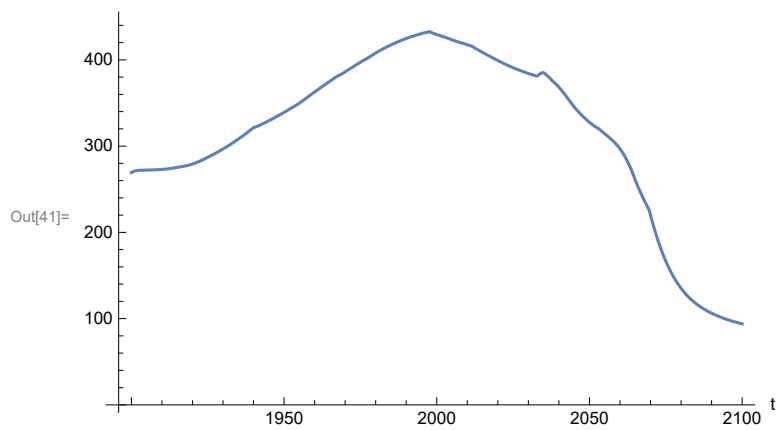
Plot the human ecological footprint, in hectares.

```
In[40]:= SystemModelPlot[testsim,
  {"Human_Ecological_Footprint1.HEF_Human_Ecological_Footprint.hef_human_ecological_
    _footprint"}]
```



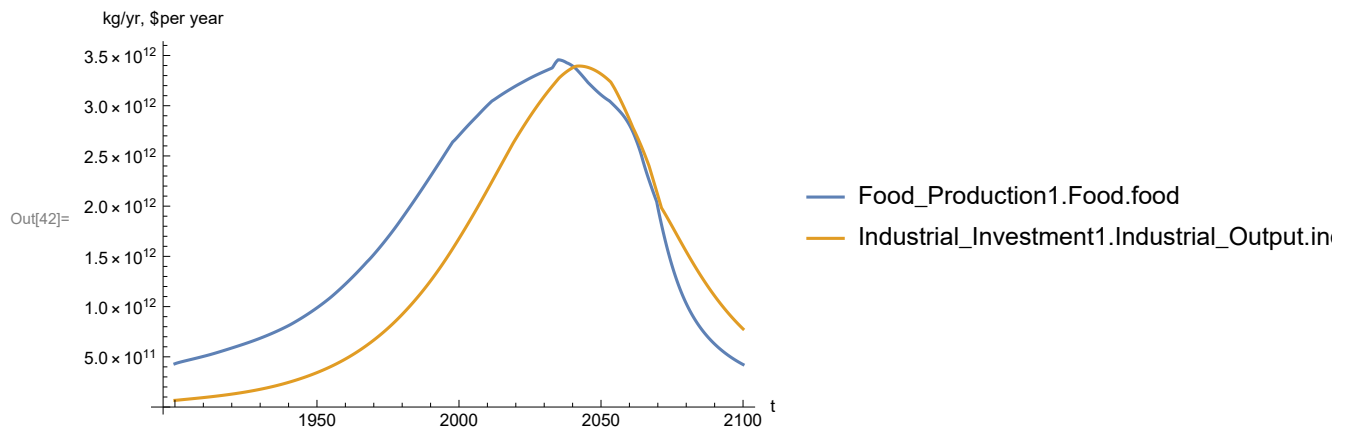
Plot per capita food production, kg/year.

```
In[41]:= SystemModelPlot[testsim, {"Food_Production1.Food_PC.y"}]
```



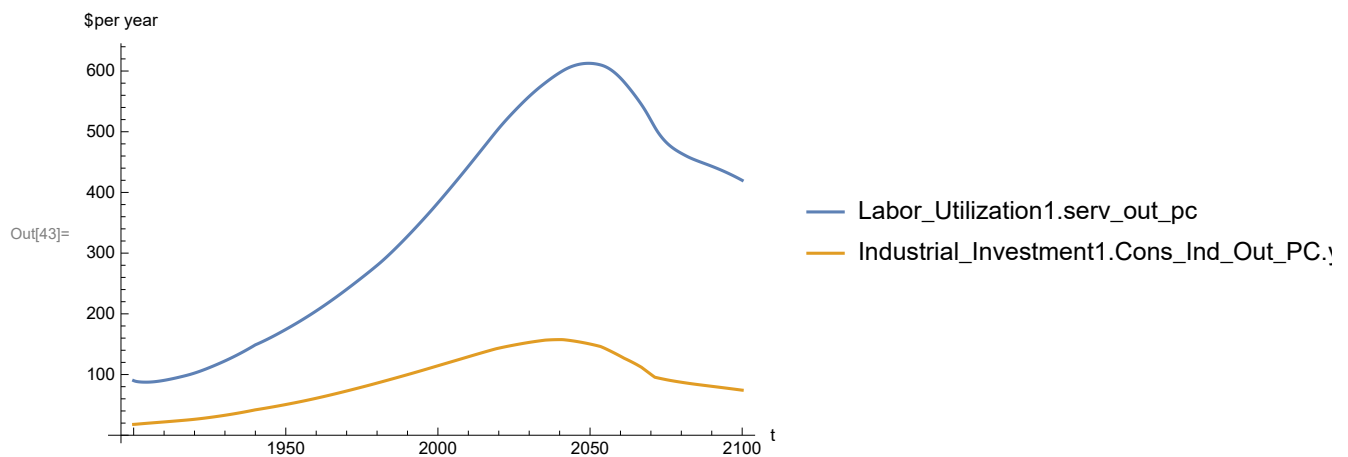
Plot total food production (kg/yr) and industrial output (in dollars).

```
In[42]:= SystemModelPlot[testsim, {"Food_Production1.Food.food",
  "Industrial_Investment1.Industrial_Output.industrial_output"}]
```



Plot labor utilization per capita and consolidated industrial output per capita (dollars/year).

```
In[43]:= SystemModelPlot[testsim,
  {"Labor_Utilization1.serv_out_pc", "Industrial_Investment1.Cons_Ind_Out_PC.y"}]
```



Find max and min of y values.

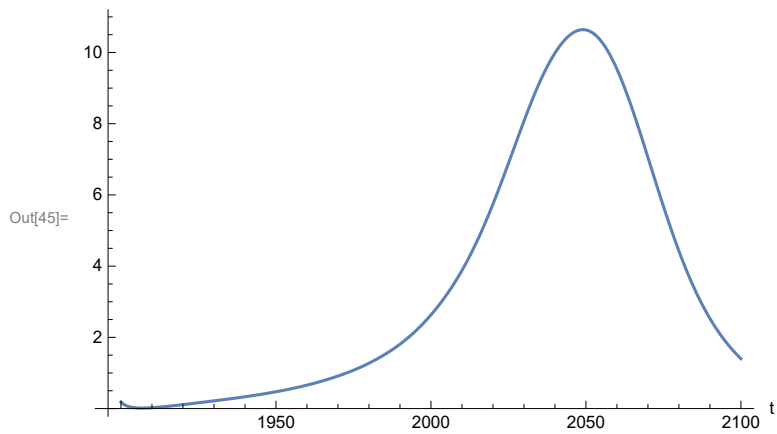
```
In[44]:= MinAndMax[testsim[{"Labor_Utilization1.serv_out_pc"}]]
```

Maximum is 612.713

Minimum is 87.4451

Plot persistent pollution index (normalized to 1970 value).

```
In[45]:= SystemModelPlot[testsim, {"Pollution_Dynamics1.PPoll_Index.y"}]
```



Find max and min of y values.

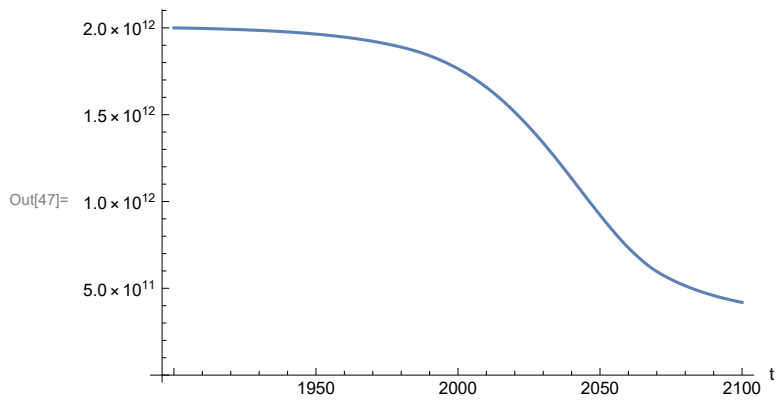
```
In[46]:= MinAndMax[testsim[{"Pollution_Dynamics1.PPoll_Index.y"}]]
```

Maximum is 10.6416

Minimum is 0.0150765

Plot non-renewable resources remaining.

```
In[47]:= SystemModelPlot[testsim, {"NR_Resource_Utilization1.NR_Resources.y"}]
```



APPENDIX 18. Effects of mitigating the impact of air pollution on agricultural land yield, beginning calendar year 1970, Scenario 4, Experiment 3

Change the value of the air pollution effect multiplier switch time `t_air_poll_time`, to calendar year 1970, and execute the resulting scenario, plotting the variables shown in Figure 2.

```
In[48]:= newmysim1970 = SystemModel[mysim, <|"ParameterValues" → {"t_air_poll_time" → 1970} |>]
```



```
In[49]:= testsim1970 = SystemModelSimulate[newmysim1970]
```

Out[49]= SystemModelSimulationData [ Model: W31fb1437af084c64b103af1d1a455589
Time: 1.90×10^3 to 2.10×10^3]

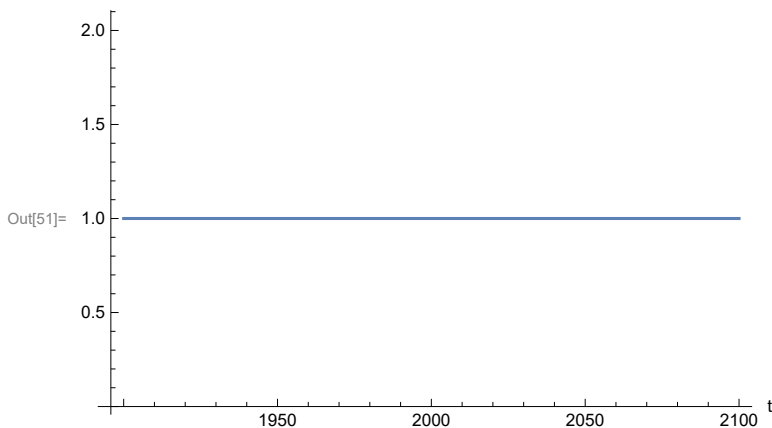
Show the value of `t_air_poll_time` (calendar year).

```
In[50]:= SystemModel[newmysim1970][{"ParameterValues", "t_air_poll_time"}]
```

Out[50]= {t_air_poll_time → 1970}

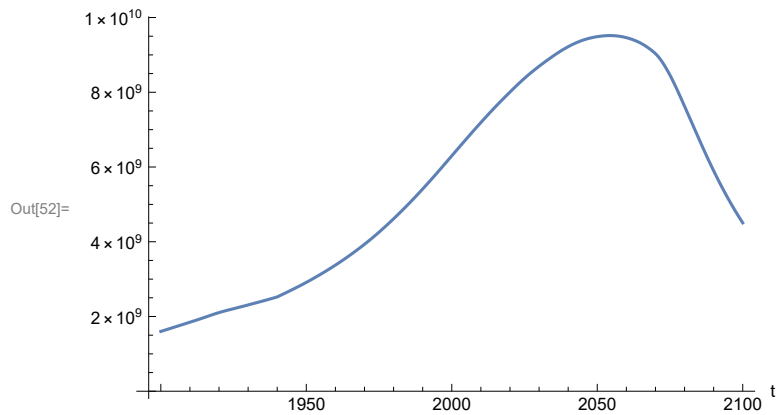
Plot air pollution multiplier of land yield.

```
In[51]:= SystemModelPlot[testsim1970, {"Food_Production1.s_yield_mlt_air_poll"}]
```



Plot the world population, people.

```
In[52]:= SystemModelPlot[testsim1970, {"Population_Dynamics1.Birth_Rate.pop"}]
```



Find max and min of y values.

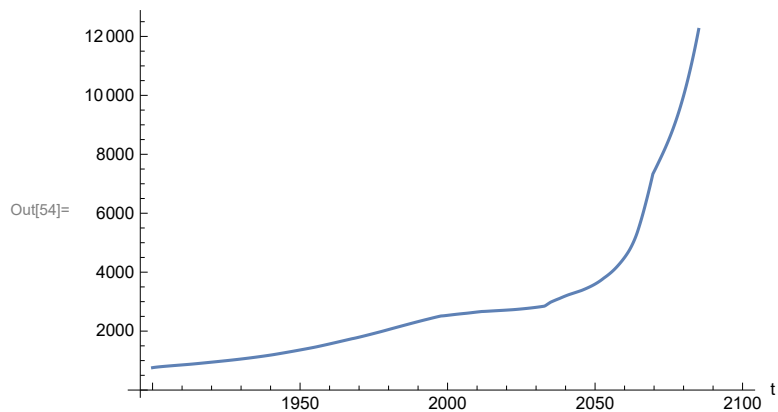
```
In[53]:= MinAndMax[testsim1970[{"Population_Dynamics1.Birth_Rate.pop"}]]
```

Maximum is 9.51746×10^9

Minimum is 1.6×10^9

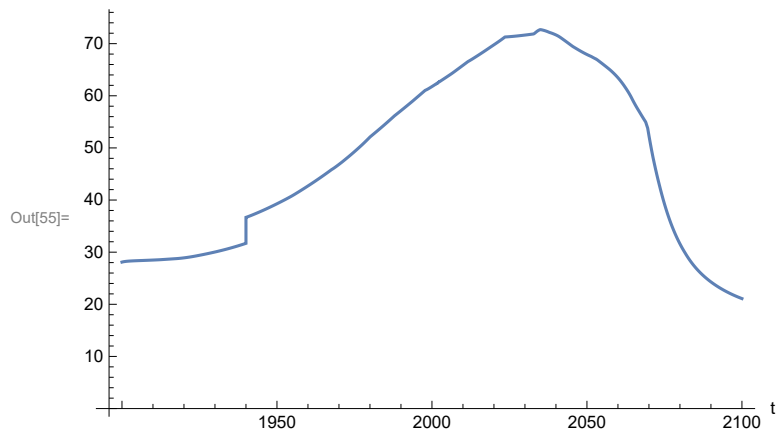
Plot land yield.

```
In[54]:= SystemModelPlot[testsim1970, {"Food_Production1.Land_Yield.y"}]
```



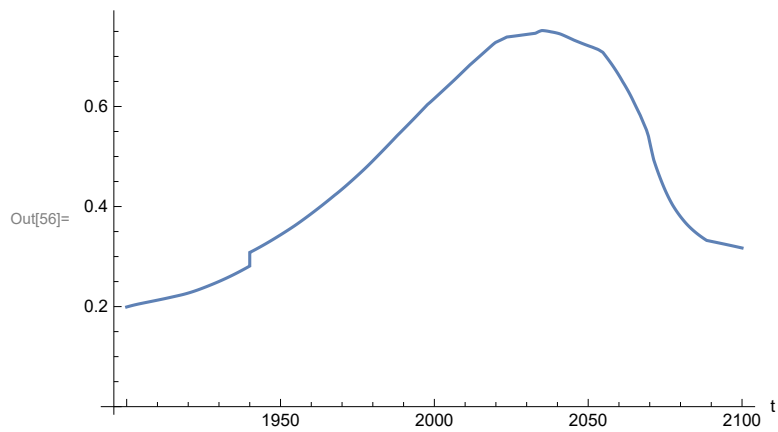
Plot life expectancy, in years.


```
In[55]:= SystemModelPlot[testsim1970, {"Life_Expectancy1.Life_Expectancy.y"}]
```



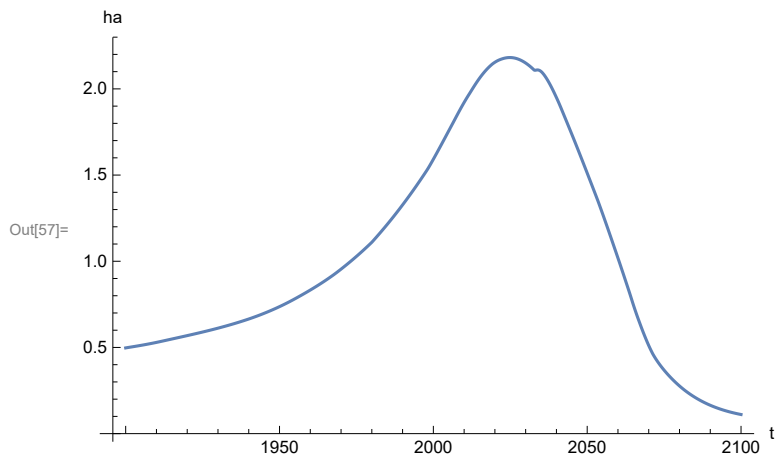
Plot the human welfare index.

```
In[56]:= SystemModelPlot[testsim1970, {"Human_Welfare_Index1.HWI_Human_Welfare_Index.hwi_human_welfare_index"}]
```



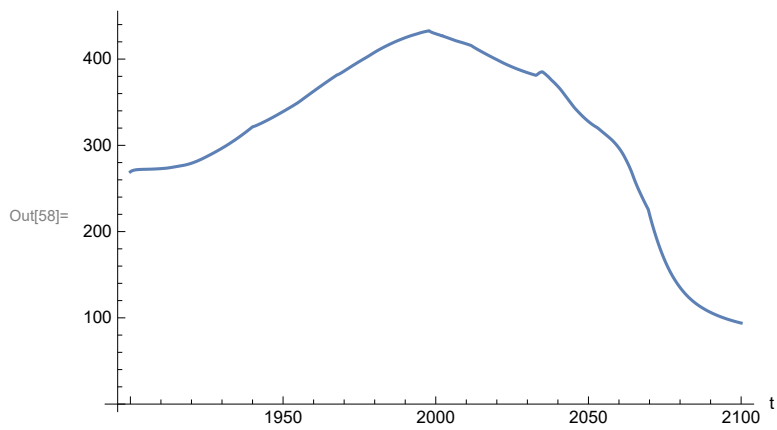
Plot the human ecological footprint, in hectares.

```
In[57]:= SystemModelPlot[testsim1970,
  {"Human_Ecological_Footprint1.HEF_Human_Ecological_Footprint.hef_human_ecological_
    _footprint"}]
```



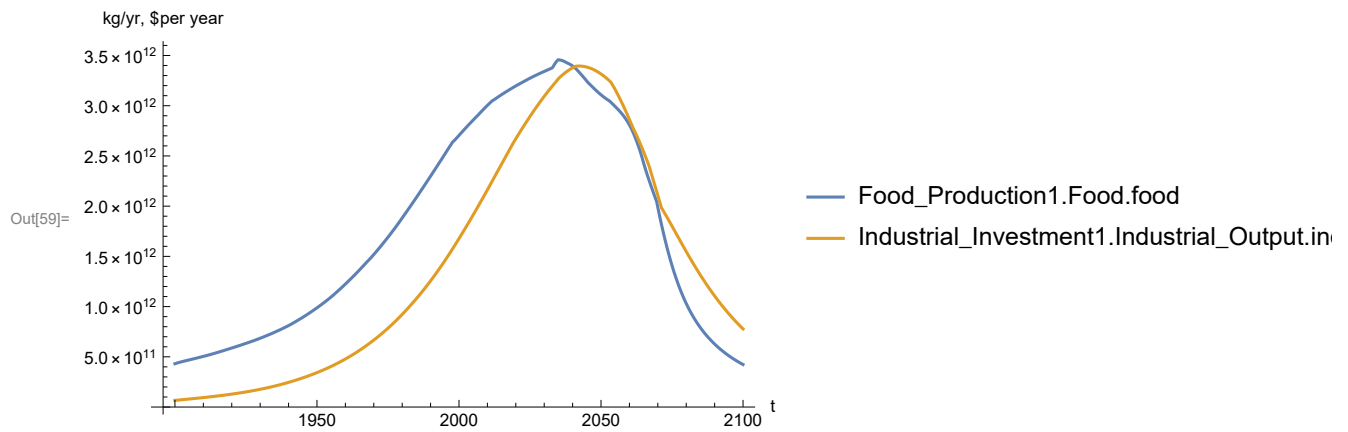
Plot per capita food production, kg/year.

```
In[58]:= SystemModelPlot[testsim1970, {"Food_Production1.Food_PC.y"}]
```



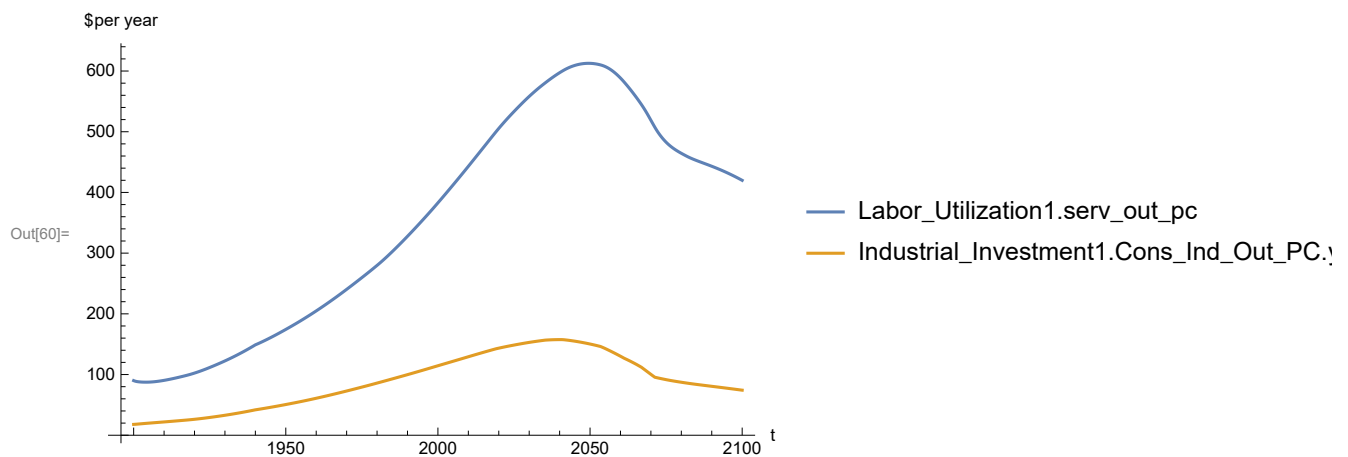
Plot total food production (kg/yr) and industrial output (in dollars).

```
In[59]:= SystemModelPlot[testsim1970, {"Food_Production1.Food.food",
  "Industrial_Investment1.Industrial_Output.industrial_output"}]
```



Plot labor utilization per capita and consolidated industrial output per capita (dollars/year).

```
In[60]:= SystemModelPlot[testsim1970,
  {"Labor_Utilization1.serv_out_pc", "Industrial_Investment1.Cons_Ind_Out_PC.y"}]
```



Find max and min of y values.

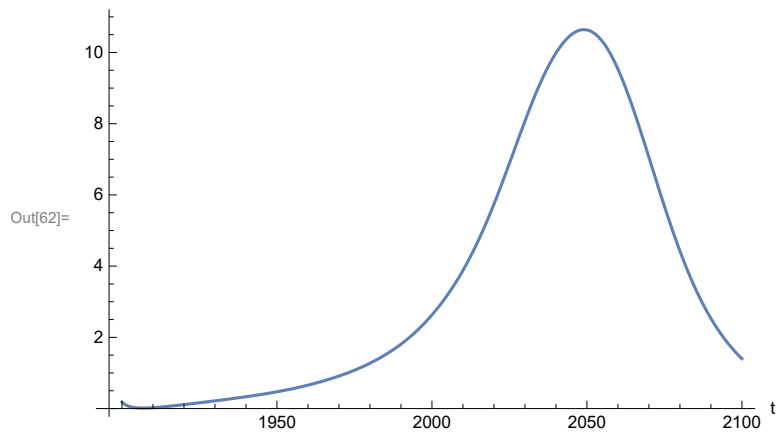
```
In[61]:= MinAndMax[testsim1970[{"Labor_Utilization1.serv_out_pc"}]]
```

Maximum is 612.714

Minimum is 87.4451

Plot persistent pollution index (normalized to 1970 value).

```
In[62]:= SystemModelPlot[testsim1970, {"Pollution_Dynamics1.PPoll_Index.y"}]
```



Find max and min of y values.

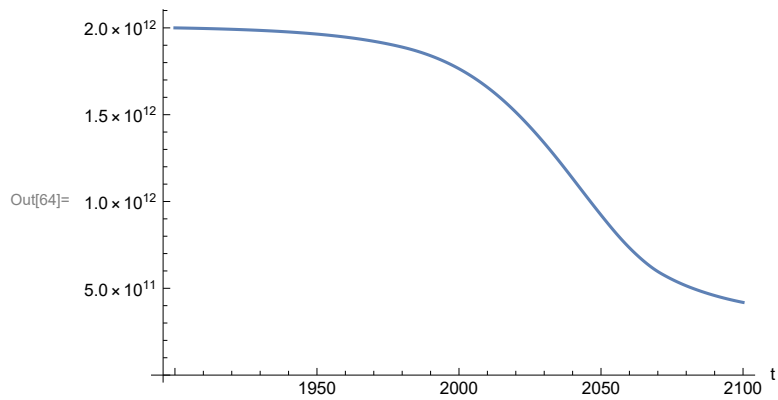
```
In[63]:= MinAndMax[testsim1970[{"Pollution_Dynamics1.PPoll_Index.y"}]]
```

Maximum is 10.6416

Minimum is 0.0150765

Plot non-renewable resources remaining.

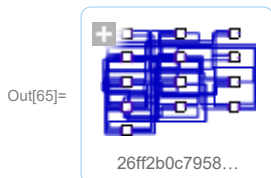
```
In[64]:= SystemModelPlot[testsim1970, {"NR_Resource_Utilization1.NR_Resources.y"}]
```



APPENDIX 19. "STRONG AIR POLLUTION" EFFECTS SCENARIO, Scenario 4, Experiment 4

Scenario 4 with air pollution effect on land yield changed as noted.

```
In[65]:= strsim = SystemModel[mysim, <|"ParameterValues" ->
      {"Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals" -> {0.7, 0.5, 0.3, 0.1}}|>]
```



```
In[66]:= basestrsim = SystemModelSimulate[strsim]
```

Out[66]= SystemModelSimulationData [ Model: W26ff2b0c79584c3ea8f613f4ea4e7906
Time: 1.90×10^3 to 2.10×10^3]

Show Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals.

```
In[67]:= SystemModel[strsim] [
      {"ParameterValues", "Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[1]"}]
```

Out[67]= {Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[1] → 0.7}

```
In[68]:= SystemModel[strsim] [
      {"ParameterValues", "Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[2]"}]
```

Out[68]= {Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[2] → 0.5}

```
In[69]:= SystemModel[strsim] [
      {"ParameterValues", "Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[3]"}]
```

Out[69]= {Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[3] → 0.3}

```
In[70]:= SystemModel[strsim] [
      {"ParameterValues", "Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[4]"}]
```

Out[70]= {Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[4] → 0.1}

Show the value of t_air_poll_time (calendar year).

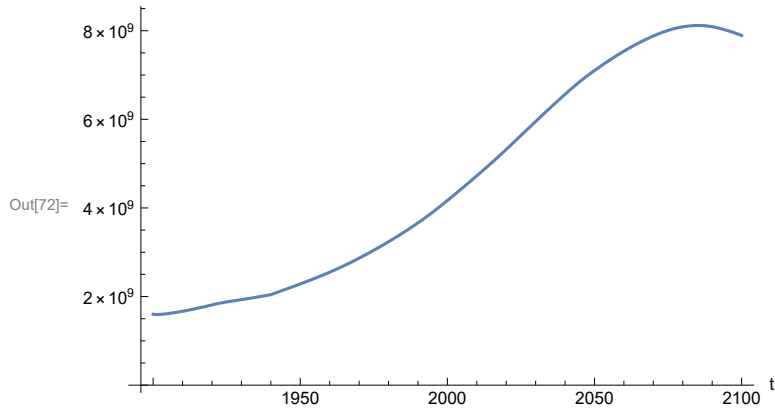
```
In[71]:= SystemModel[strsim] [{"ParameterValues", "t_air_poll_time"}]
```

Out[71]= {t_air_poll_time → 4000}

Plot the world population, people. Note that the peak population is about one billion less, and about

20 years later, than the peak population forecast by Experiments 1-3.

```
In[72]:= SystemModelPlot[basestransim, {"Population_Dynamics1.Birth_Rate.pop"}]
```



Find max and min of y values.

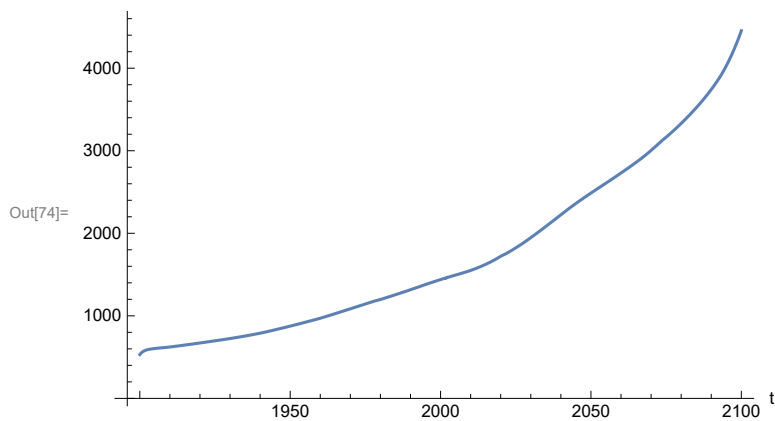
```
In[73]:= MinAndMax[basestransim[{"Population_Dynamics1.Birth_Rate.pop"}]]
```

Maximum is 8.11845×10^9

Minimum is 1.59431×10^9

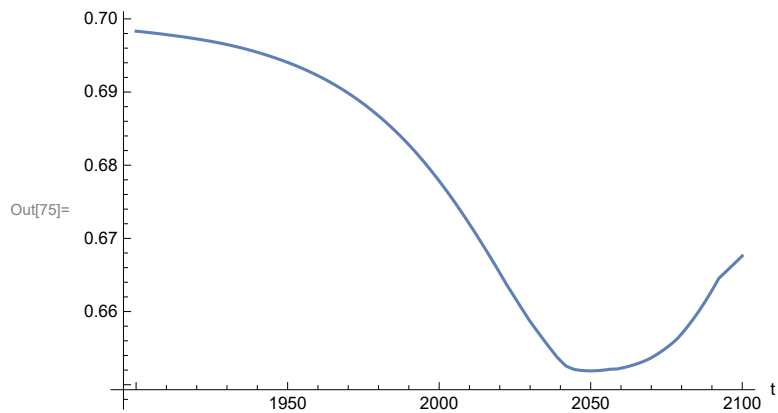
Plot land yield.

```
In[74]:= SystemModelPlot[basestransim, {"Food_Production1.Land_Yield.y"}]
```



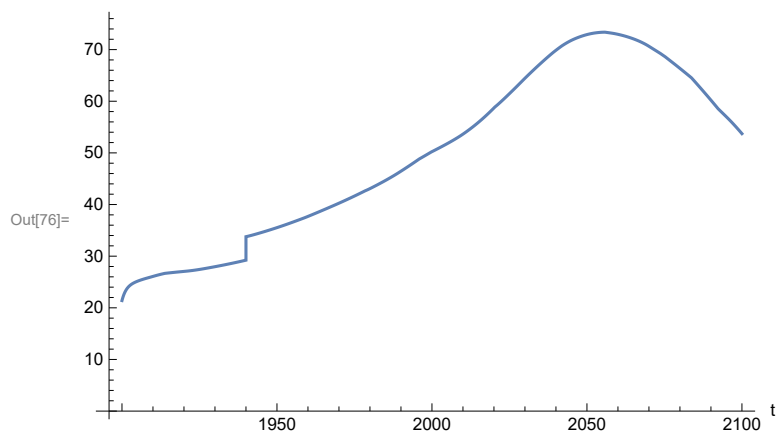
Plot multiplier of air pollution on land yield.

```
In[75]:= SystemModelPlot[basestransim, {"Food_Production1.s_yield_mlt_air_poll"}]
```



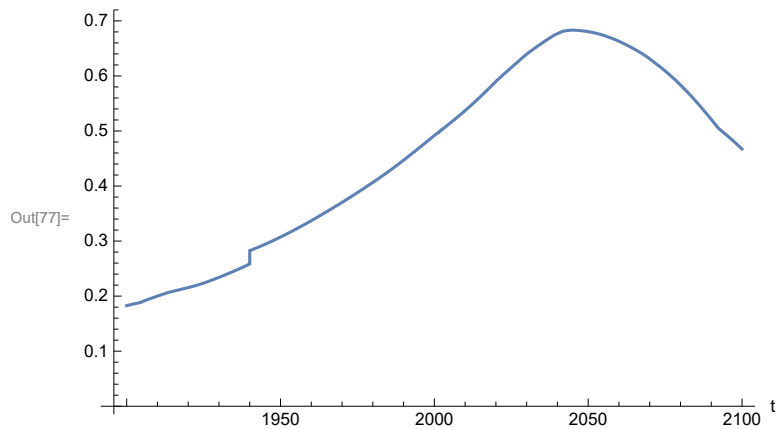
Plot life expectancy, in years.

```
In[76]:= SystemModelPlot[basestransim, {"Life_Expectancy1.Life_Expectancy.y"}]
```



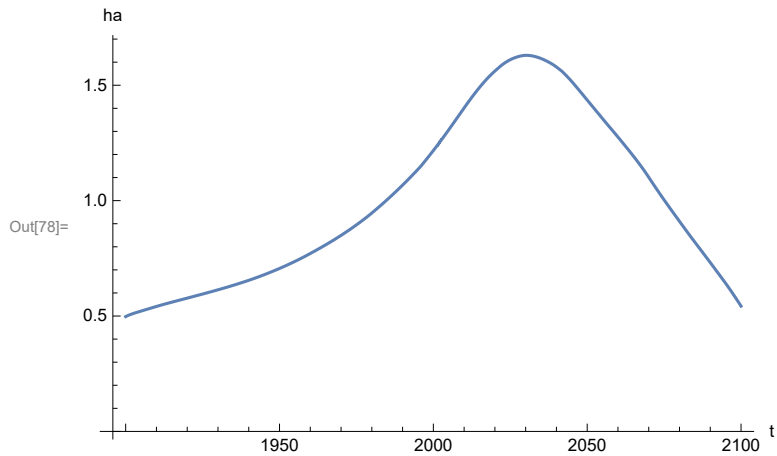
Plot the human welfare index.

```
In[77]:= SystemModelPlot[basestransim, {"Human_Welfare_Index1.HWI_Human_Welfare_Index.hwi_human_welfare_index"}]
```



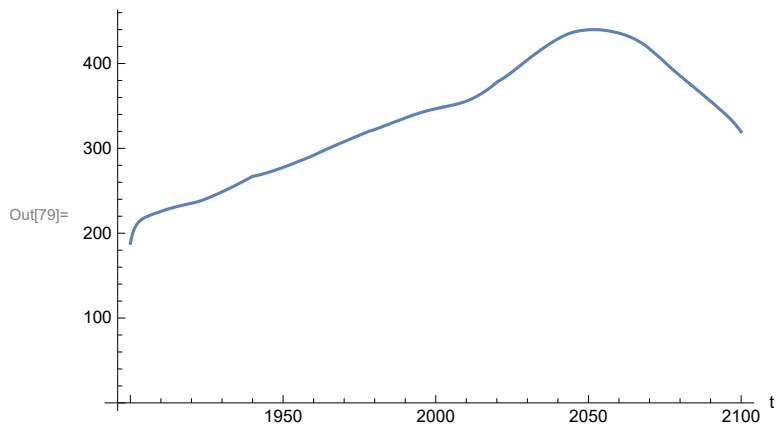
Plot the human ecological footprint, in hectares.

```
In[78]:= SystemModelPlot[basestrsim,
  {"Human_Ecological_Footprint1.HEF_Human_Ecological_Footprint.hef_human_ecological_
    _footprint"}]
```



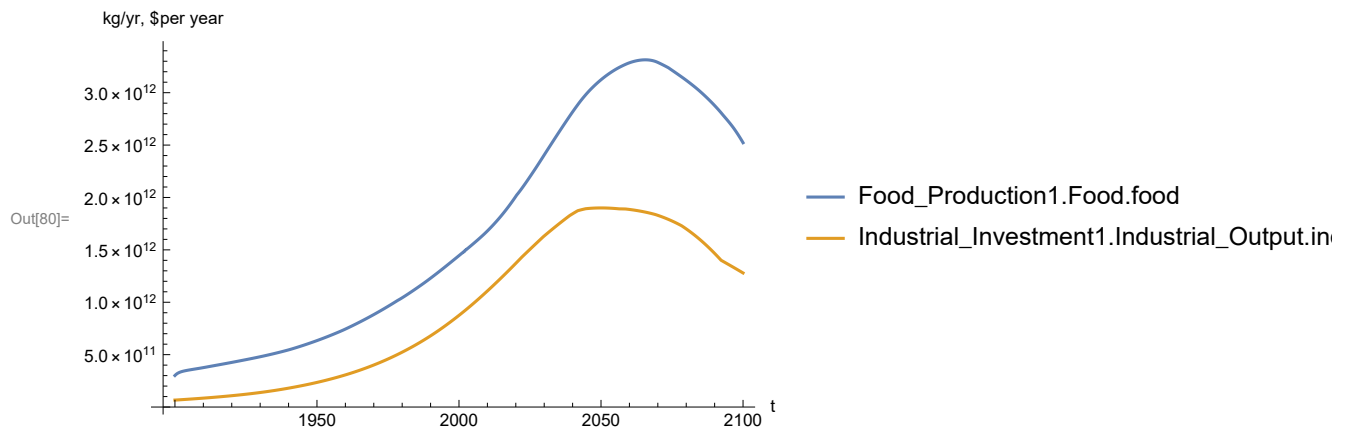
Plot per capita food production, kg/year.

```
In[79]:= SystemModelPlot[basestrsim, {"Food_Production1.Food_PC.y"}]
```



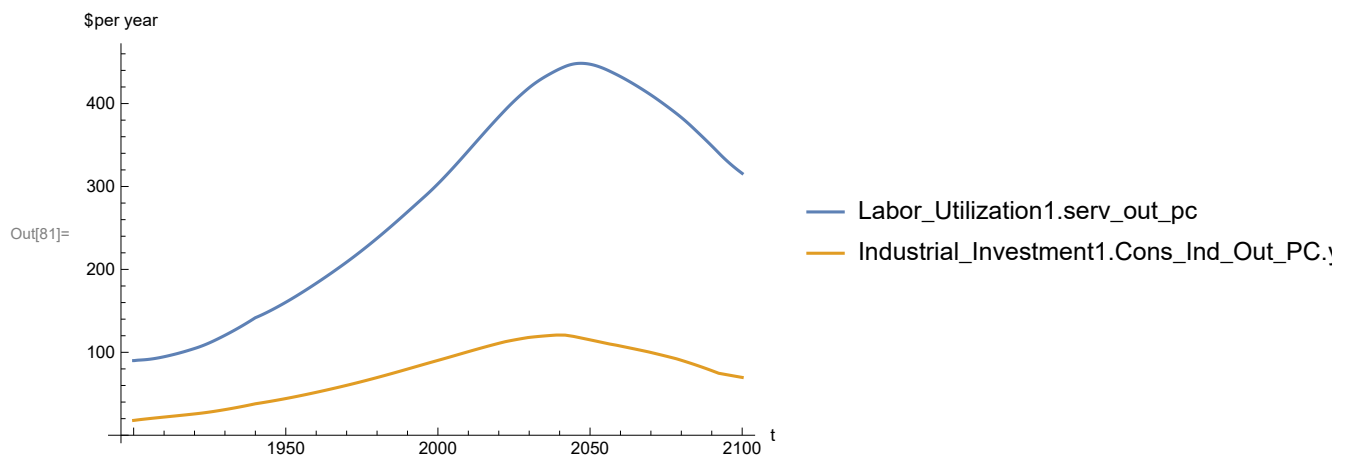
Plot total food production (kg/yr) and industrial output (in dollars).


```
In[80]:= SystemModelPlot[basestransim, {"Food_Production1.Food.food",
  "Industrial_Investment1.Industrial_Output.industrial_output"}]
```



Plot labor utilization per capita and consolidated industrial output per capita (dollars/year).

```
In[81]:= SystemModelPlot[basestransim, {"Labor_Utilization1.serv_out_pc", "Industrial_Investment1.Cons_Ind_Out_PC.y"}]
```



Find max and min of y values.

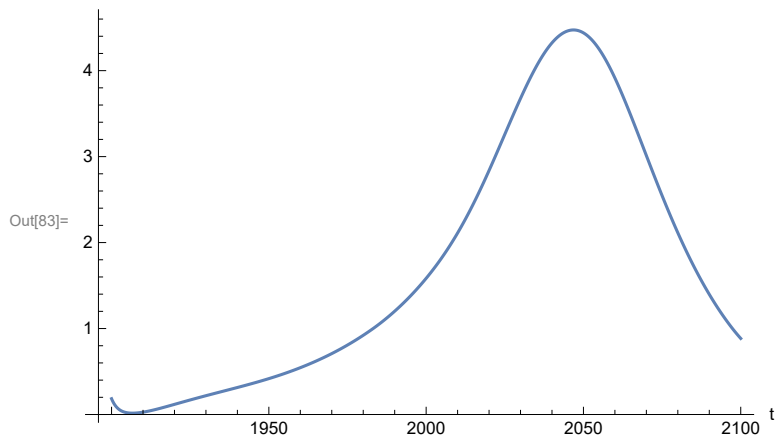
```
In[82]:= MinAndMax[basestransim[{"Labor_Utilization1.serv_out_pc"}]]
```

Maximum is 448.54

Minimum is 89.9974

Plot persistent pollution index (normalized to 1970 value).

```
In[83]:= SystemModelPlot[basestransim, {"Pollution_Dynamics1.PPoll_Index.y"}]
```



Find max and min of y values.

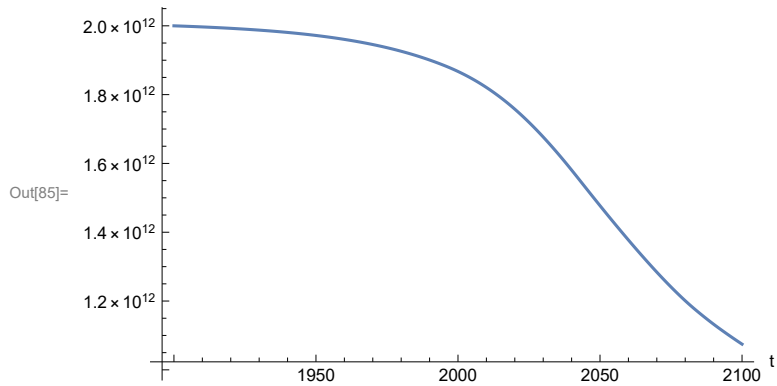
```
In[84]:= MinAndMax[basestransim[{"Pollution_Dynamics1.PPoll_Index.y"}]]
```

Maximum is 4.47338

Minimum is 0.0157768

Plot non-renewable resources remaining.

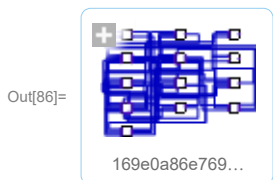
```
In[85]:= SystemModelPlot[basestransim, {"NR_Resource_Utilization1.NR_Resources.y"}]
```



APPENDIX 20. SEVERE LAND LOSS DUE TO AIR POLLUTION, Scenario 4, Experiment 5

Scenario 4 with air pollution effect on land yield changed as noted.

```
In[86]:= sevsim = SystemModel[mysim, <|"ParameterValues" ->
      {"Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals" -> {0.7, 0.1, 0.1, 0.1}}|>]
```



```
In[87]:= basesevsim = SystemModelSimulate[sevsim]
```

Out[87]= SystemModelSimulationData [  Model: W169e0a86e7694917966607f02fa74752
Time: 1.90×10^3 to 2.10×10^3]

Show Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals.

```
In[88]:= SystemModel[sevsim] [
      {"ParameterValues", "Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[1]"}]
```

Out[88]= {Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[1] → 0.7}

```
In[89]:= SystemModel[sevsim] [
      {"ParameterValues", "Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[2]"}]
```

Out[89]= {Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[2] → 0.1}

```
In[90]:= SystemModel[sevsim] [
      {"ParameterValues", "Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[3]"}]
```

Out[90]= {Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[3] → 0.1}

```
In[91]:= SystemModel[sevsim] [
      {"ParameterValues", "Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[4]"}]
```

Out[91]= {Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[4] → 0.1}

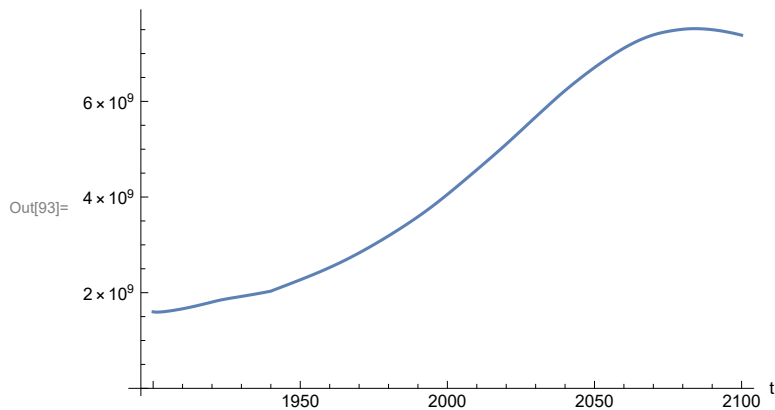
Show the value of t_air_poll_time (calendar year).

```
In[92]:= SystemModel[sevsim][{"ParameterValues", "t_air_poll_time"}]
```

```
Out[92]:= {t_air_poll_time → 4000}
```

Plot the world population, people. Note that the peak population is about one billion less, and about 20 years later, than the peak population forecast by Experiments 1-3.

```
In[93]:= SystemModelPlot[basesevsim, {"Population_Dynamics1.Birth_Rate.pop"}]
```



Find max and min of y values.

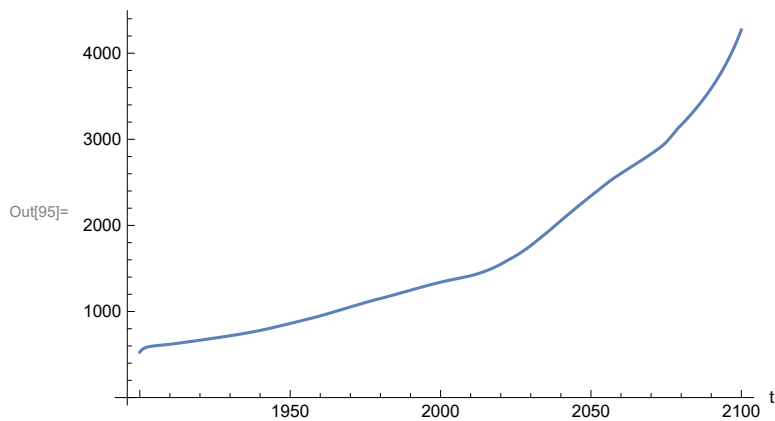
```
In[94]:= MinAndMax[basesevsim[{"Population_Dynamics1.Birth_Rate.pop"}]]
```

```
Maximum is 7.52043 × 109
```

```
Minimum is 1.59367 × 109
```

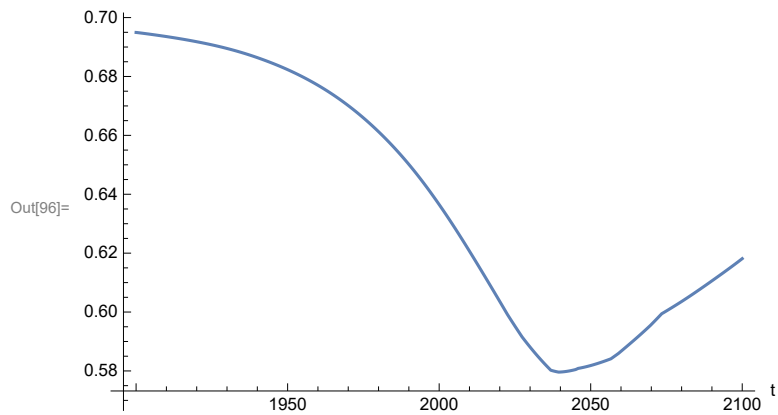
Plot land yield.

```
In[95]:= SystemModelPlot[basesevsim, {"Food_Production1.Land_Yield.y"}]
```



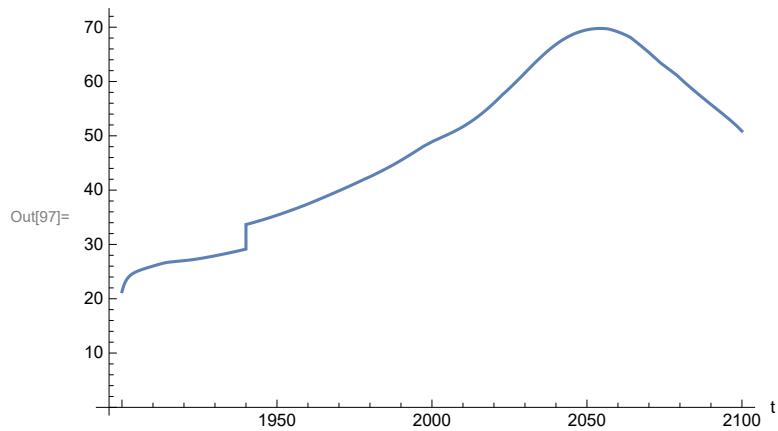
Plot multiplier of air pollution on land yield.

```
In[96]:= SystemModelPlot[basesevsim, {"Food_Production1.s_yield_mlt_air_poll"}]
```



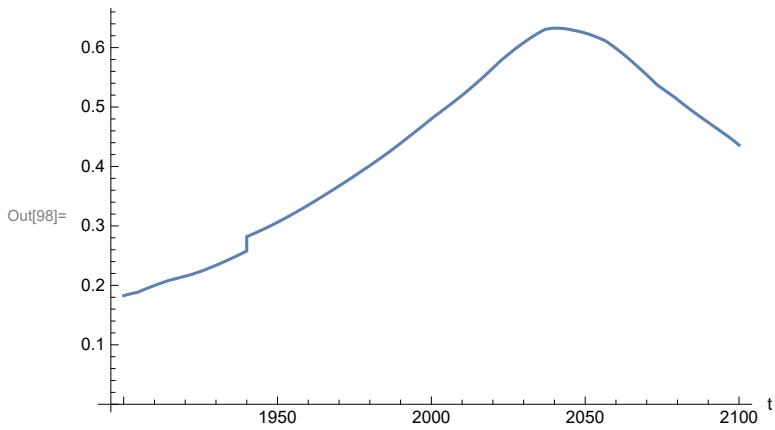
Plot life expectancy, in years.

```
In[97]:= SystemModelPlot[basesevsim, {"Life_Expectancy1.Life_Expectancy.y"}]
```



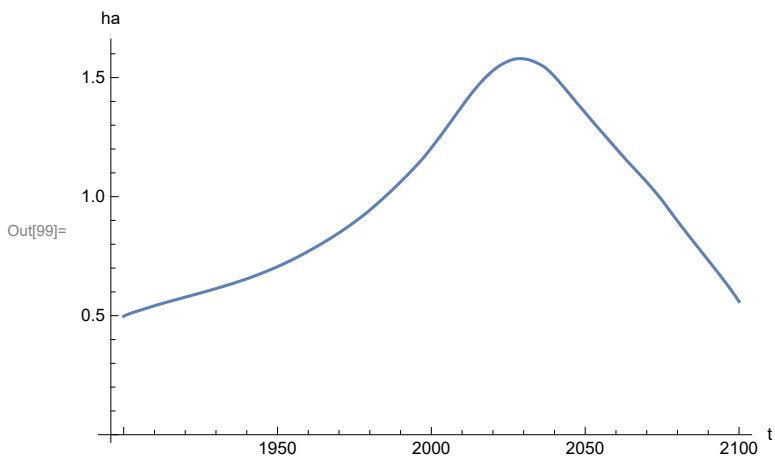
Plot the human welfare index.

```
In[98]:= SystemModelPlot[basesevsim,
  {"Human_Welfare_Index1.HWI_Human_Welfare_Index.hwi_human_welfare_index"}]
```



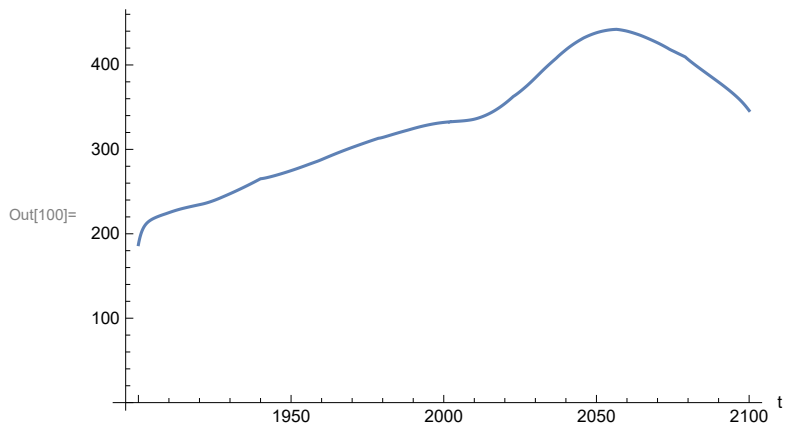
Plot the human ecological footprint, in hectares.

```
In[99]:= SystemModelPlot[basesevsim,
  {"Human_Ecological_Footprint1.HEF_Human_Ecological_Footprint.hef_human_ecological_
    _footprint"}]
```



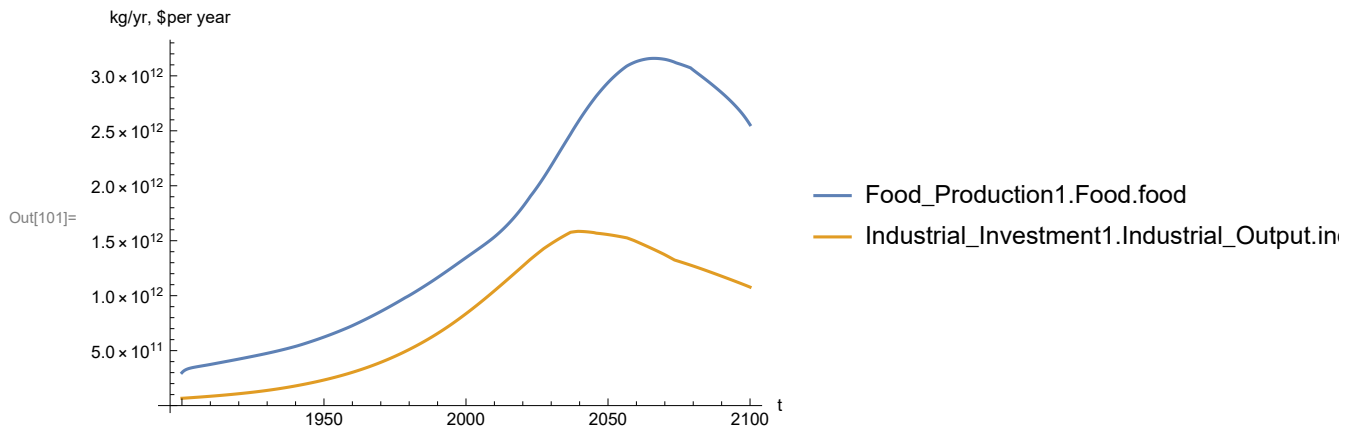
Plot per capita food production, kg/year.

```
In[100]:= SystemModelPlot[basesevsim, {"Food_Production1.Food_PC.y"}]
```



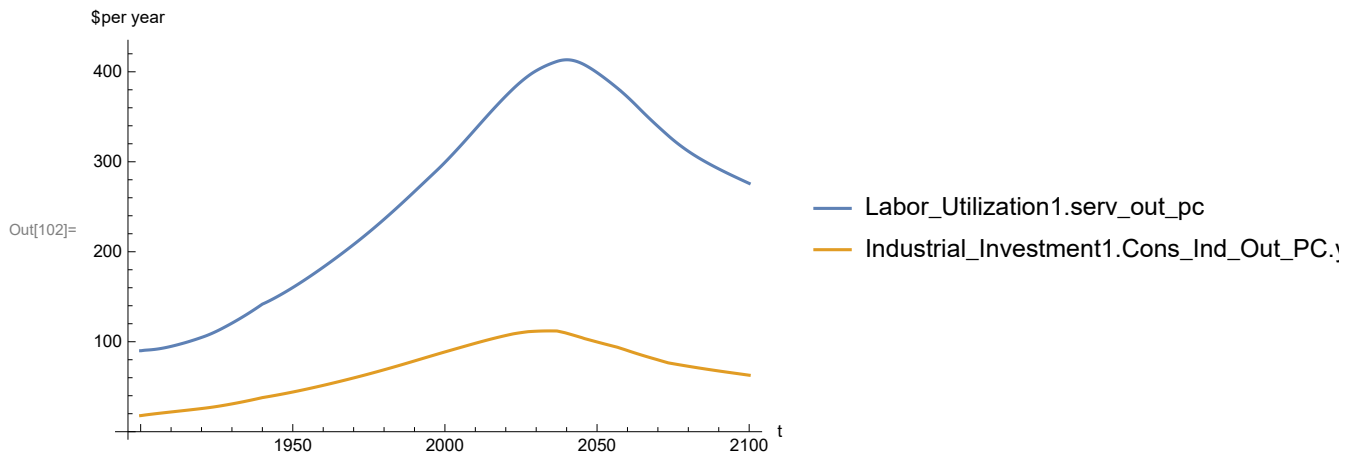
Plot total food production (kg/yr) and industrial output (in dollars).

```
In[101]:= SystemModelPlot[basesevsim, {"Food_Production1.Food.food",
  "Industrial_Investment1.Industrial_Output.industrial_output"}]
```



Plot consolidated industrial output per capita (dollars/year).

```
In[102]:= SystemModelPlot[basesevsim,
  {"Labor_Utilization1.serv_out_pc", "Industrial_Investment1.Cons_Ind_Out_PC.y"}]
```



Find max and min of y values.

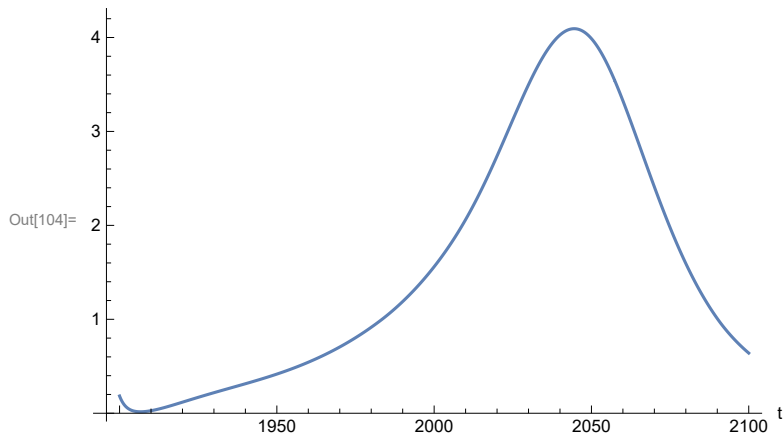
```
In[103]:= MinAndMax[basesevsim[{"Labor_Utilization1.serv_out_pc"}]]
```

Maximum is 413.342

Minimum is 90.

Plot persistent pollution index (normalized to 1970 value).

```
In[104]:= SystemModelPlot[basesevsim, {"Pollution_Dynamics1.PPoll_Index.y"}]
```



Find max and min of y values.

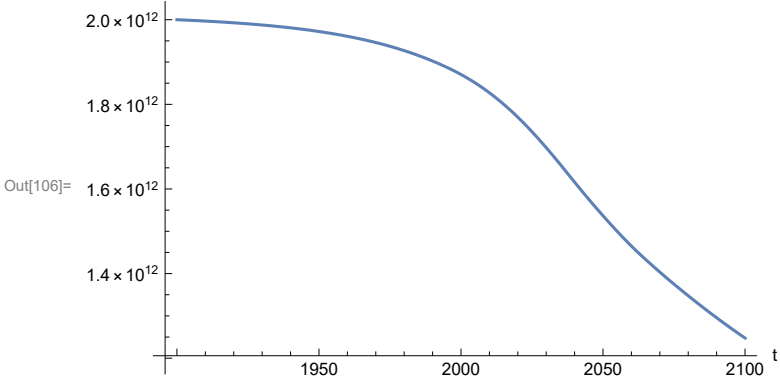
```
In[105]:= MinAndMax[basesevsim[{"Pollution_Dynamics1.PPoll_Index.y"}]]
```

Maximum is 4.09362

Minimum is 0.0157849

Plot non-renewable resources remaining.

```
In[106]:= SystemModelPlot[basesevsim, {"NR_Resource_Utilization1.NR_Resources.y"}]
```



APPENDIX 21. BENCHMARK SIMULATIONS, Scenario 5, Experiment 1

Here are some high-level properties of Benchmark Scenario 5.

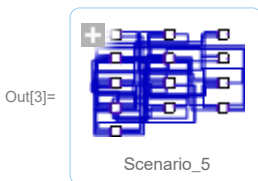
Define a function that extracts range data from scenario data. (The right-hand-side of this definition is specific to a *World3* data structure and assumes that the function whose range is being extracted is globally (i.e., not piecewise) defined.)

```
In[1]:= RangeData[data_] := data[[1]][[4]][[3]];
```

Define a procedure to determine and print minimum and maximum of “y” values.

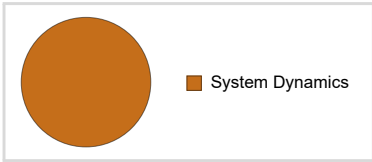
```
In[2]:= MinAndMax[data_] := (myscenseries = RangeData[data];  
Print["Maximum is ", Max[myscenseries]]; Print["Minimum is ", Min[myscenseries]])
```

```
In[3]:= mysim = SystemModel["SystemDynamics.WorldDynamics.World3.Scenario_5"]
```



```
In[4]:= mysummary = mysim["Summary"]
```

Out[4]=

ModelName	SystemDynamics.WorldDynamics.World3.Scenario_5
Description	More accessible non-recoverable natural resources, pollution control, land yield .
SimulationModel	True
Plots	0
Components	106
Balanced	True
SystemEquations	1583
SystemVariables	1583
Domain	

Show the value of `t_air_poll_time`.

```
In[5]:= SystemModel[mysim][{"ParameterValues", "t_air_poll_time"}]
```

```
Out[5]= {t_air_poll_time → 4000}
```

Show Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals.

```
In[6]:= SystemModel[mysim][
  {"ParameterValues", "Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[1]"}]
```

```
Out[6]= {Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[1] → 1}
```

```
In[7]:= SystemModel[mysim][
  {"ParameterValues", "Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[2]"}]
```

```
Out[7]= {Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[2] → 1}
```

```
In[8]:= SystemModel[mysim][
  {"ParameterValues", "Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[3]"}]
```

```
Out[8]= {Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[3] → 0.7}
```

```
In[9]:= SystemModel[mysim][
  {"ParameterValues", "Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[4]"}]
```

```
Out[9]= {Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[4] → 0.4}
```

Show Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_2.y_vals.

```
In[10]:= SystemModel[mysim][
  {"ParameterValues", "Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_2.y_vals[1]"}]
```

```
Out[10]= {Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_2.y_vals[1] → 1}
```

```
In[11]:= SystemModel[mysim][
  {"ParameterValues", "Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_2.y_vals[2]"}]
```

```
Out[11]= {Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_2.y_vals[2] → 1}
```

```
In[12]:= SystemModel[mysim][
  {"ParameterValues", "Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_2.y_vals[3]"}]
```

```
Out[12]= {Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_2.y_vals[3] → 0.98}
```

```
In[13]:= SystemModel[mysim][
  {"ParameterValues", "Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_2.y_vals[4]"}]
```

```
Out[13]= {Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_2.y_vals[4] → 0.95}
```

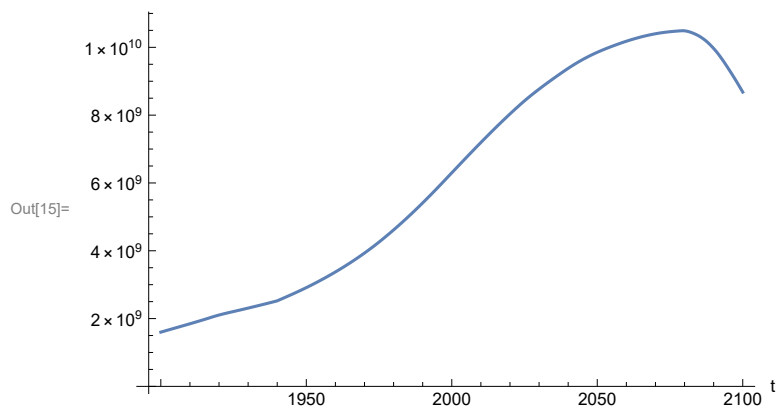
Execute Benchmark Simulation 5 and plot the variables shown in Figure 2.

In[14]:= **basesim = SystemModelSimulate[mysim]**

Out[14]:= SystemModelSimulationData [ Model: Scenario_5
Time: 1.90×10^3 to 2.10×10^3]

Plot total population, people.

In[15]:= **SystemModelPlot[basesim, {"Population_Dynamics1.Birth_Rate.pop"}]**



Find max and min of population values.

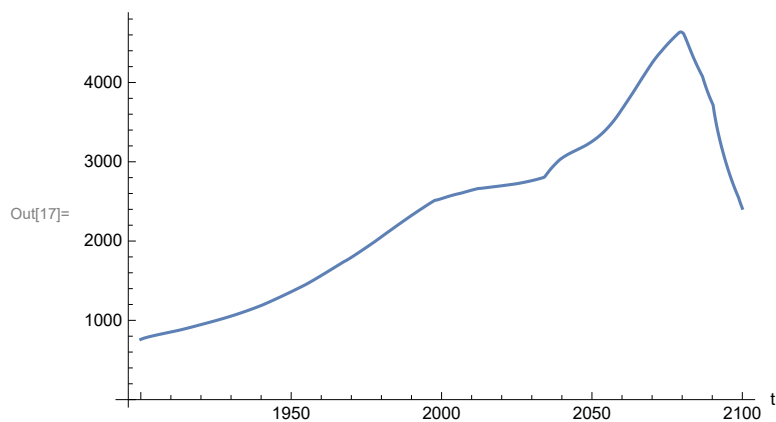
In[16]:= **MinAndMax[basesim[{"Population_Dynamics1.Birth_Rate.pop"}]]**

Maximum is 1.04901×10^{10}

Minimum is 1.6×10^9

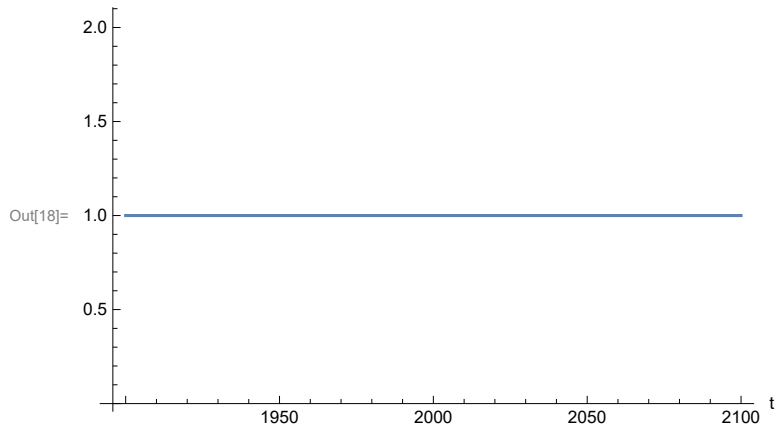
Plot land yield.

In[17]:= **SystemModelPlot[basesim, {"Food_Production1.Land_Yield.y"}]**



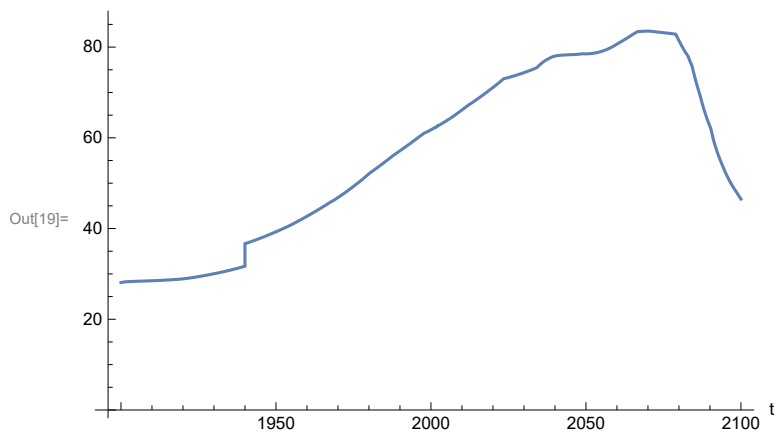
Plot multiplier of air pollution on land yield.

```
In[18]:= SystemModelPlot[basesim, {"Food_Production1.s_yield_mlt_air_poll"}]
```



Plot life expectancy, years.

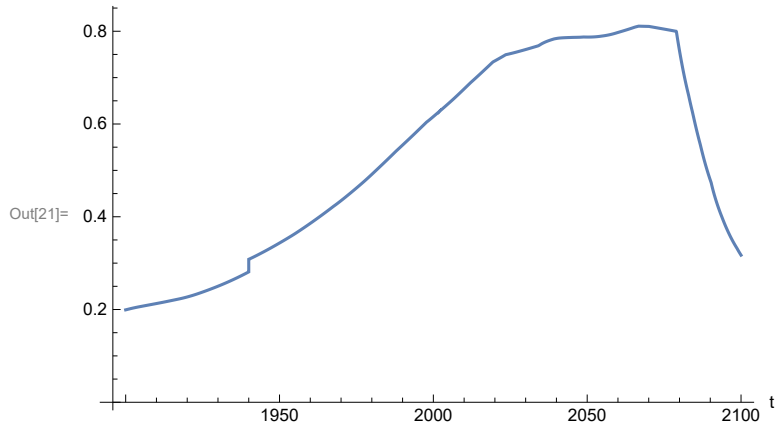
```
In[19]:= SystemModelPlot[basesim, {"Life_Expectancy1.Life_Expectancy.y"}]
```



```
In[20]:=
```

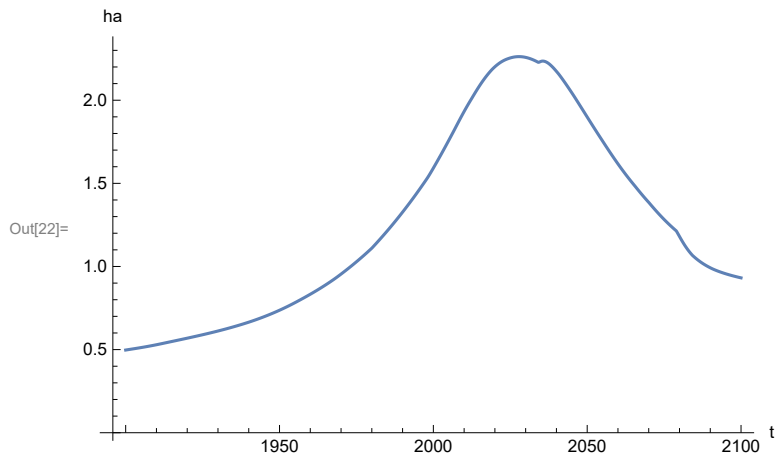
Plot human welfare index.

```
In[21]:= SystemModelPlot[basesim,
  {"Human_Welfare_Index1.HWI_Human_Welfare_Index.hwi_human_welfare_index"}]
```



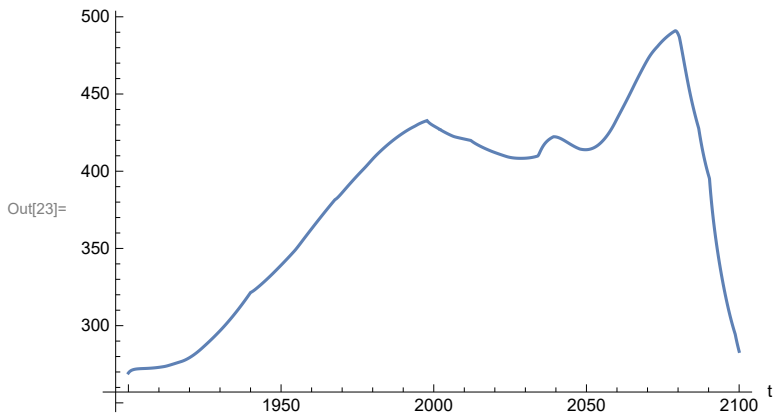
Plot per capita ecological footprint, hectares.

```
In[22]:= SystemModelPlot[basesim,
  {"Human_Ecological_Footprint1.HEF_Human_Ecological_Footprint.hef_human_ecological_footprint"}]
```



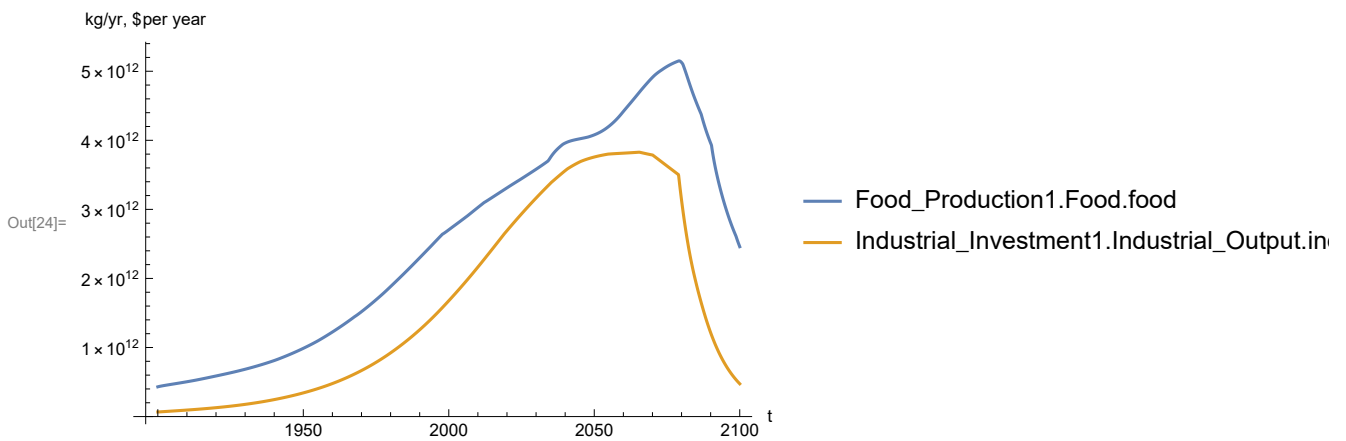
Plot food production per capita (kg/year).

In[23]:= `SystemModelPlot[basesim, {"Food_Production1.Food_PC.y"}]`



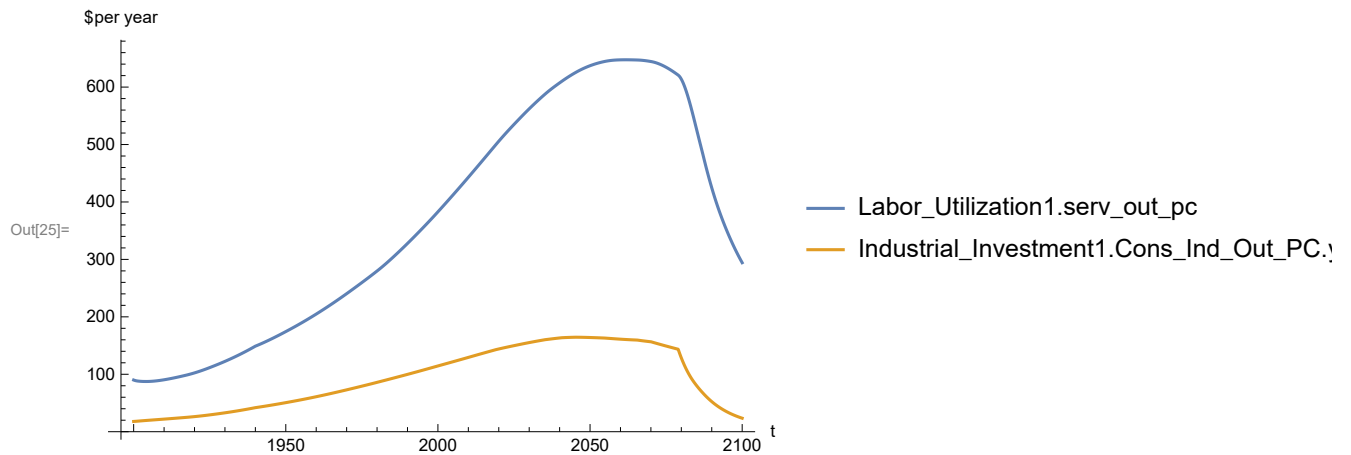
Plot total food production (kg/year), and industrial output (dollars/year).

In[24]:= `SystemModelPlot[basesim, {"Food_Production1.Food.food", "Industrial_Investment1.Industrial_Output.industrial_output"}]`



Plot labor utilization per capita (dollars/year), and consolidated industrial output per capita (dollars/year)

```
In[25]:= SystemModelPlot[basesim,
  {"Labor_Utilization1.serv_out_pc", "Industrial_Investment1.Cons_Ind_Out_PC.y"}]
```



Find max and min of y values.

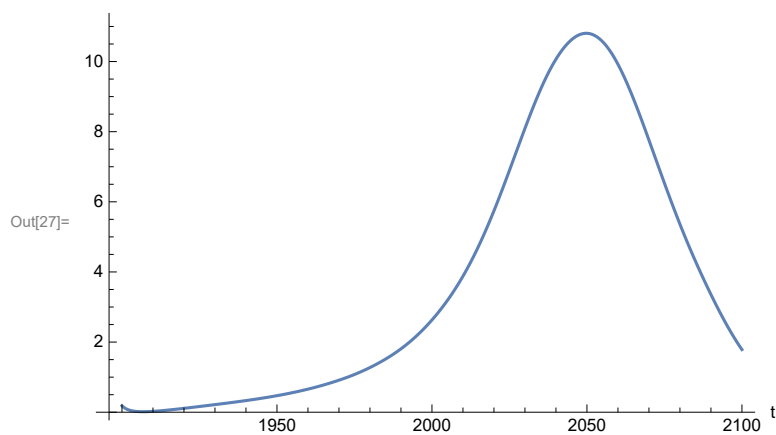
```
In[26]:= MinAndMax[basesim[{"Labor_Utilization1.serv_out_pc"}]]
```

Maximum is 647.557

Minimum is 87.4451

Plot persistent pollution index.

```
In[27]:= SystemModelPlot[basesim, {"Pollution_Dynamics1.PPoll_Index.y"}]
```



Find max and min of y values.

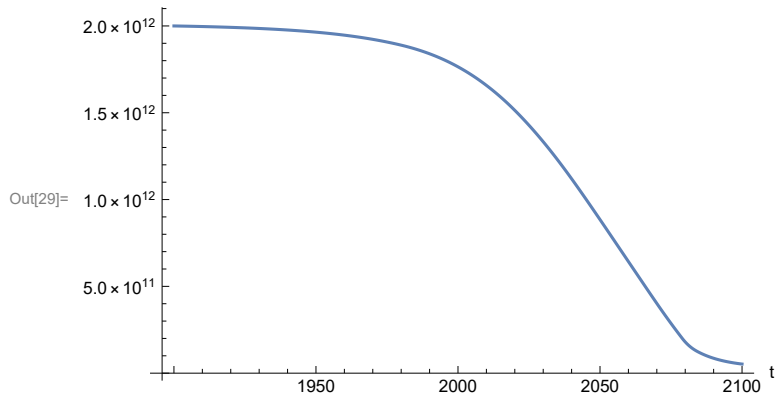
```
In[28]:= MinAndMax[basesim[{"Pollution_Dynamics1.PPoll_Index.y"}]]
```

Maximum is 10.8051

Minimum is 0.0150765

Plot non-renewable resources remaining.

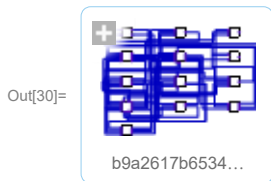
In[29]:= SystemModelPlot[basesim, {"NR_Resource_Utilization1.NR_Resources.y"}]



APPENDIX 22. Effects of mitigating the impact of air pollution on agricultural land yield, beginning calendar year 2020, Scenario 5, Experiment 2

Change the value of the air pollution effect multiplier switch time `t_air_poll_time`, to calendar year 2020, and execute the resulting scenario, plotting the variables shown in Figure 2.

```
In[30]:= newmysim = SystemModel[mysim, <|"ParameterValues" → {"t_air_poll_time" → 2020}|>]
```



```
In[31]:= testsim = SystemModelSimulate[newmysim]
```

Out[31]= SystemModelSimulationData [ Model: Wb9a2617b653448be8161837f4b063084
Time: 1.90×10^3 to 2.10×10^3]

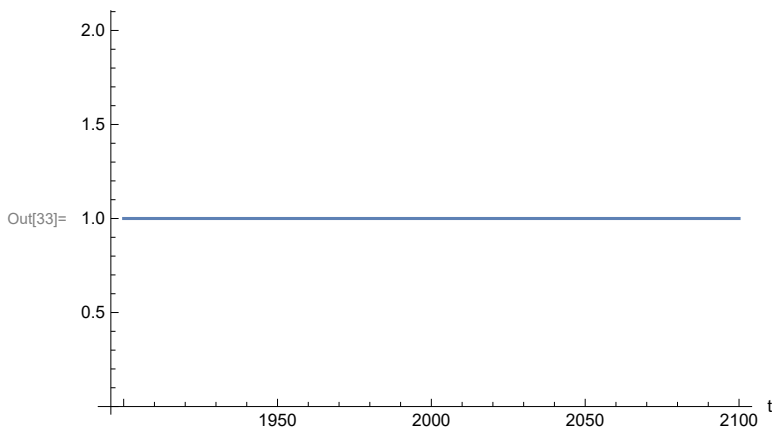
Show the value of `t_air_poll_time` (calendar year).

```
In[32]:= SystemModel[newmysim][{"ParameterValues", "t_air_poll_time"}]
```

Out[32]= {t_air_poll_time → 2020}

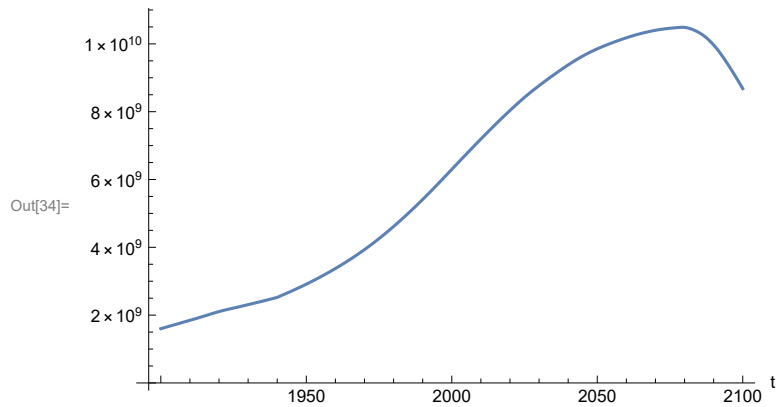
Plot air pollution multiplier of land yield.

```
In[33]:= SystemModelPlot[testsim, {"Food_Production1.s_yield_mlt_air_poll"}]
```



Plot the world population, people.

```
In[34]:= SystemModelPlot[testsim, {"Population_Dynamics1.Birth_Rate.pop"}]
```



Find max and min of y values.

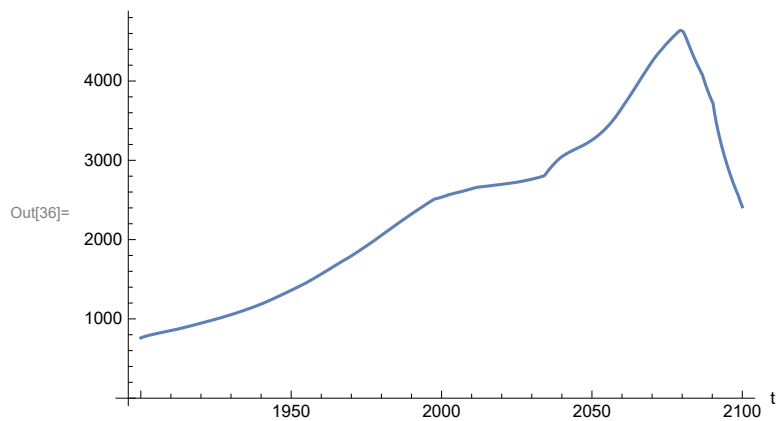
```
In[35]:= MinAndMax[testsim[{"Population_Dynamics1.Birth_Rate.pop"}]]
```

Maximum is 1.04901×10^{10}

Minimum is 1.6×10^9

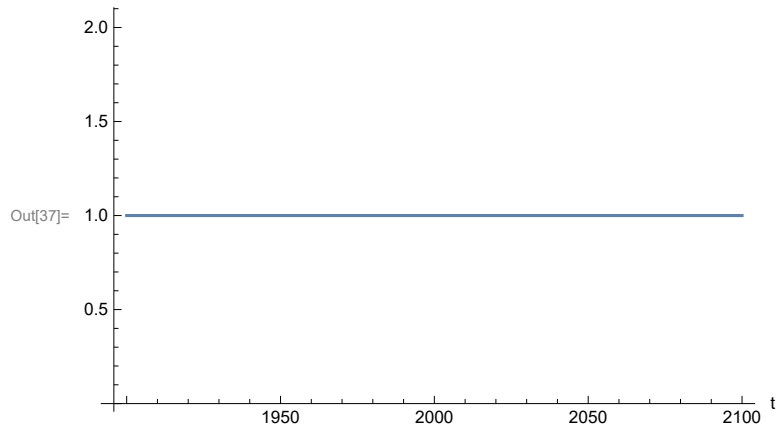
Plot land yield.

```
In[36]:= SystemModelPlot[testsim, {"Food_Production1.Land_Yield.y"}]
```



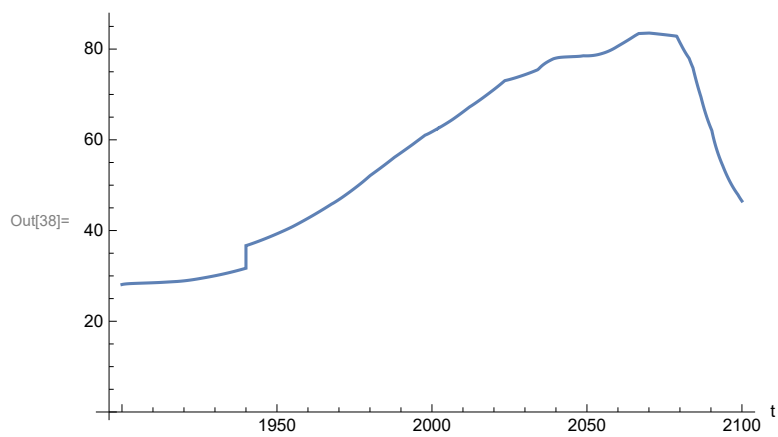
Plot multiplier of air pollution on land yield.

```
In[37]:= SystemModelPlot[testsim, {"Food_Production1.s_yield_mlt_air_poll"}]
```



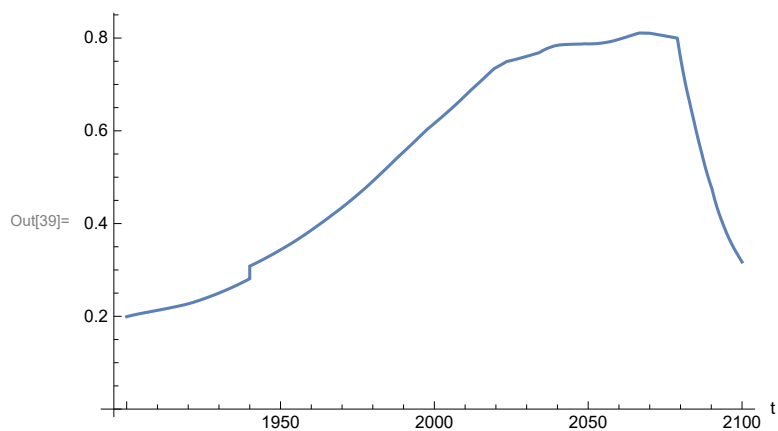
Plot life expectancy, in years.

```
In[38]:= SystemModelPlot[testsim, {"Life_Expectancy1.Life_Expectancy.y"}]
```



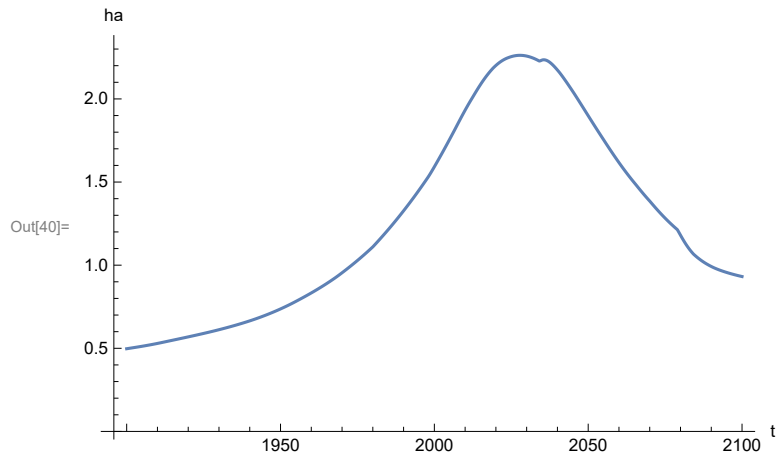
Plot the human welfare index.

```
In[39]:= SystemModelPlot[testsim, {"Human_Welfare_Index1.HWI_Human_Welfare_Index.hwi_human_welfare_index"}]
```



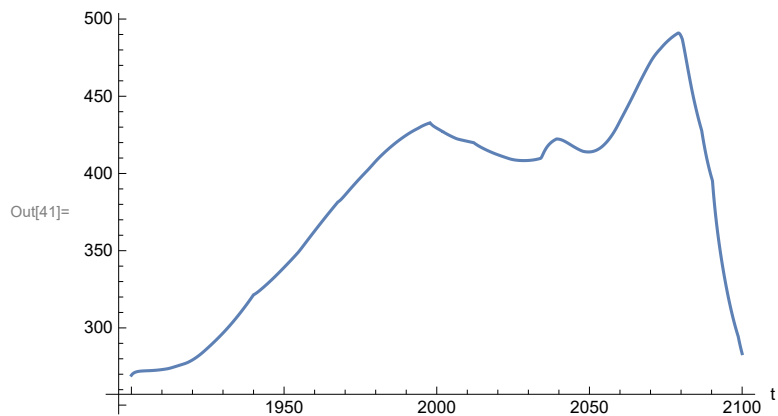
Plot the human ecological footprint, in hectares.

```
In[40]:= SystemModelPlot[testsim,
  {"Human_Ecological_Footprint1.HEF_Human_Ecological_Footprint.hef_human_ecological_
    _footprint"}]
```



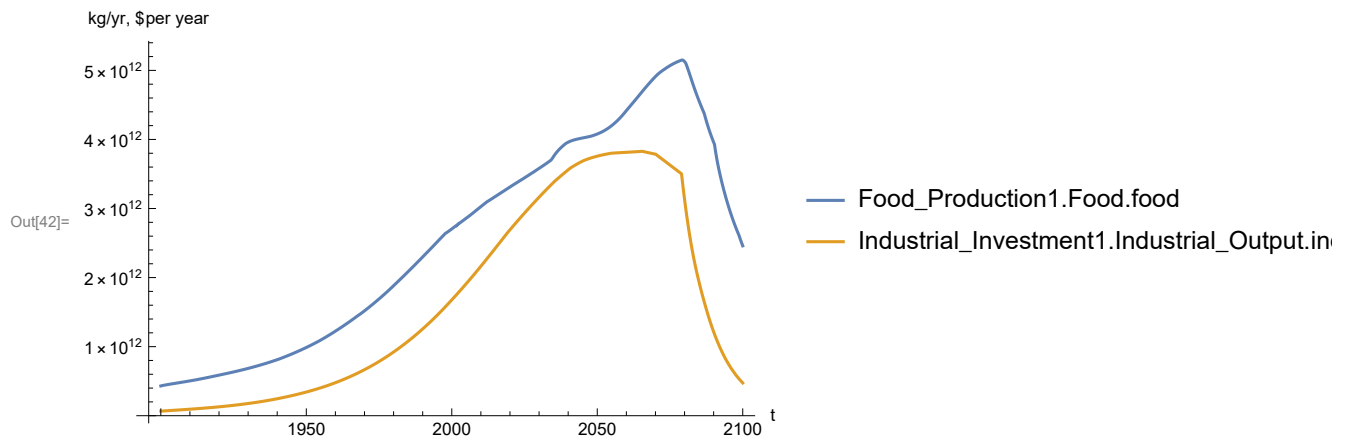
Plot per capita food production, kg/year.

```
In[41]:= SystemModelPlot[testsim, {"Food_Production1.Food_PC.y"}]
```



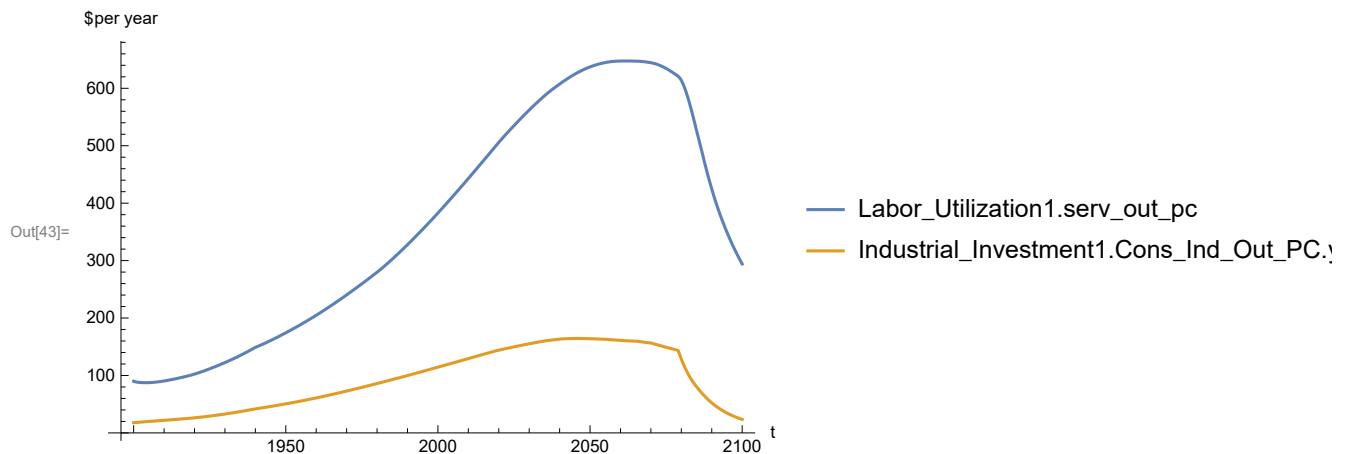
Plot total food production (kg/yr) and industrial output (in dollars).

```
In[42]:= SystemModelPlot[testsim, {"Food_Production1.Food.food",
  "Industrial_Investment1.Industrial_Output.industrial_output"}]
```



Plot labor utilization per capita and consolidated industrial output per capita (dollars/year).

```
In[43]:= SystemModelPlot[testsim,
  {"Labor_Utilization1.serv_out_pc", "Industrial_Investment1.Cons_Ind_Out_PC.y"}]
```



Find max and min of y values.

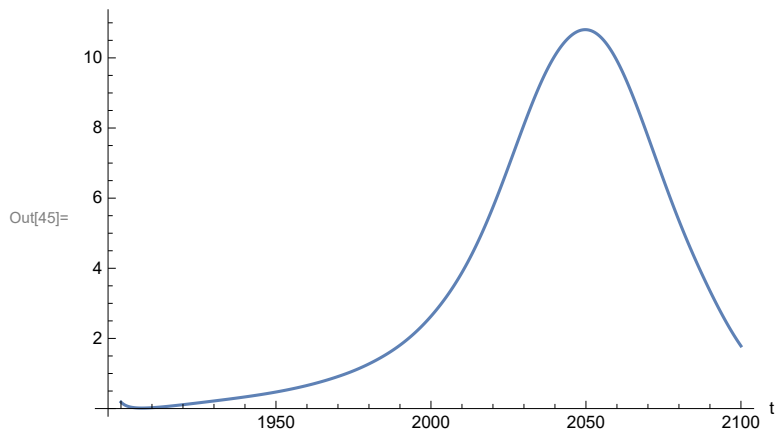
```
In[44]:= MinAndMax[testsim[{"Labor_Utilization1.serv_out_pc"}]]
```

Maximum is 647.557

Minimum is 87.4451

Plot persistent pollution index (normalized to 1970 value).

```
In[45]:= SystemModelPlot[testsim, {"Pollution_Dynamics1.PPoll_Index.y"}]
```



Find max and min of y values.

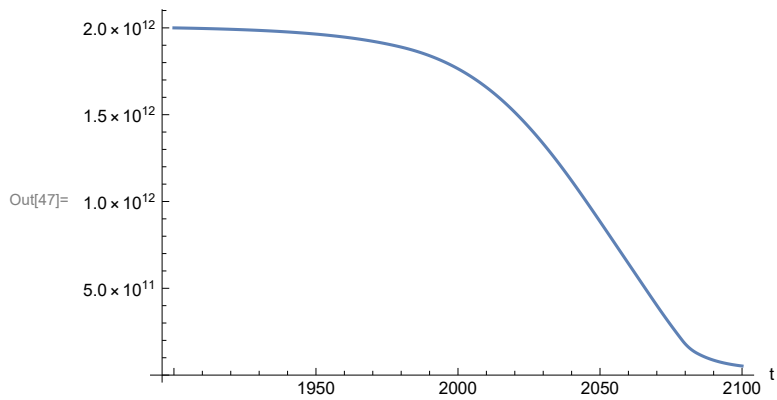
```
In[46]:= MinAndMax[testsim[{"Pollution_Dynamics1.PPoll_Index.y"}]]
```

Maximum is 10.8051

Minimum is 0.0150765

Plot non-renewable resources remaining.

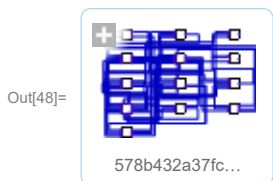
```
In[47]:= SystemModelPlot[testsim, {"NR_Resource_Utilization1.NR_Resources.y"}]
```



APPENDIX 23. Effects of mitigating the impact of air pollution on agricultural land yield, beginning calendar year 1970, Scenario 5, Experiment 3

Change the value of the air pollution effect multiplier switch time `t_air_poll_time`, to calendar year 1970, and execute the resulting scenario, plotting the variables shown in Figure 2.

```
In[48]:= newmysim1970 = SystemModel[mysim, <|"ParameterValues" → {"t_air_poll_time" → 1970} |>]
```



```
In[49]:= testsim1970 = SystemModelSimulate[newmysim1970]
```

Out[49]= SystemModelSimulationData [ Model: W578b432a37fc4f46a803ef58f08d8a79
Time: 1.90×10^3 to 2.10×10^3]

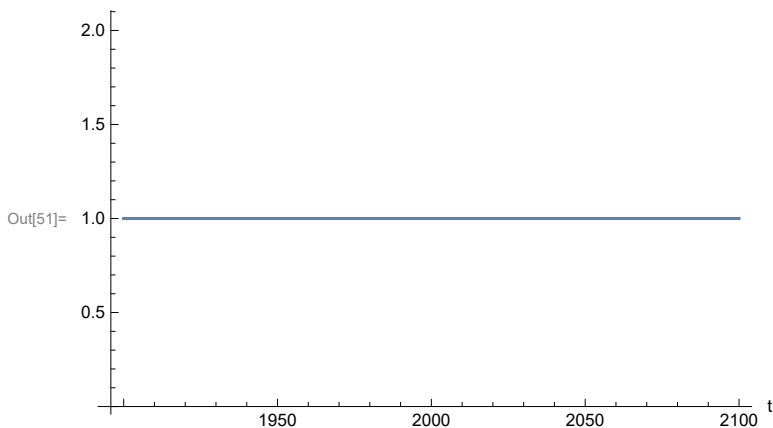
Show the value of `t_air_poll_time` (calendar year).

```
In[50]:= SystemModel[newmysim1970][{"ParameterValues", "t_air_poll_time"}]
```

Out[50]= {t_air_poll_time → 1970}

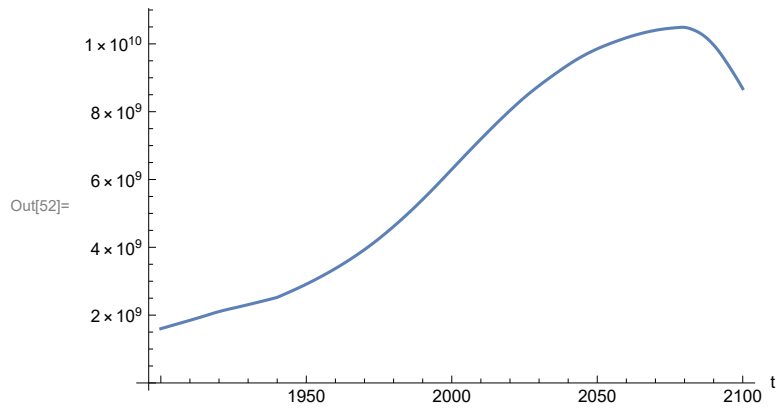
Plot air pollution multiplier of land yield.

```
In[51]:= SystemModelPlot[testsim1970, {"Food_Production1.s_yield_mlt_air_poll"}]
```



Plot the world population, people.

```
In[52]:= SystemModelPlot[testsim1970, {"Population_Dynamics1.Birth_Rate.pop"}]
```



Find max and min of y values.

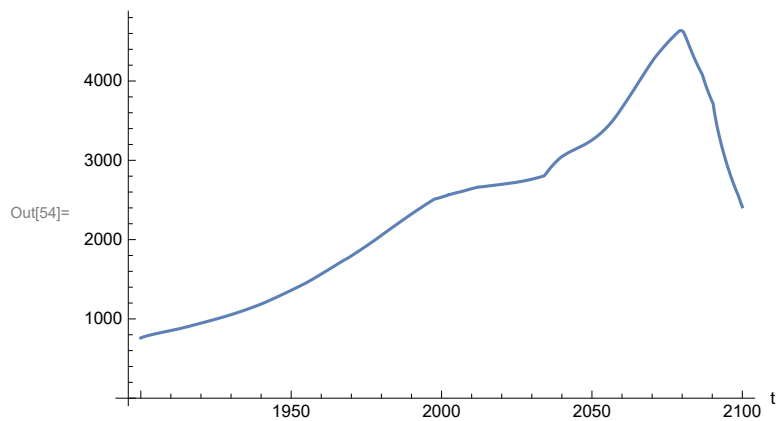
```
In[53]:= MinAndMax[testsim1970[{"Population_Dynamics1.Birth_Rate.pop"}]]
```

Maximum is 1.04901×10^{10}

Minimum is 1.6×10^9

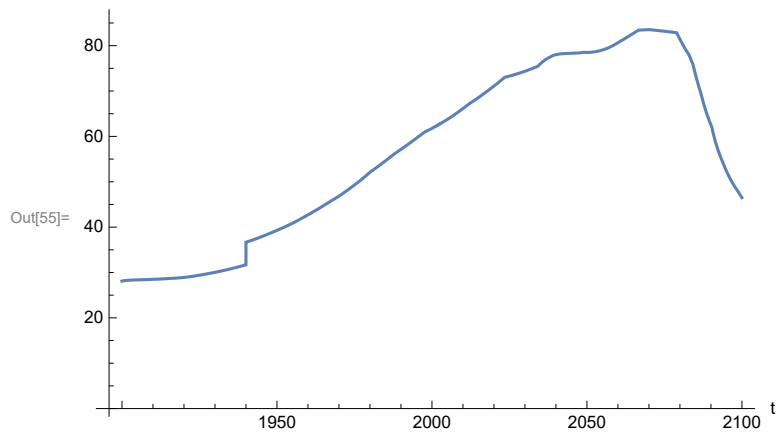
Plot land yield.

```
In[54]:= SystemModelPlot[testsim1970, {"Food_Production1.Land_Yield.y"}]
```



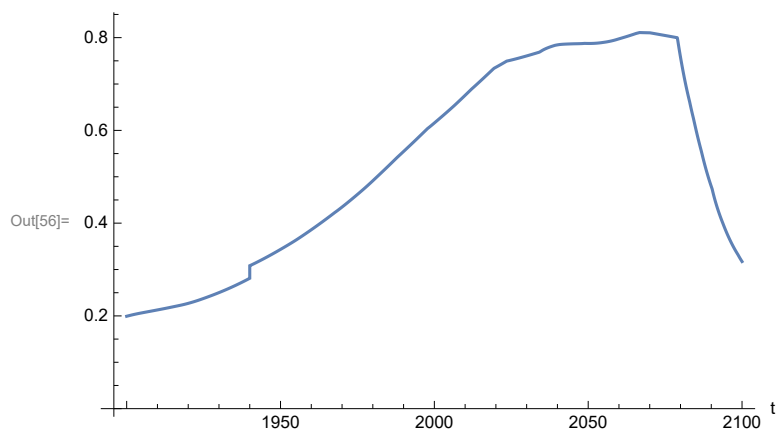
Plot life expectancy, in years.

In[55]:= `SystemModelPlot[testsim1970, {"Life_Expectancy1.Life_Expectancy.y"}]`



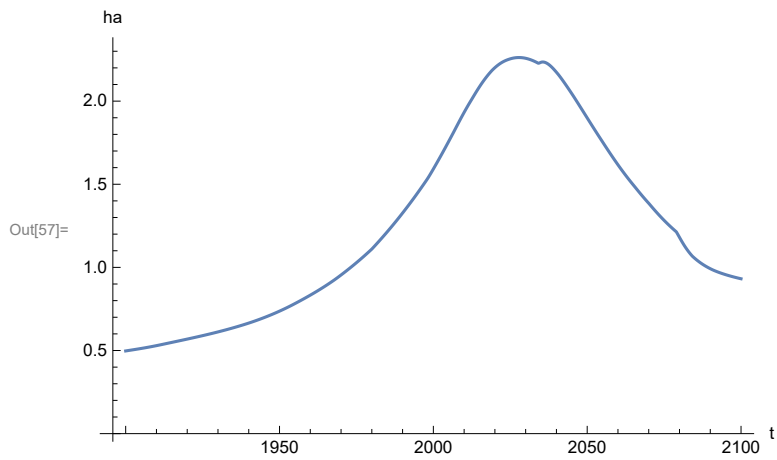
Plot the human welfare index.

In[56]:= `SystemModelPlot[testsim1970, {"Human_Welfare_Index1.HWI_Human_Welfare_Index.hwi_human_welfare_index"}]`



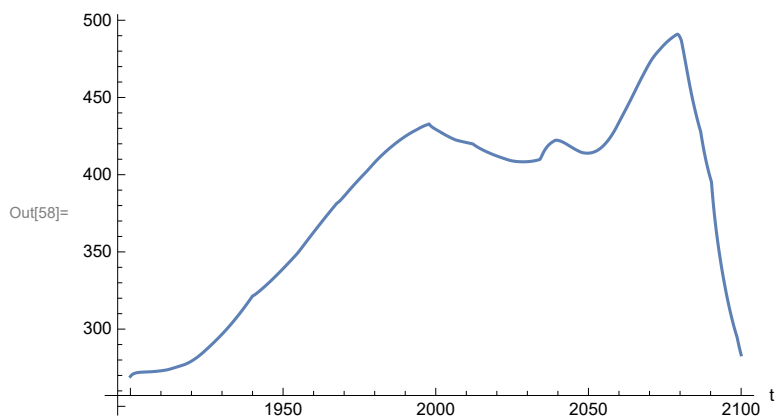
Plot the human ecological footprint, in hectares.

```
In[57]:= SystemModelPlot[testsim1970,
  {"Human_Ecological_Footprint1.HEF_Human_Ecological_Footprint.hef_human_ecological_
    _footprint"}]
```



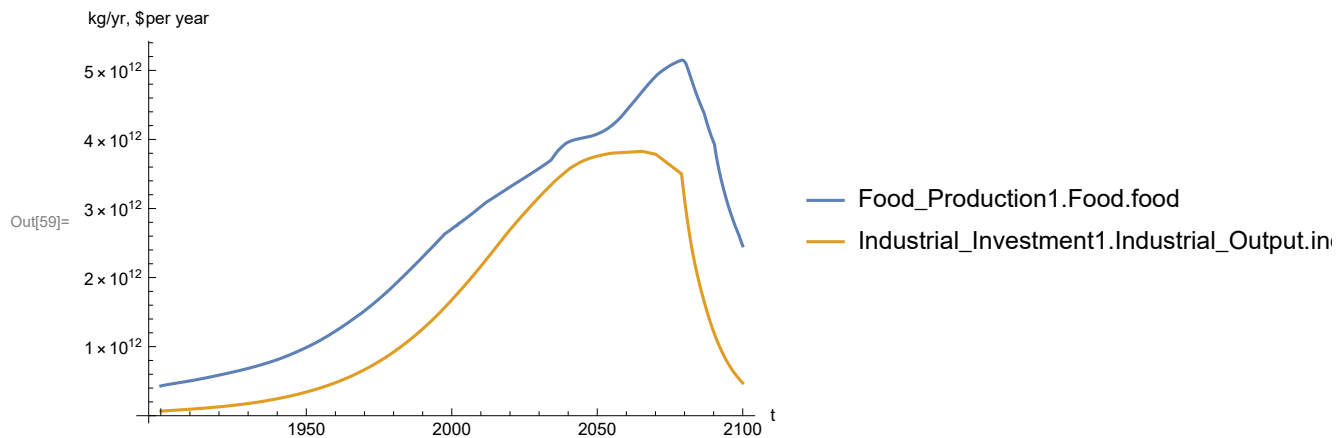
Plot per capita food production, kg/year.

```
In[58]:= SystemModelPlot[testsim1970, {"Food_Production1.Food_PC.y"}]
```



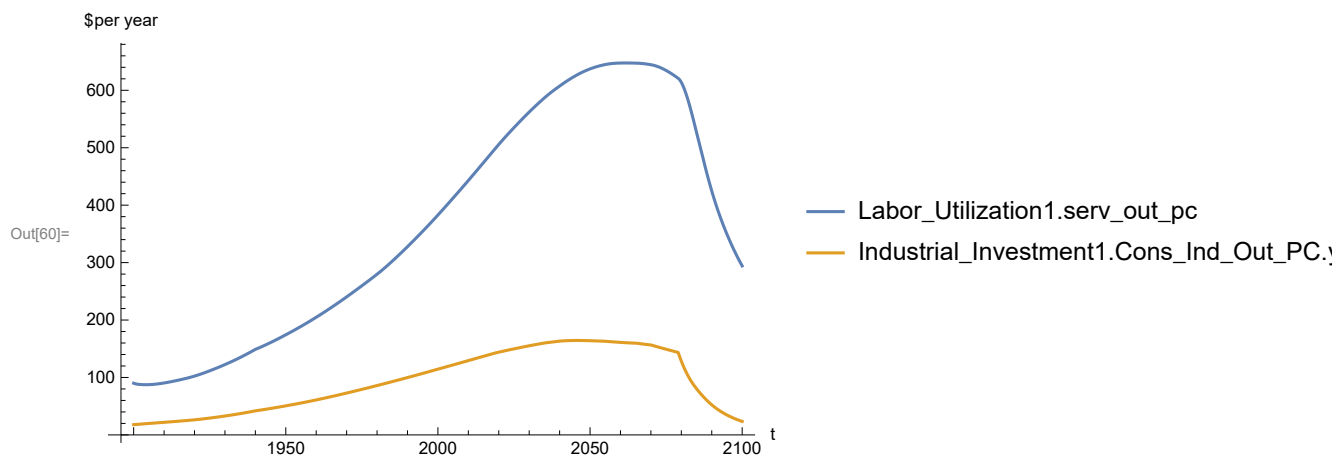
Plot total food production (kg/yr) and industrial output (in dollars).

```
In[59]:= SystemModelPlot[testsim1970, {"Food_Production1.Food.food",
  "Industrial_Investment1.Industrial_Output.industrial_output"}]
```



Plot labor utilization per capita consolidated industrial output per capita (dollars/year).

```
In[60]:= SystemModelPlot[testsim1970,
  {"Labor_Utilization1.serv_out_pc", "Industrial_Investment1.Cons_Ind_Out_PC.y"}]
```



Find max and min of y values.

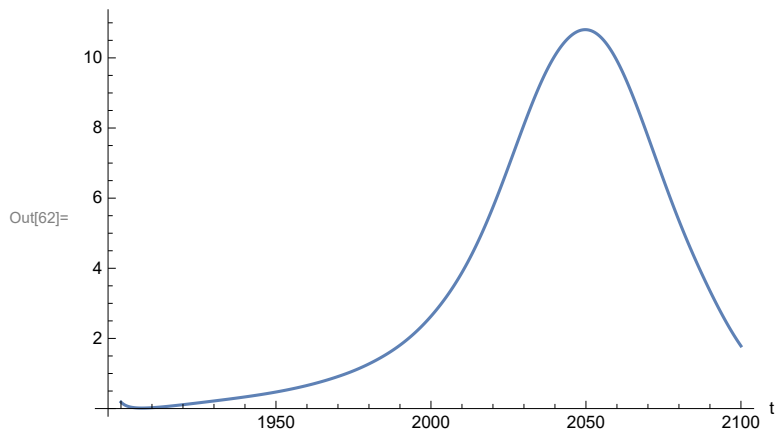
```
In[61]:= MinAndMax[testsim1970[{"Labor_Utilization1.serv_out_pc"}]]
```

Maximum is 647.557

Minimum is 87.4451

Plot persistent pollution index (normalized to 1970 value).

```
In[62]:= SystemModelPlot[testsim1970, {"Pollution_Dynamics1.PPoll_Index.y"}]
```



Find max and min of y values.

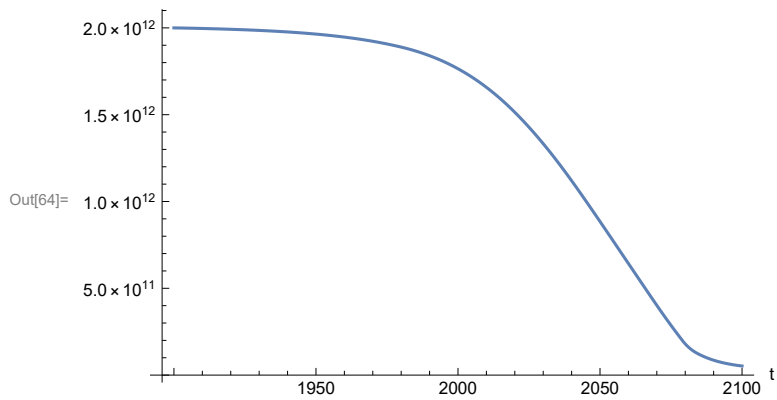
```
In[63]:= MinAndMax[testsim1970[{"Pollution_Dynamics1.PPoll_Index.y"}]]
```

Maximum is 10.8051

Minimum is 0.0150765

Plot non-renewable resources remaining.

```
In[64]:= SystemModelPlot[testsim1970, {"NR_Resource_Utilization1.NR_Resources.y"}]
```




APPENDIX 24. "STRONG AIR POLLUTION" EFFECTS SCENARIO, Scenario 5, Experiment 4

Scenario 5 with air pollution effect on land yield changed as noted.

```
In[65]:= strsim = SystemModel[mysim, <|"ParameterValues" ->
      {"Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals" -> {0.7, 0.5, 0.3, 0.1}}|>]
```



```
In[66]:= basestrsim = SystemModelSimulate[strsim]
```

Out[66]= SystemModelSimulationData [ Model: W35c6963b618d4feb99799c6ead740d02
Time: 1.90×10^3 to 2.10×10^3]

Show Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals.

```
In[67]:= SystemModel[strsim] [
      {"ParameterValues", "Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[1]"}]
```

Out[67]= {Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[1] → 0.7}

```
In[68]:= SystemModel[strsim] [
      {"ParameterValues", "Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[2]"}]
```

Out[68]= {Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[2] → 0.5}

```
In[69]:= SystemModel[strsim] [
      {"ParameterValues", "Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[3]"}]
```

Out[69]= {Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[3] → 0.3}

```
In[70]:= SystemModel[strsim] [
      {"ParameterValues", "Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[4]"}]
```

Out[70]= {Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[4] → 0.1}

Show the value of t_air_poll_time (calendar year).

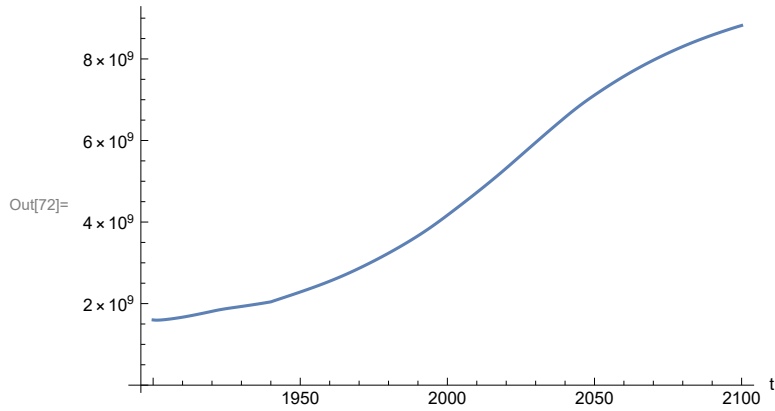
```
In[71]:= SystemModel[strsim] [{"ParameterValues", "t_air_poll_time"}]
```

Out[71]= {t_air_poll_time → 4000}

Plot the world population, people. Note that the peak population is about one billion less, and about

20 years later, than the peak population forecast by Experiments 1-3.

```
In[72]:= SystemModelPlot[basestransim, {"Population_Dynamics1.Birth_Rate.pop"}]
```



Find max and min of y values.

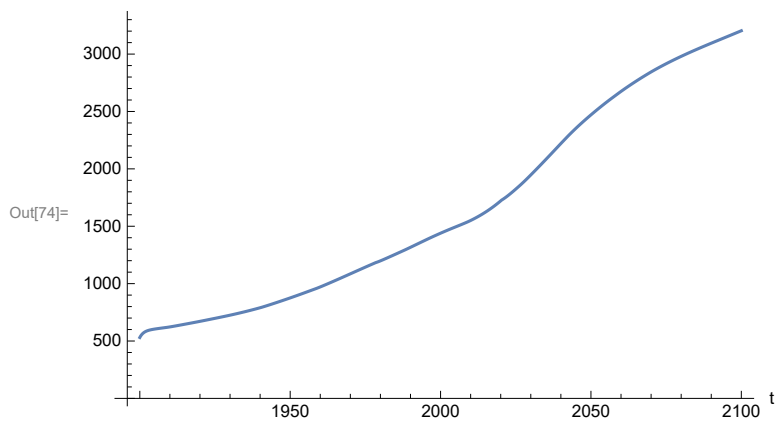
```
In[73]:= MinAndMax[basestransim[{"Population_Dynamics1.Birth_Rate.pop"}]]
```

Maximum is 8.82067×10^9

Minimum is 1.59431×10^9

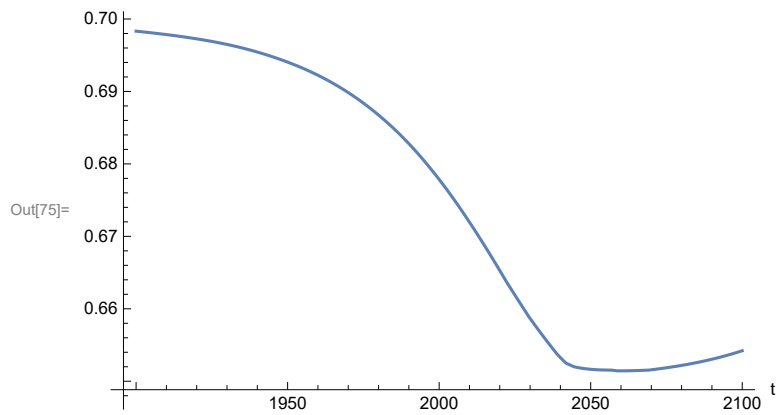
Plot land yield.

```
In[74]:= SystemModelPlot[basestransim, {"Food_Production1.Land_Yield.y"}]
```



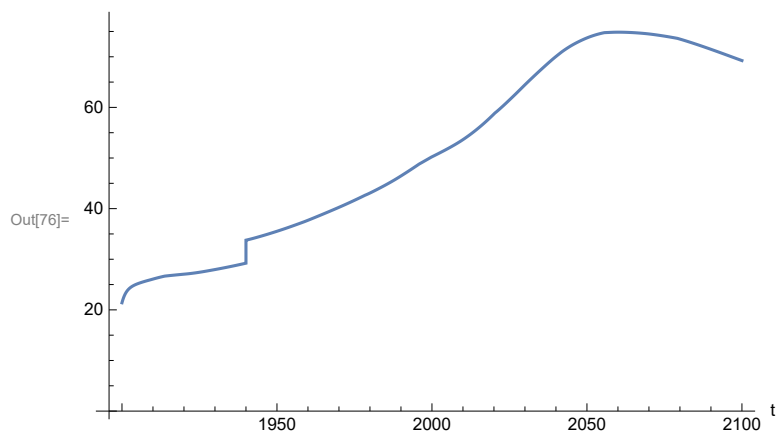
Plot multiplier of air pollution on land yield.

```
In[75]:= SystemModelPlot[basestransim, {"Food_Production1.s_yield_mlt_air_poll"}]
```



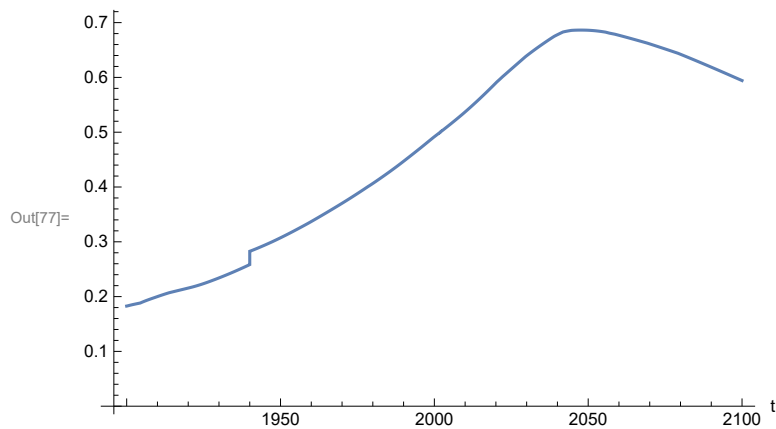
Plot life expectancy, in years.

```
In[76]:= SystemModelPlot[basestransim, {"Life_Expectancy1.Life_Expectancy.y"}]
```



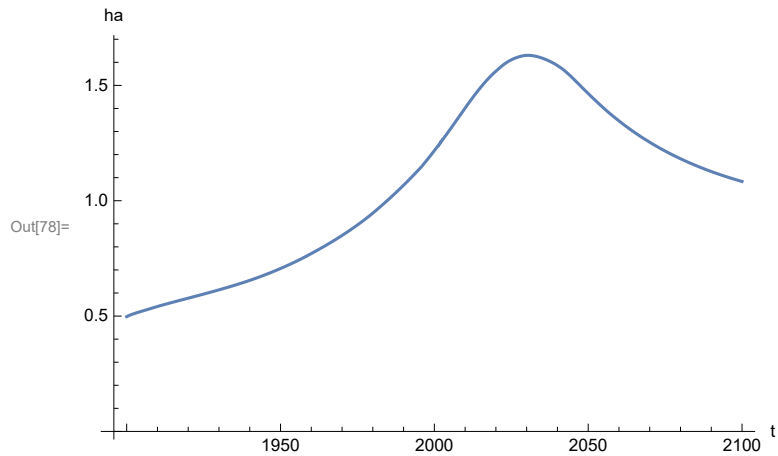
Plot the human welfare index.

```
In[77]:= SystemModelPlot[basestransim, {"Human_Welfare_Index1.HWI_Human_Welfare_Index.hwi_human_welfare_index"}]
```



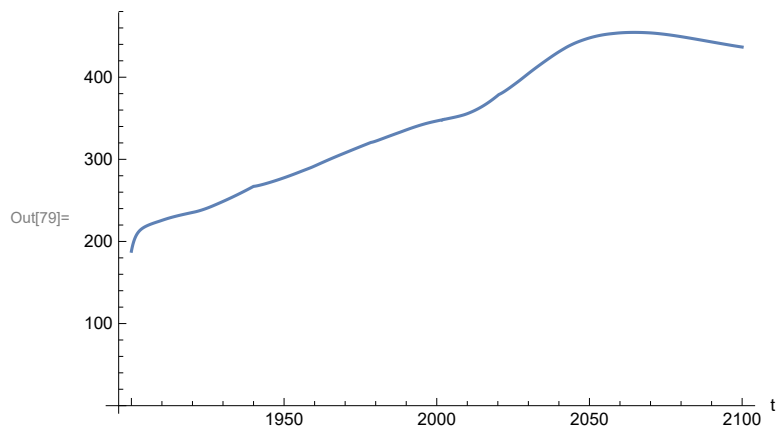
Plot the human ecological footprint, in hectares.

```
In[78]:= SystemModelPlot[basestrsim,
  {"Human_Ecological_Footprint1.HEF_Human_Ecological_Footprint.hef_human_ecological_
    _footprint"}]
```



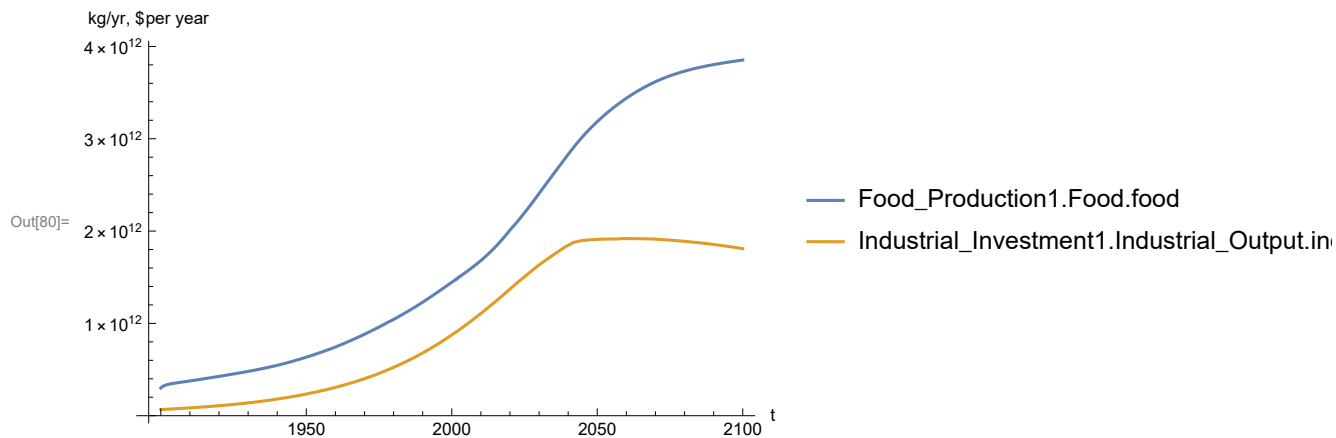
Plot per capita food production, kg/year.

```
In[79]:= SystemModelPlot[basestrsim, {"Food_Production1.Food_PC.y"}]
```



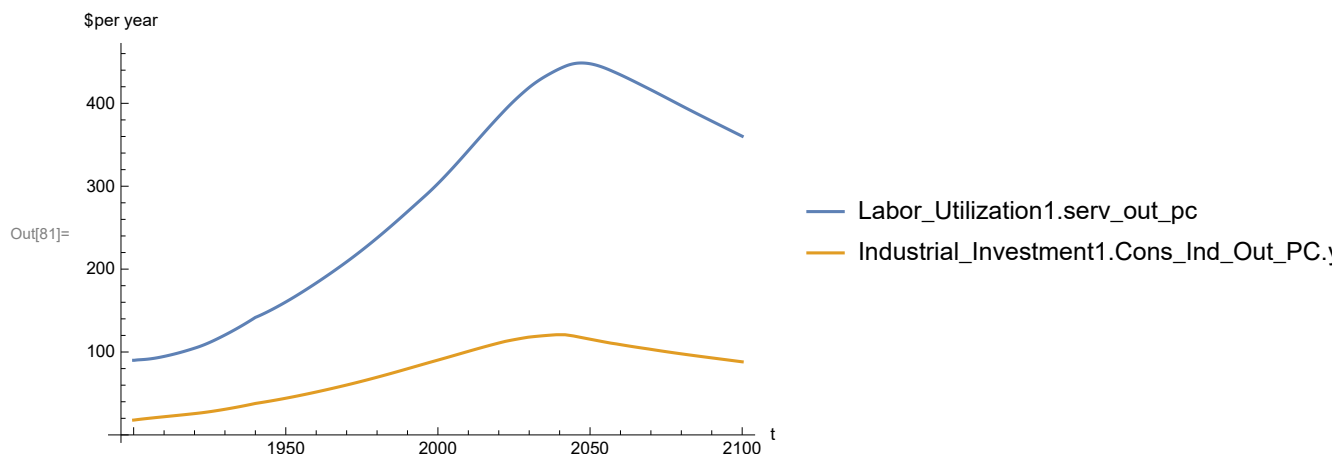
Plot total food production (kg/yr) and industrial output (in dollars).

```
In[80]:= SystemModelPlot[basestrsim, {"Food_Production1.Food.food",
  "Industrial_Investment1.Industrial_Output.industrial_output"}]
```



Plot labor utilization per capita and consolidated industrial output per capita (dollars/year).

```
In[81]:= SystemModelPlot[basestrsim,
  {"Labor_Utilization1.serv_out_pc", "Industrial_Investment1.Cons_Ind_Out_PC.y"}]
```



Find max and min of y values.

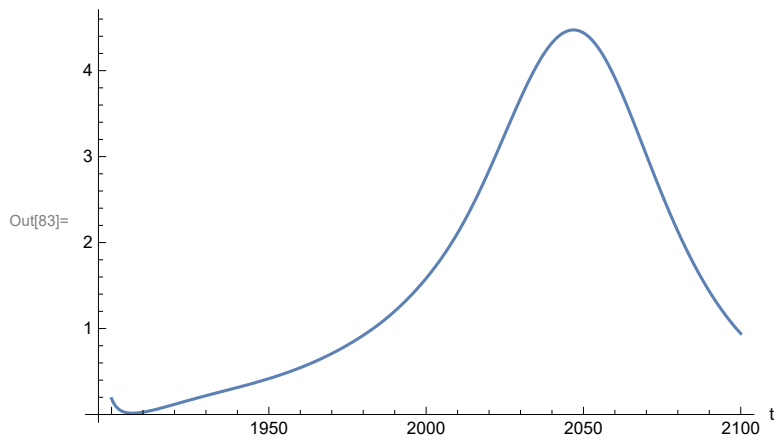
```
In[82]:= MinAndMax[basestrsim[{"Labor_Utilization1.serv_out_pc"}]]
```

Maximum is 448.672

Minimum is 89.9974

Plot persistent pollution index (normalized to 1970 value).

```
In[83]:= SystemModelPlot[basestransim, {"Pollution_Dynamics1.PPoll_Index.y"}]
```



Find max and min of y values.

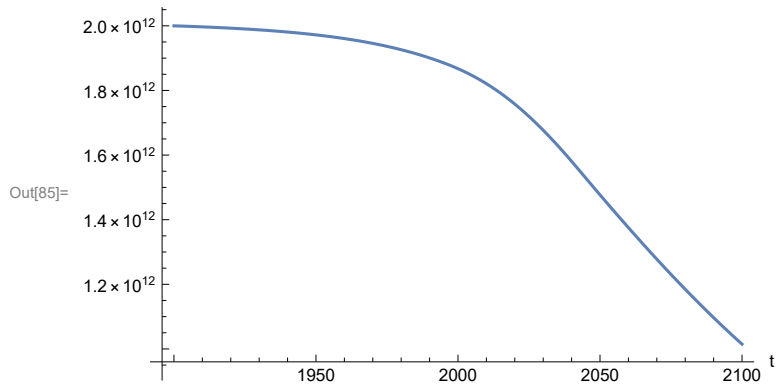
```
In[84]:= MinAndMax[basestransim[{"Pollution_Dynamics1.PPoll_Index.y"}]]
```

Maximum is 4.47343

Minimum is 0.0157768

Plot non-renewable resources remaining.

```
In[85]:= SystemModelPlot[basestransim, {"NR_Resource_Utilization1.NR_Resources.y"}]
```




APPENDIX 25. SEVERE LAND LOSS DUE TO AIR POLLUTION, Scenario 5, Experiment 5

Scenario 5 with air pollution effect on land yield changed as noted.

```
In[86]:= sevsim = SystemModel[mysim, <|"ParameterValues" ->
  {"Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals" -> {0.7, 0.1, 0.1, 0.1}}|>]
```



```
In[87]:= basesevsim = SystemModelSimulate[sevsim]
```

Out[87]= SystemModelSimulationData [ Model: Wc5f0335ad96648a297fe3ab2dff4de5c
Time: 1.90×10^3 to 2.10×10^3]

Show Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals.

```
In[88]:= SystemModel[sevsim] [
  {"ParameterValues", "Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[1]"}]
```

Out[88]= {Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[1] → 0.7}

```
In[89]:= SystemModel[sevsim] [
  {"ParameterValues", "Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[2]"}]
```

Out[89]= {Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[2] → 0.1}

```
In[90]:= SystemModel[sevsim] [
  {"ParameterValues", "Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[3]"}]
```

Out[90]= {Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[3] → 0.1}

```
In[91]:= SystemModel[sevsim] [
  {"ParameterValues", "Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[4]"}]
```

Out[91]= {Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[4] → 0.1}

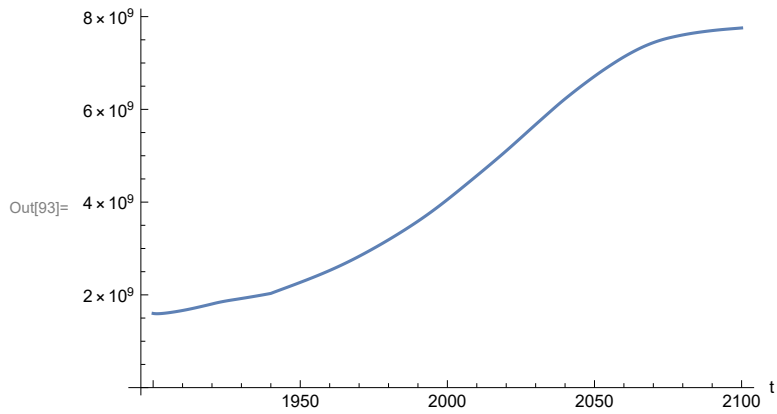
Show the value of t_air_poll_time (calendar year).

```
In[92]:= SystemModel[sevsim][{"ParameterValues", "t_air_poll_time"}]
```

```
Out[92]:= {t_air_poll_time → 4000}
```

Plot the world population, people.

```
In[93]:= SystemModelPlot[basesevsim, {"Population_Dynamics1.Birth_Rate.pop"}]
```



Find max and min of y values.

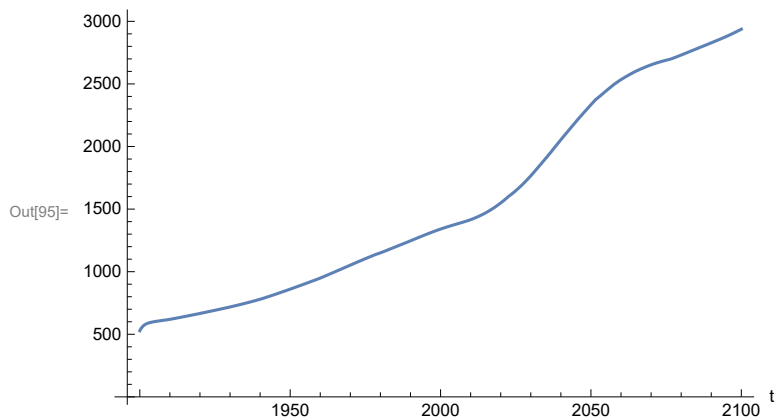
```
In[94]:= MinAndMax[basesevsim[{"Population_Dynamics1.Birth_Rate.pop"}]]
```

```
Maximum is 7.75562 × 109
```

```
Minimum is 1.59367 × 109
```

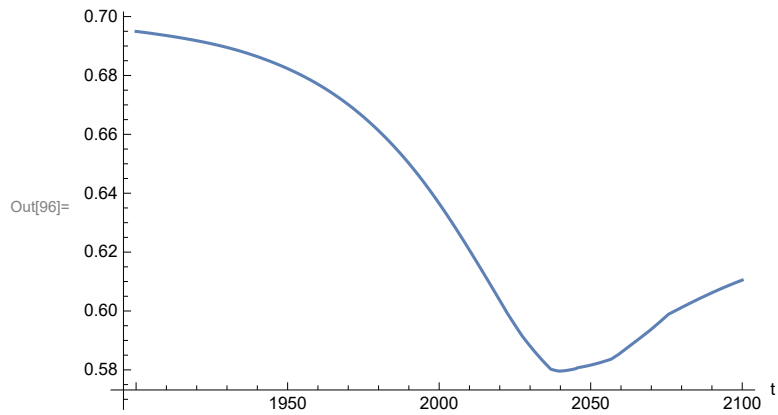
Plot land yield.

```
In[95]:= SystemModelPlot[basesevsim, {"Food_Production1.Land_Yield.y"}]
```



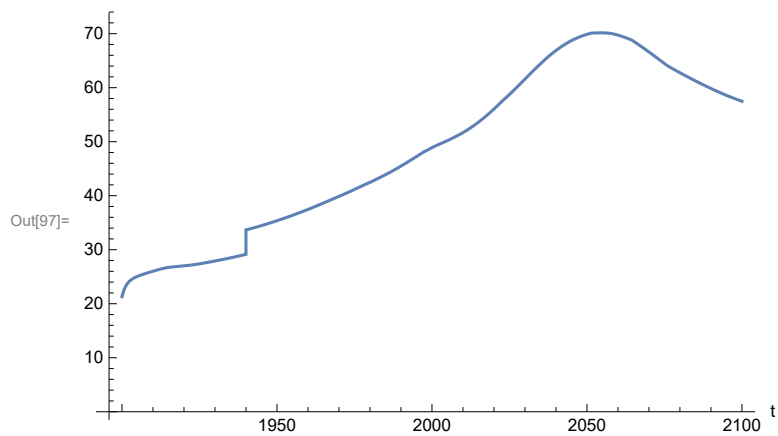
Plot multiplier of air pollution on land yield.

```
In[96]:= SystemModelPlot[basesevsim, {"Food_Production1.s_yield_mlt_air_poll"}]
```



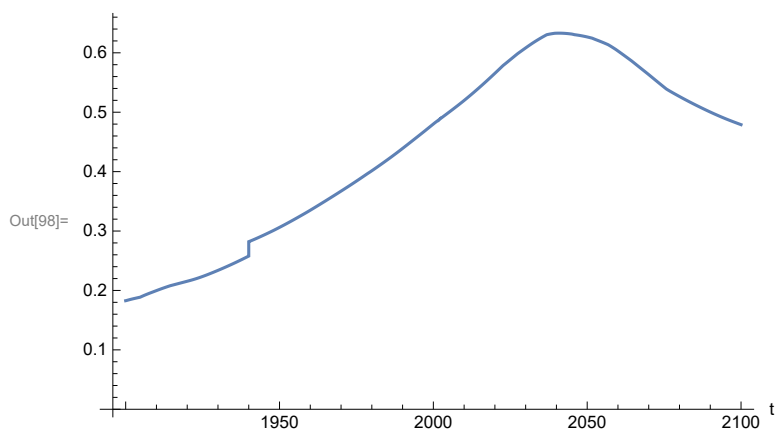
Plot life expectancy, in years.

```
In[97]:= SystemModelPlot[basesevsim, {"Life_Expectancy1.Life_Expectancy.y"}]
```



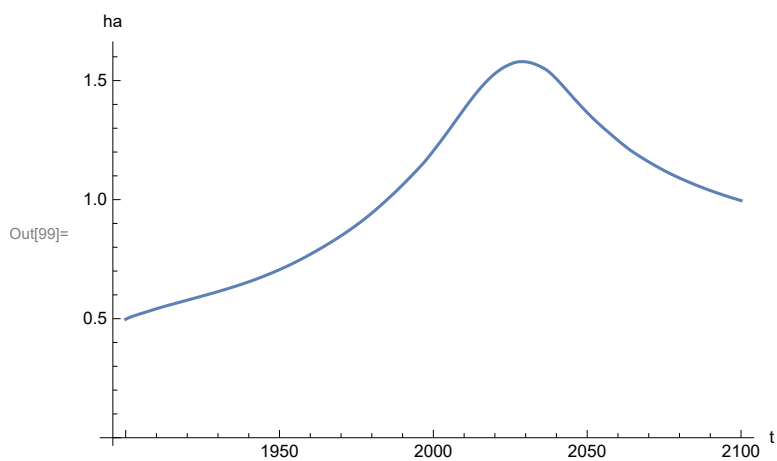
Plot the human welfare index.

```
In[98]:= SystemModelPlot[basesevsim,
  {"Human_Welfare_Index1.HWI_Human_Welfare_Index.hwi_human_welfare_index"}]
```



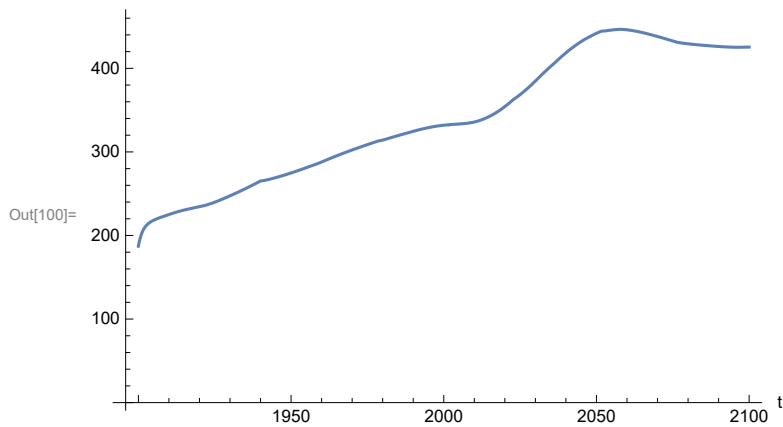
Plot the human ecological footprint, in hectares.

```
In[99]:= SystemModelPlot[basesevsim,
  {"Human_Ecological_Footprint1.HEF_Human_Ecological_Footprint.hef_human_ecological_
    _footprint"}]
```



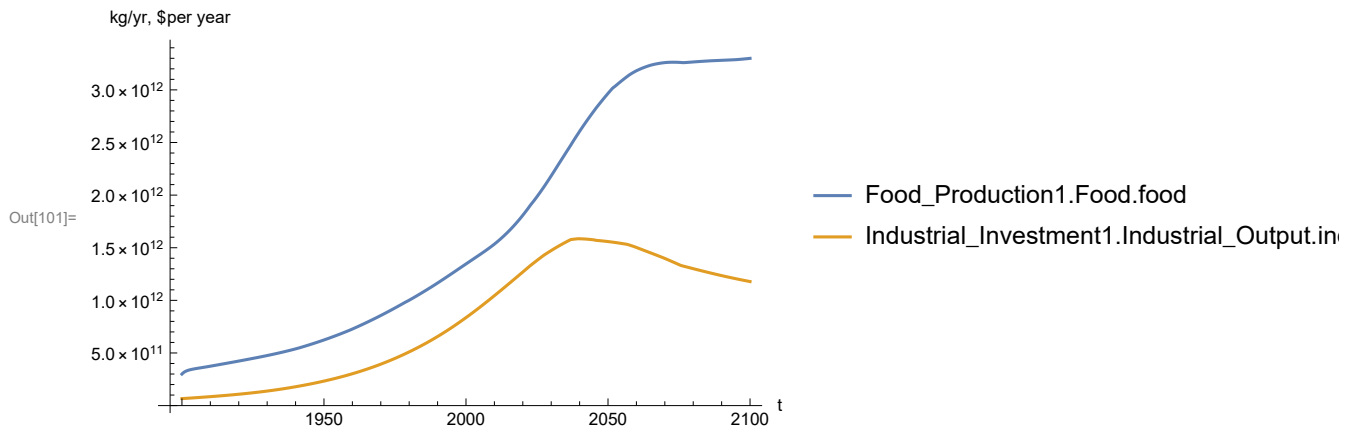
Plot per capita food production, kg/year. Note that food production per capita in 2100 has fallen to approximately the level it had in 1900 (before the rise of mechanized agriculture).

```
In[100]:= SystemModelPlot[basesevsim, {"Food_Production1.Food_PC.y"}]
```



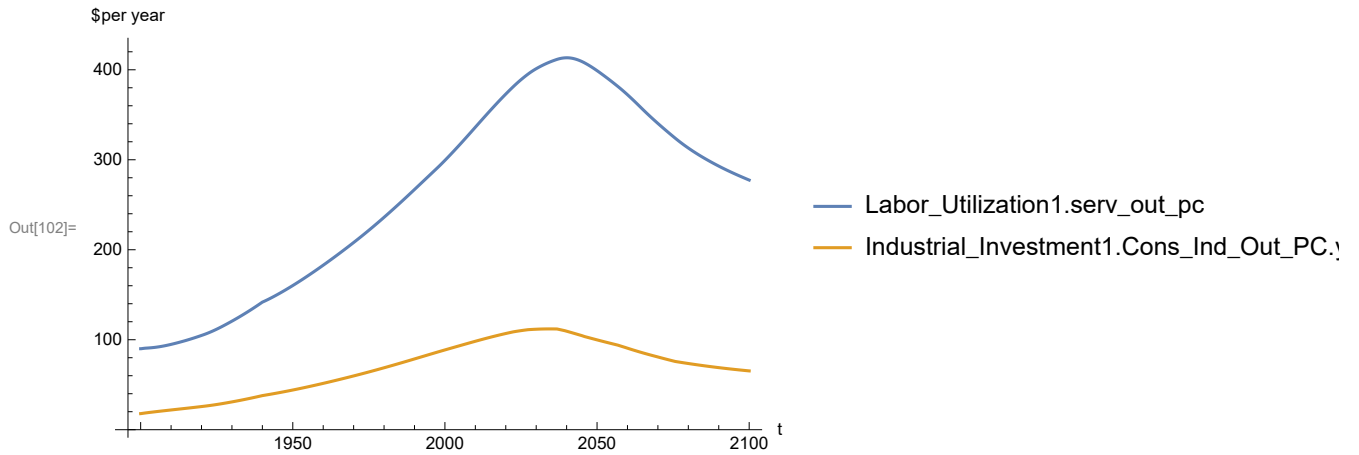
Plot total food production (kg/yr) and industrial output (in dollars).

```
In[101]:= SystemModelPlot[basesevsim, {"Food_Production1.Food.food",
  "Industrial_Investment1.Industrial_Output.industrial_output"}]
```



Plot labor utilization per capita and consolidated industrial output per capita (dollars/year).


```
In[102]:= SystemModelPlot[basesevsim,
  {"Labor_Utilization1.serv_out_pc", "Industrial_Investment1.Cons_Ind_Out_PC.y"}]
```



Find max and min of y values.

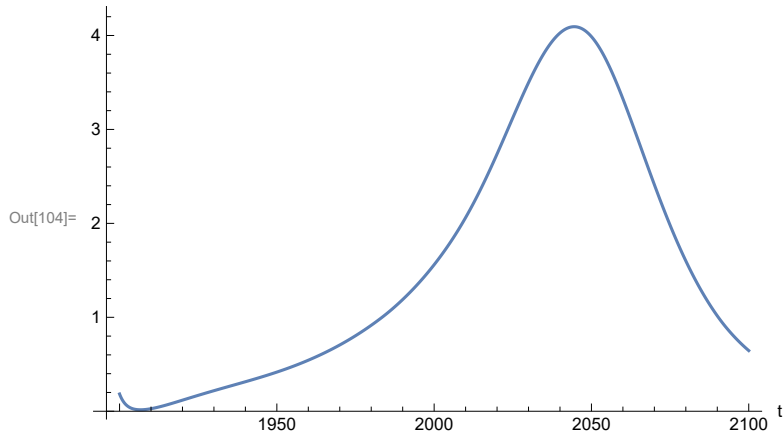
```
In[103]:= MinAndMax[basesevsim[{"Labor_Utilization1.serv_out_pc"}]]
```

Maximum is 413.328

Minimum is 90.

Plot persistent pollution index (normalized to 1970 value).

```
In[104]:= SystemModelPlot[basesevsim, {"Pollution_Dynamics1.PPoll_Index.y"}]
```



Find max and min of y values.

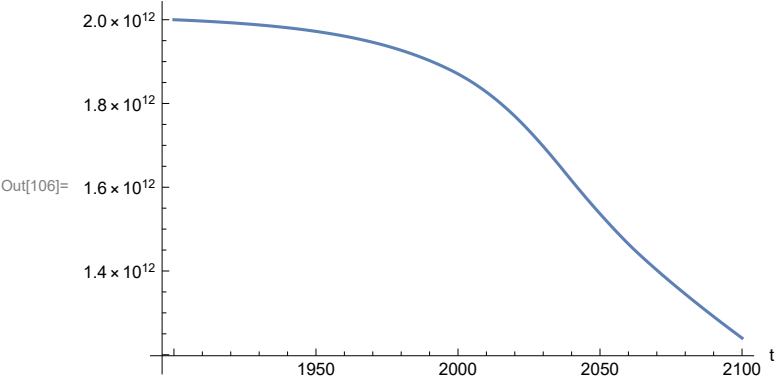
```
In[105]:= MinAndMax[basesevsim[{"Pollution_Dynamics1.PPoll_Index.y"}]]
```

Maximum is 4.0936

Minimum is 0.0157849

Plot non-renewable resources remaining.

```
In[106]:= SystemModelPlot[basesevsim, {"NR_Resource_Utilization1.NR_Resources.y"}]
```



APPENDIX 26. BENCHMARK SCENARIO 6 SIMULATIONS, Experiment 1

Define a function that extracts range data from scenario data. (The right-hand-side of this definition is specific to a *World3* data structure and assumes that the function whose range is being extracted is globally (i.e., not piecewise) defined.)

```
In[1]:= RangeData[data_] := data[[1]][[4]][[3]];
```

Define a procedure to determine and print minimum and maximum of “y” values.

```
In[2]:= MinAndMax[data_] := (myscenseries = RangeData[data];
  Print["Maximum is ", Max[myscenseries]]; Print["Minimum is ", Min[myscenseries]])
```

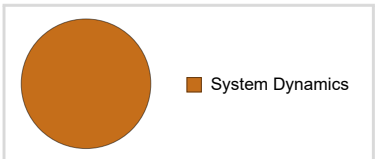
Here are some high-level properties of Benchmark Scenario 6.

```
In[3]:= mysim = SystemModel["SystemDynamics.WorldDynamics.World3.Scenario_6"]
```



```
In[4]:= mysummary = mysim["Summary"]
```

Out[4]=

ModelName	SystemDynamics.WorldDynamics.World3.Scenario_6
Description	More accessible non-recoverable natural resources, pollution control, land yield
SimulationModel	True
Plots	0
Components	106
Balanced	True
SystemEquations	1583
SystemVariables	1583
Domain	

Show the value of `t_air_poll_time`.

```
In[5]= SystemModel[mysim][{"ParameterValues", "t_air_poll_time"}]
```

```
Out[5]= {t_air_poll_time → 4000}
```

Show Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals.

```
In[6]= SystemModel[mysim][
  {"ParameterValues", "Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[1]"}]
```

```
Out[6]= {Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[1] → 1}
```

```
In[7]= SystemModel[mysim][
  {"ParameterValues", "Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[2]"}]
```

```
Out[7]= {Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[2] → 1}
```

```
In[8]= SystemModel[mysim][
  {"ParameterValues", "Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[3]"}]
```

```
Out[8]= {Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[3] → 0.7}
```

```
In[9]= SystemModel[mysim][
  {"ParameterValues", "Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[4]"}]
```

```
Out[9]= {Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[4] → 0.4}
```

Show Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_2.y_vals.

```
In[10]= SystemModel[mysim][
  {"ParameterValues", "Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_2.y_vals[1]"}]
```

```
Out[10]= {Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_2.y_vals[1] → 1}
```

```
In[11]= SystemModel[mysim][
  {"ParameterValues", "Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_2.y_vals[2]"}]
```

```
Out[11]= {Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_2.y_vals[2] → 1}
```

```
In[12]= SystemModel[mysim][
  {"ParameterValues", "Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_2.y_vals[3]"}]
```

```
Out[12]= {Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_2.y_vals[3] → 0.98}
```

```
In[13]= SystemModel[mysim][
  {"ParameterValues", "Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_2.y_vals[4]"}]
```

```
Out[13]= {Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_2.y_vals[4] → 0.95}
```

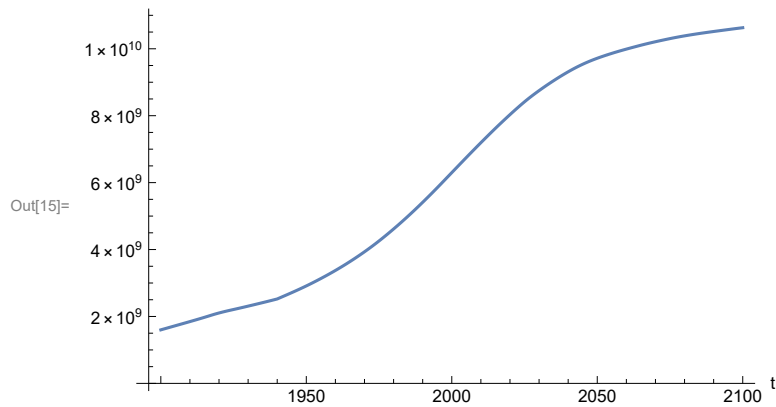
Execute Benchmark Simulation 6 and plot the variables shown in Figure 2.

In[14]:= **basesim = SystemModelSimulate[mysim]**

Out[14]= SystemModelSimulationData [ Model: Scenario_6
Time: 1.90×10^3 to 2.10×10^3]

Plot total population, people.

In[15]:= **SystemModelPlot[basesim, {"Population_Dynamics1.Birth_Rate.pop"}]**



Find max and min of population values.

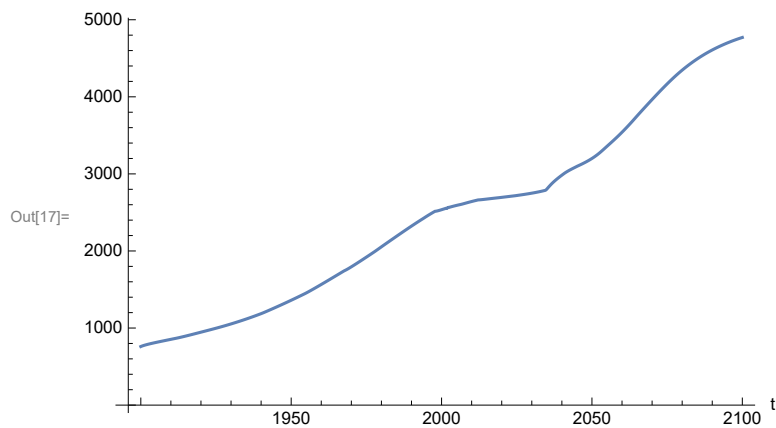
In[16]:= **MinAndMax[basesim[{"Population_Dynamics1.Birth_Rate.pop"}]]**

Maximum is 1.06293×10^{10}

Minimum is 1.6×10^9

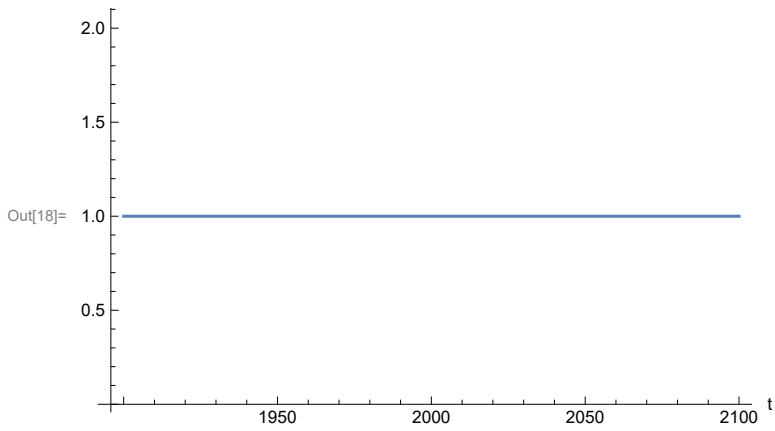
Plot land yield.

In[17]:= **SystemModelPlot[basesim, {"Food_Production1.Land_Yield.y"}]**



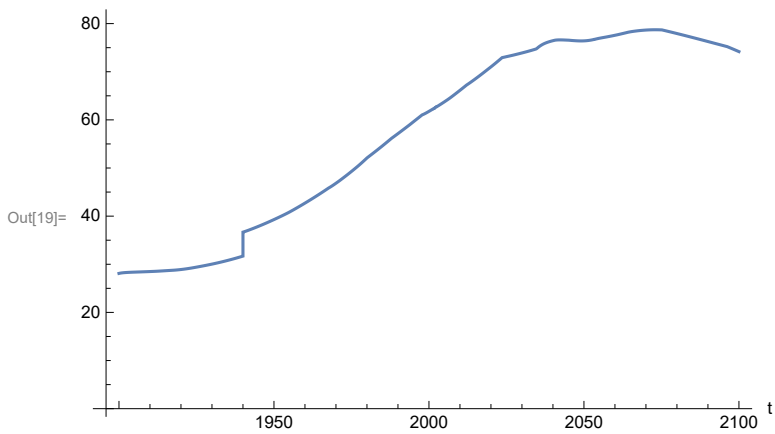
Plot multiplier of air pollution on land yield.

```
In[18]:= SystemModelPlot[basesim, {"Food_Production1.s_yield_mlt_air_poll"}]
```



Plot life expectancy, years.

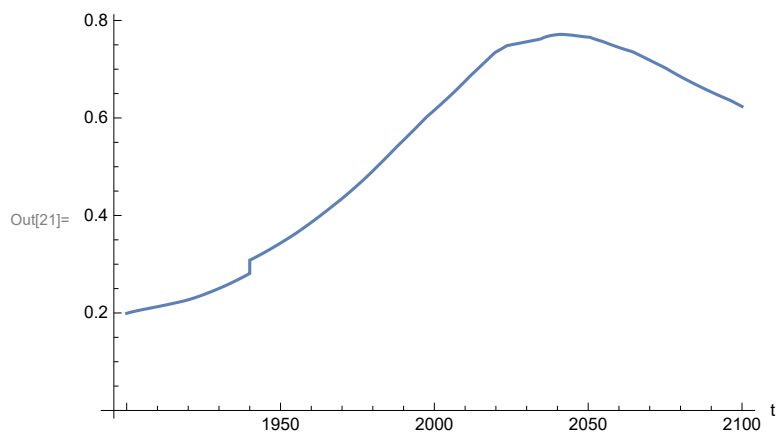
```
In[19]:= SystemModelPlot[basesim, {"Life_Expectancy1.Life_Expectancy.y"}]
```



```
In[20]:=
```

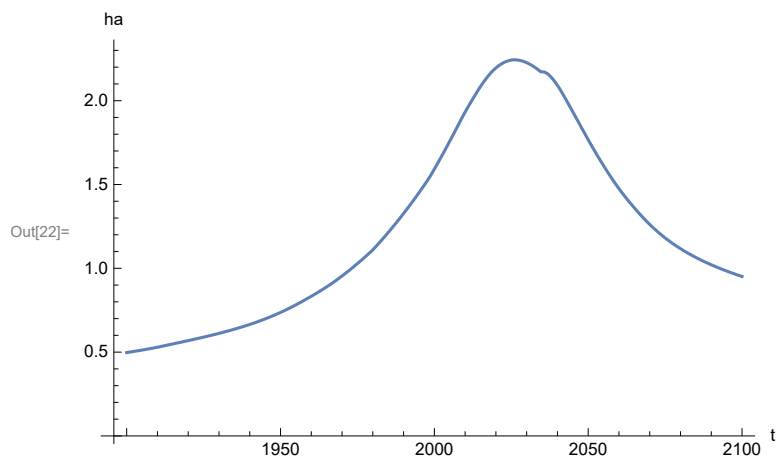
Plot human welfare index.

```
In[21]:= SystemModelPlot[basesim,
  {"Human_Welfare_Index1.HWI_Human_Welfare_Index.hwi_human_welfare_index"}]
```



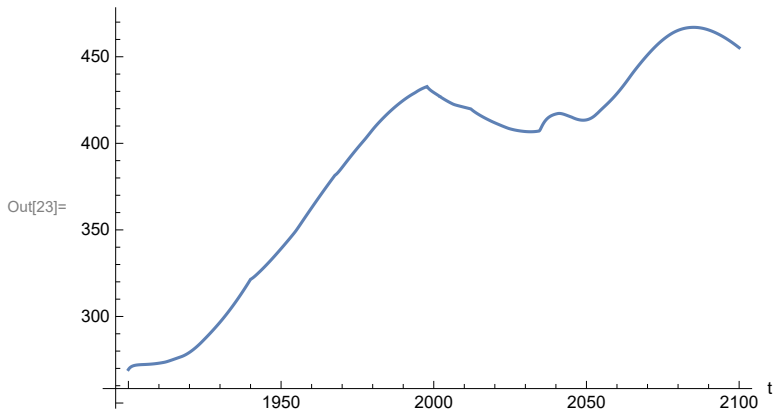
Plot per capita ecological footprint, hectares.

```
In[22]:= SystemModelPlot[basesim,
  {"Human_Ecological_Footprint1.HEF_Human_Ecological_Footprint.hef_human_ecological_
    _footprint"}]
```



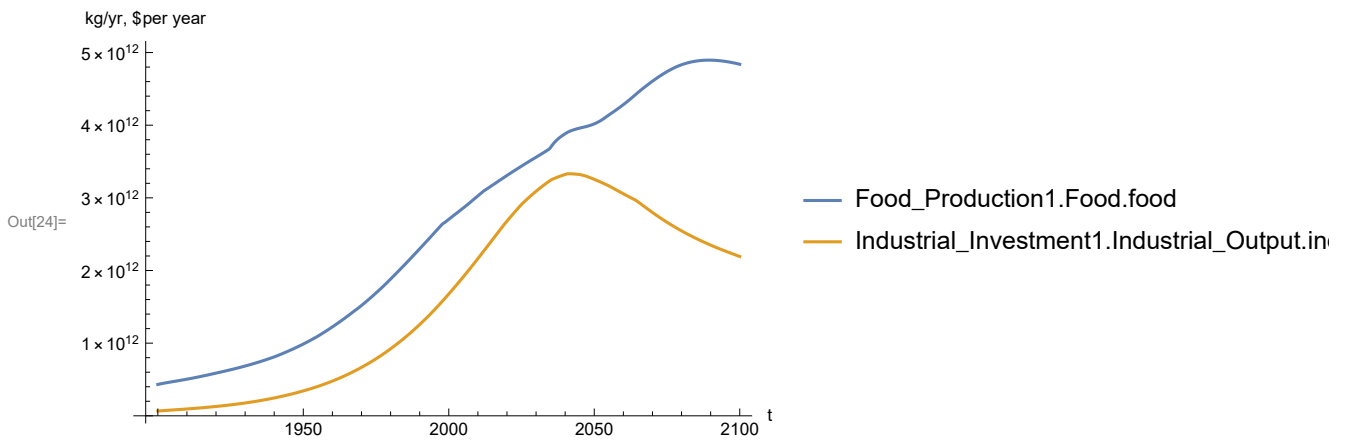
Plot food production per capita (kg/year).

In[23]:= `SystemModelPlot[basesim, {"Food_Production1.Food_PC.y"}]`



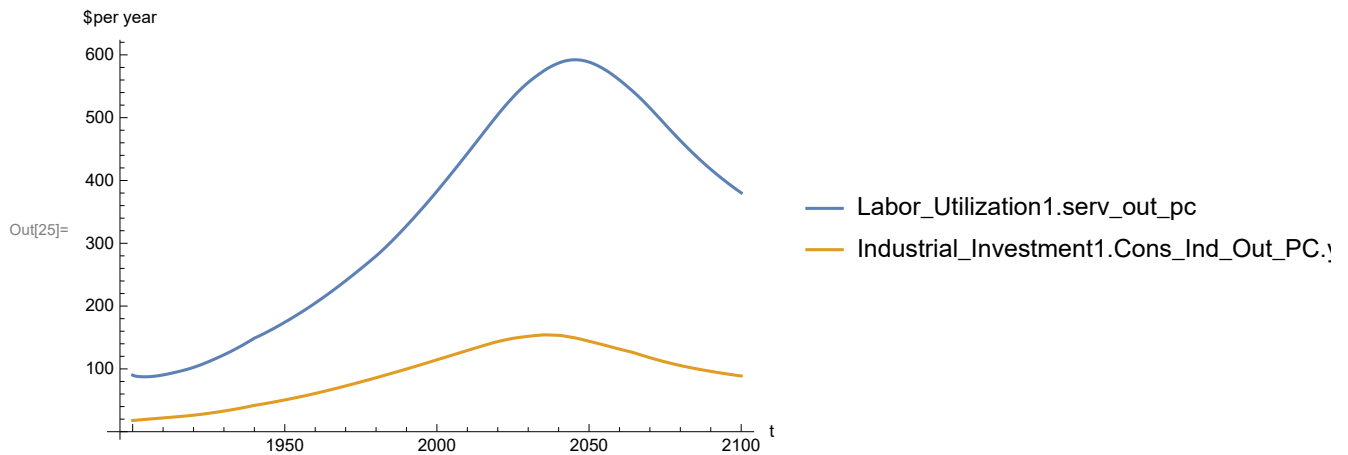
Plot total food production (kg/year), and industrial output (dollars/year).

In[24]:= `SystemModelPlot[basesim, {"Food_Production1.Food.food", "Industrial_Investment1.Industrial_Output.industrial_output"}]`



Plot labor utilization per capita (dollars/year), and consolidated industrial output per capita (dollars/year)


```
In[25]:= SystemModelPlot[basesim,
  {"Labor_Utilization1.serv_out_pc", "Industrial_Investment1.Cons_Ind_Out_PC.y"}]
```



Find max and min of y values.

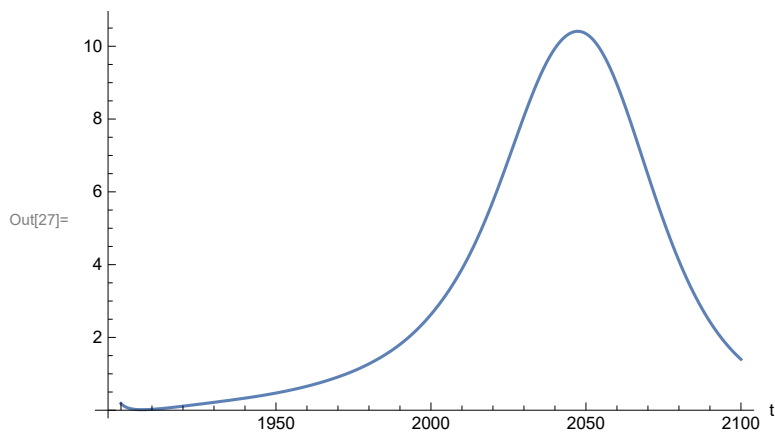
```
In[26]:= MinAndMax[basesim[{"Labor_Utilization1.serv_out_pc"}]]
```

Maximum is 592.187

Minimum is 87.4451

Plot persistent pollution index.

```
In[27]:= SystemModelPlot[basesim, {"Pollution_Dynamics1.PPoll_Index.y"}]
```



Find max and min of y values.

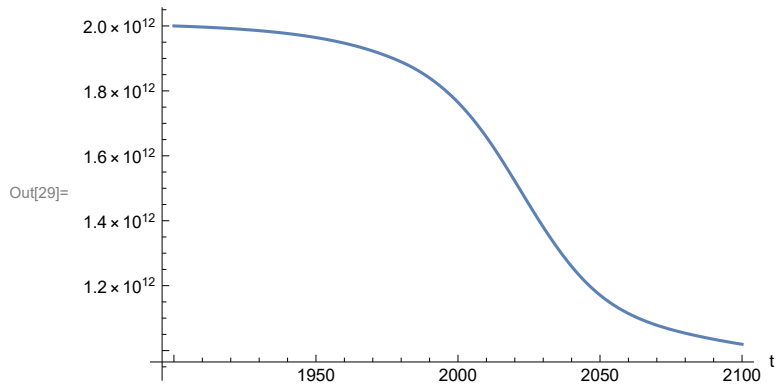
```
In[28]:= MinAndMax[basesim[{"Pollution_Dynamics1.PPoll_Index.y"}]]
```

Maximum is 10.4113

Minimum is 0.0150765

Plot non-renewable resources remaining.

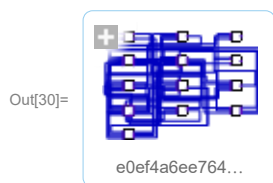
In[29]:= SystemModelPlot[basesim, {"NR_Resource_Utilization1.NR_Resources.y"}]



APPENDIX 27. Effects of mitigating the impact of air pollution on agricultural land yield, beginning calendar year 2020, Scenario 6, Experiment 2

Change the value of the air pollution effect multiplier switch time `t_air_poll_time`, to calendar year 2020, and execute the resulting scenario, plotting the variables shown in Figure 2.

```
In[30]:= newmysim = SystemModel[mysim, <|"ParameterValues" → {"t_air_poll_time" → 2020}|>]
```



```
In[31]:= testsim = SystemModelSimulate[newmysim]
```

Out[31]= SystemModelSimulationData [  Model: We0ef4a6ee76442e8bb0db35e3a3c905e
Time: 1.90×10^3 to 2.10×10^3]

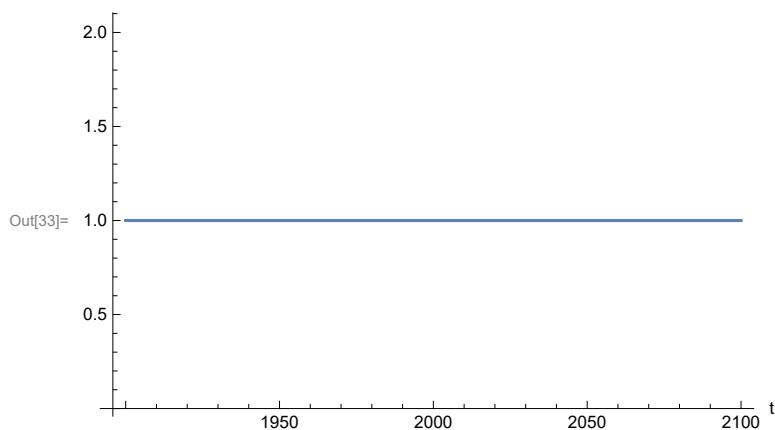
Show the value of `t_air_poll_time` (calendar year).

```
In[32]:= SystemModel[newmysim][{"ParameterValues", "t_air_poll_time"}]
```

Out[32]= {t_air_poll_time → 2020}

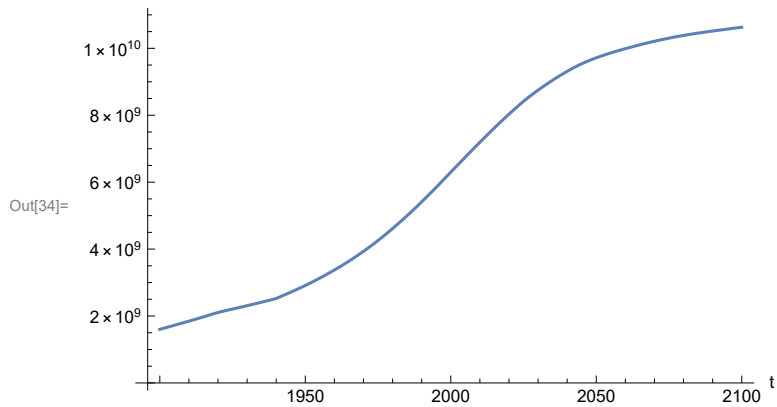
Plot air pollution multiplier of land yield.

```
In[33]:= SystemModelPlot[testsim, {"Food_Production1.s_yield_mlt_air_poll"}]
```



Plot the world population, people.

```
In[34]:= SystemModelPlot[testsim, {"Population_Dynamics1.Birth_Rate.pop"}]
```



Find max and min of y values.

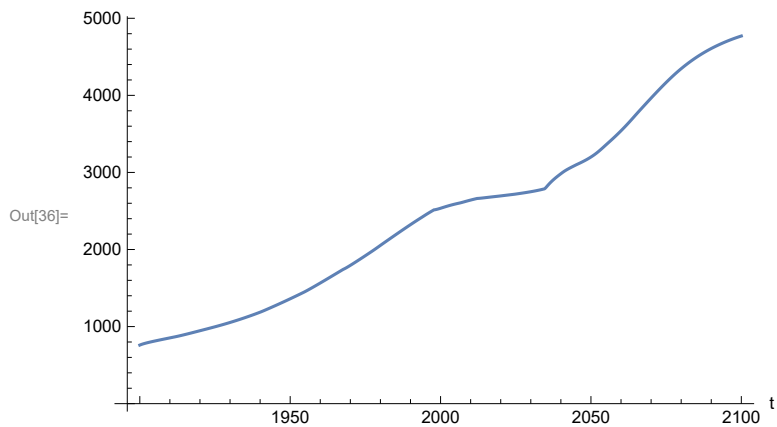
```
In[35]:= MinAndMax[testsim[{"Population_Dynamics1.Birth_Rate.pop"}]]
```

Maximum is 1.06293×10^{10}

Minimum is 1.6×10^9

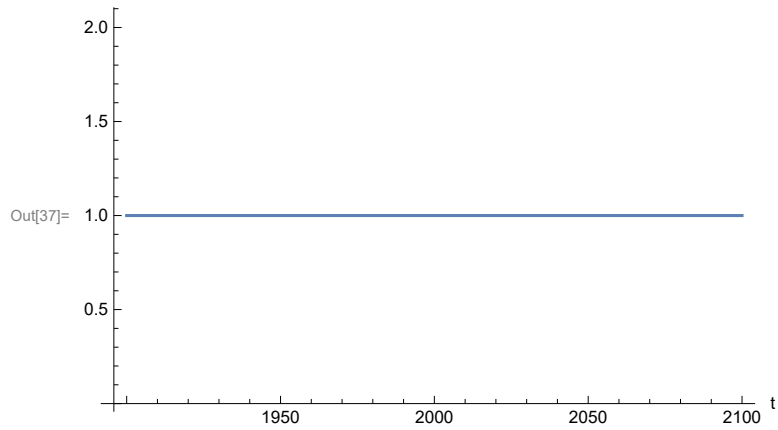
Plot land yield.

```
In[36]:= SystemModelPlot[testsim, {"Food_Production1.Land_Yield.y"}]
```



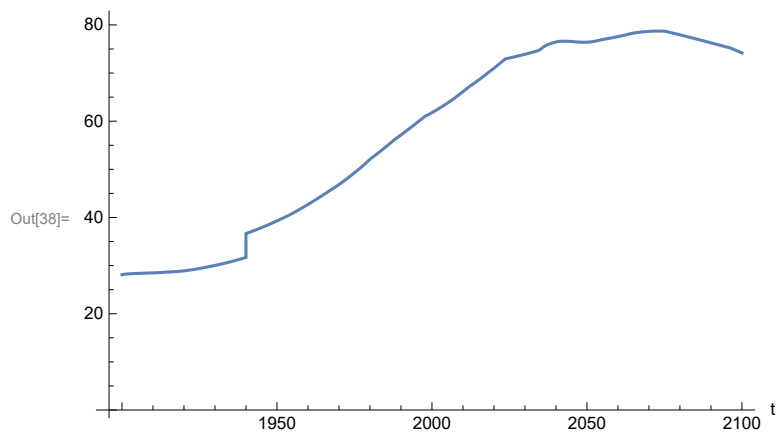
Plot multiplier of air pollution on land yield.

```
In[37]:= SystemModelPlot[testsim, {"Food_Production1.s_yield_mlt_air_poll"}]
```



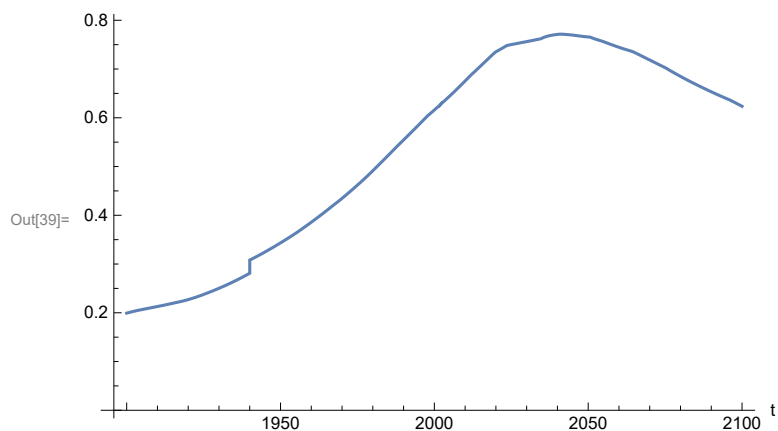
Plot life expectancy, in years.

```
In[38]:= SystemModelPlot[testsim, {"Life_Expectancy1.Life_Expectancy.y"}]
```



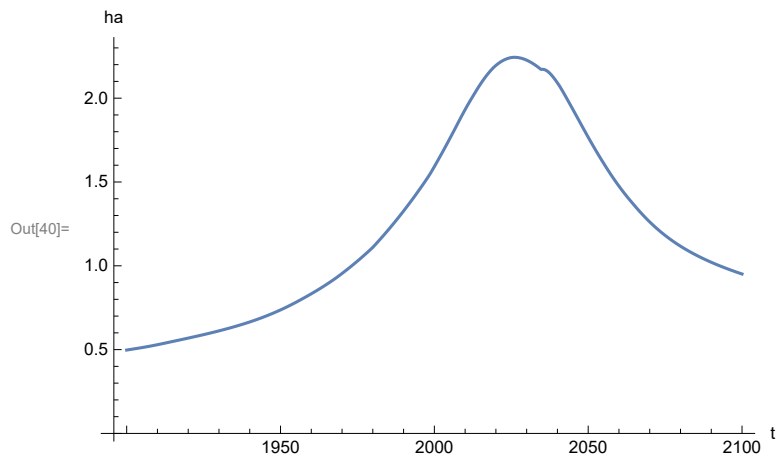
Plot the human welfare index.

```
In[39]:= SystemModelPlot[testsim, {"Human_Welfare_Index1.HWI_Human_Welfare_Index.hwi_human_welfare_index"}]
```



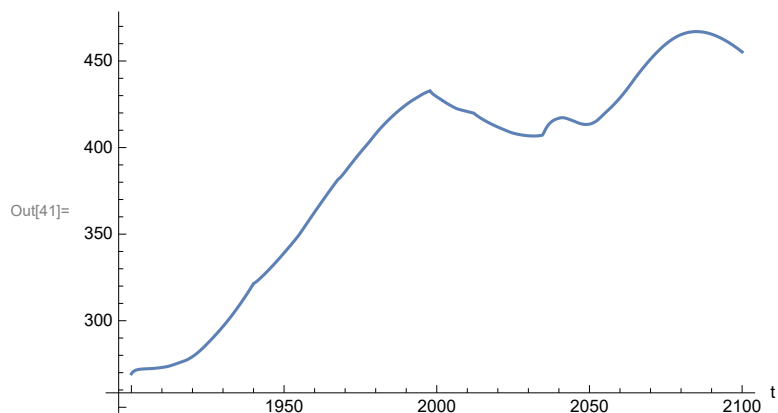
Plot the human ecological footprint, in hectares.

```
In[40]:= SystemModelPlot[testsim,
  {"Human_Ecological_Footprint1.HEF_Human_Ecological_Footprint.hef_human_ecological_
    _footprint"}]
```



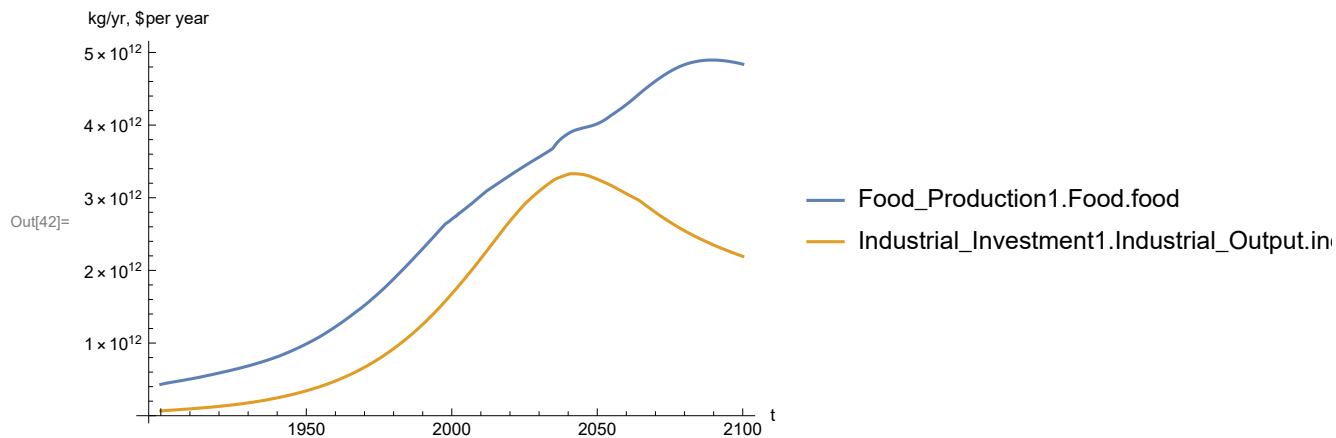
Plot per capita food production, kg/year.

```
In[41]:= SystemModelPlot[testsim, {"Food_Production1.Food_PC.y"}]
```



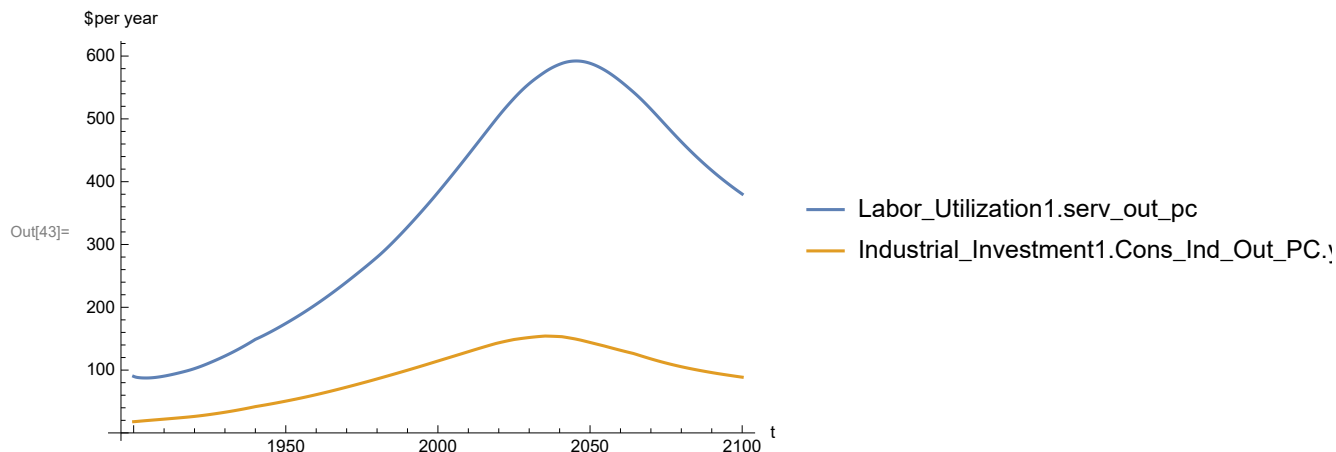
Plot total food production (kg/yr) and industrial output (in dollars).

```
In[42]:= SystemModelPlot[testsim, {"Food_Production1.Food.food",
  "Industrial_Investment1.Industrial_Output.industrial_output"}]
```



Plot labor utilization per capita and consolidated industrial output per capita (dollars/year).

```
In[43]:= SystemModelPlot[testsim,
  {"Labor_Utilization1.serv_out_pc", "Industrial_Investment1.Cons_Ind_Out_PC.y"}]
```



Find max and min of y values.

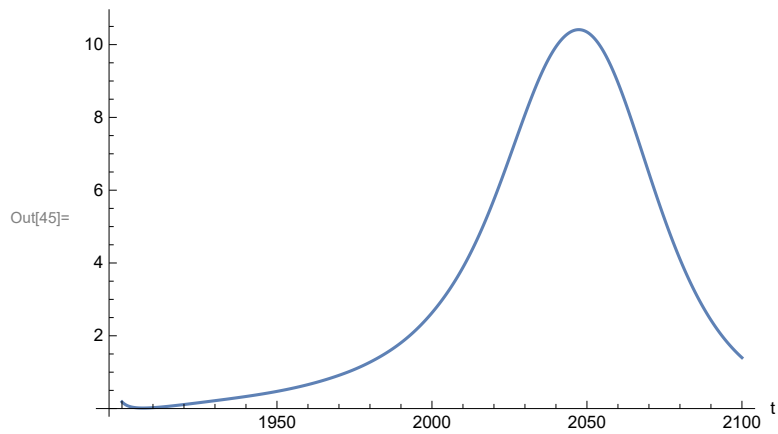
```
In[44]:= MinAndMax[testsim[{"Labor_Utilization1.serv_out_pc"}]]
```

Maximum is 592.186

Minimum is 87.4451

Plot persistent pollution index (normalized to 1970 value).

```
In[45]:= SystemModelPlot[testsim, {"Pollution_Dynamics1.PPoll_Index.y"}]
```



Find max and min of y values.

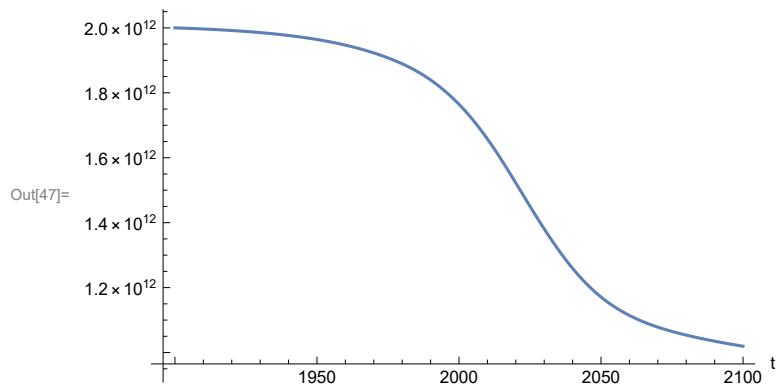
```
In[46]:= MinAndMax[testsim[{"Pollution_Dynamics1.PPoll_Index.y"}]]
```

Maximum is 10.4113

Minimum is 0.0150765

Plot non-renewable resources remaining.

```
In[47]:= SystemModelPlot[testsim, {"NR_Resource_Utilization1.NR_Resources.y"}]
```



APPENDIX 28. Effects of mitigating the impact of air pollution on agricultural land yield, beginning calendar year 1970, Scenario 6, Experiment 3

Change the value of the air pollution effect multiplier switch time $t_{\text{air_poll_time}}$, to calendar year 1970, and execute the resulting scenario, plotting the variables shown in Figure 2.

```
In[48]:= newmysim1970 = SystemModel[mysim, <|"ParameterValues" → {"t_air_poll_time" → 1970} |>]
```



```
In[49]:= testsim1970 = SystemModelSimulate[newmysim1970]
```

Out[49]= SystemModelSimulationData [ Model: W6201224556af453b967389b0c2147595
Time: 1.90×10^3 to 2.10×10^3]

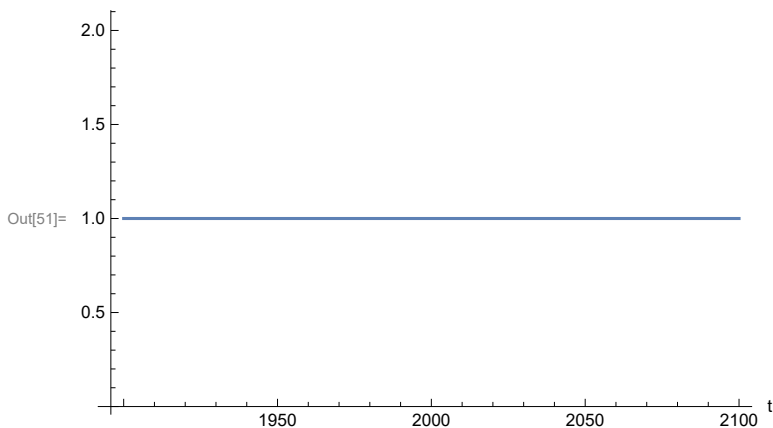
Show the value of $t_{\text{air_poll_time}}$ (calendar year).

```
In[50]:= SystemModel[newmysim1970][{"ParameterValues", "t_air_poll_time"}]
```

Out[50]= {t_air_poll_time → 1970}

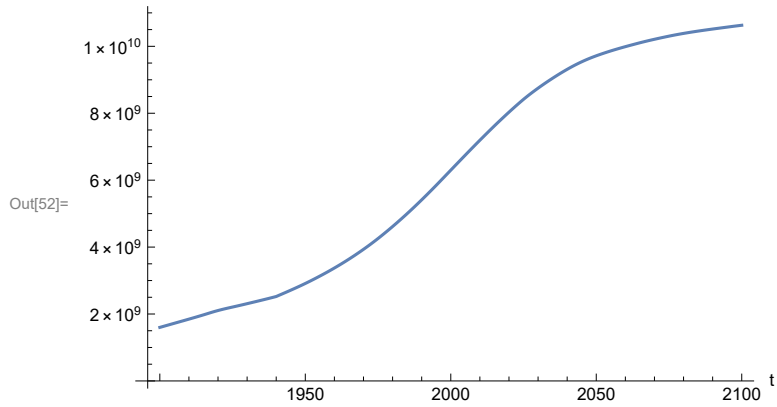
Plot air pollution multiplier of land yield.

```
In[51]:= SystemModelPlot[testsim1970, {"Food_Production1.s_yield_mlt_air_poll"}]
```



Plot the world population, people.

```
In[52]:= SystemModelPlot[testsim1970, {"Population_Dynamics1.Birth_Rate.pop"}]
```



Find max and min of y values.

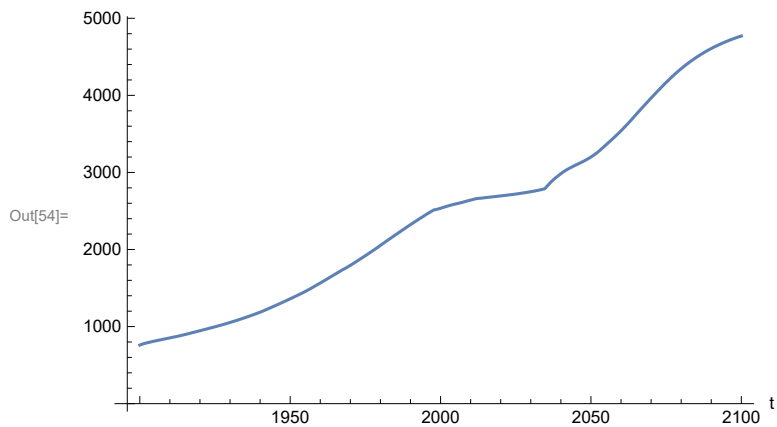
```
In[53]:= MinAndMax[testsim1970[{"Population_Dynamics1.Birth_Rate.pop"}]]
```

Maximum is 1.06293×10^{10}

Minimum is 1.6×10^9

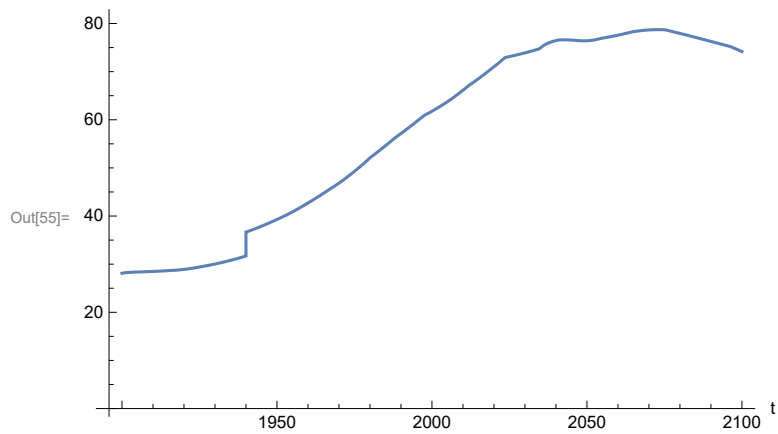
Plot land yield.

```
In[54]:= SystemModelPlot[testsim1970, {"Food_Production1.Land_Yield.y"}]
```



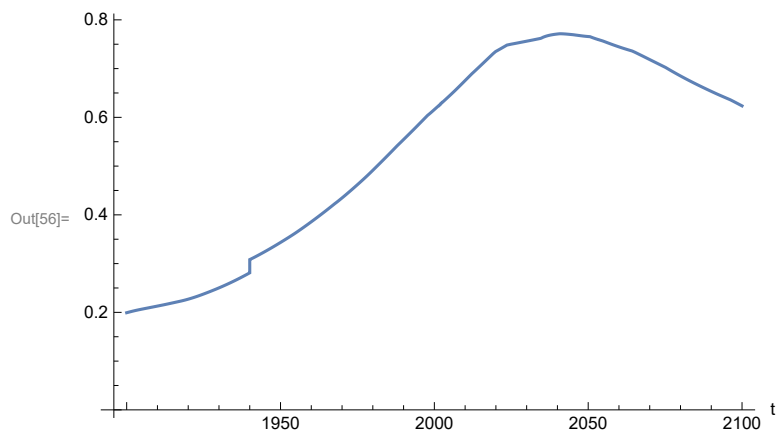
Plot life expectancy, in years.

```
In[55]:= SystemModelPlot[testsim1970, {"Life_Expectancy1.Life_Expectancy.y"}]
```



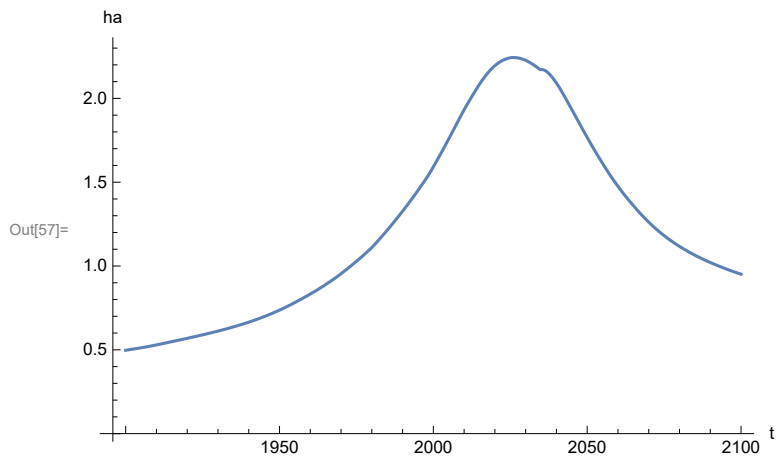
Plot the human welfare index.

```
In[56]:= SystemModelPlot[testsim1970, {"Human_Welfare_Index1.HWI_Human_Welfare_Index.hwi_human_welfare_index"}]
```



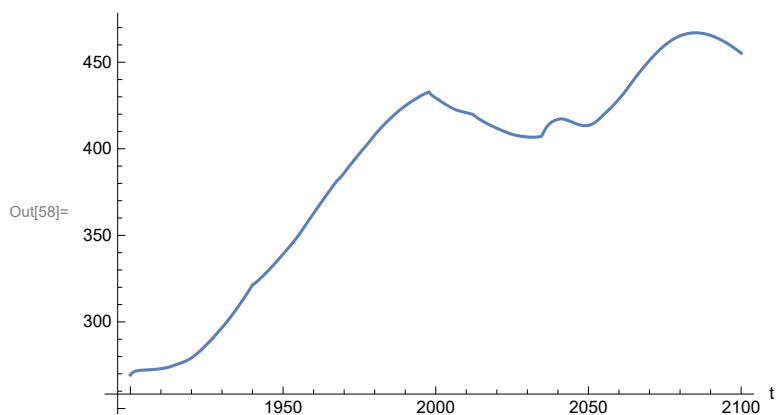
Plot the human ecological footprint, in hectares.

```
In[57]:= SystemModelPlot[testsim1970,
  {"Human_Ecological_Footprint1.HEF_Human_Ecological_Footprint.hef_human_ecological_
    _footprint"}]
```



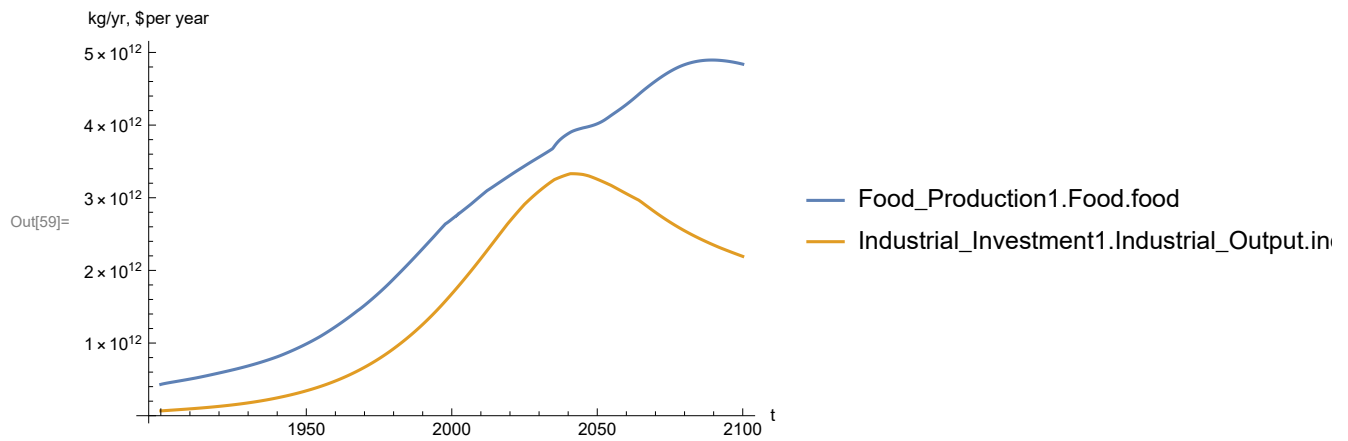
Plot per capita food production, kg/year.

```
In[58]:= SystemModelPlot[testsim1970, {"Food_Production1.Food_PC.y"}]
```



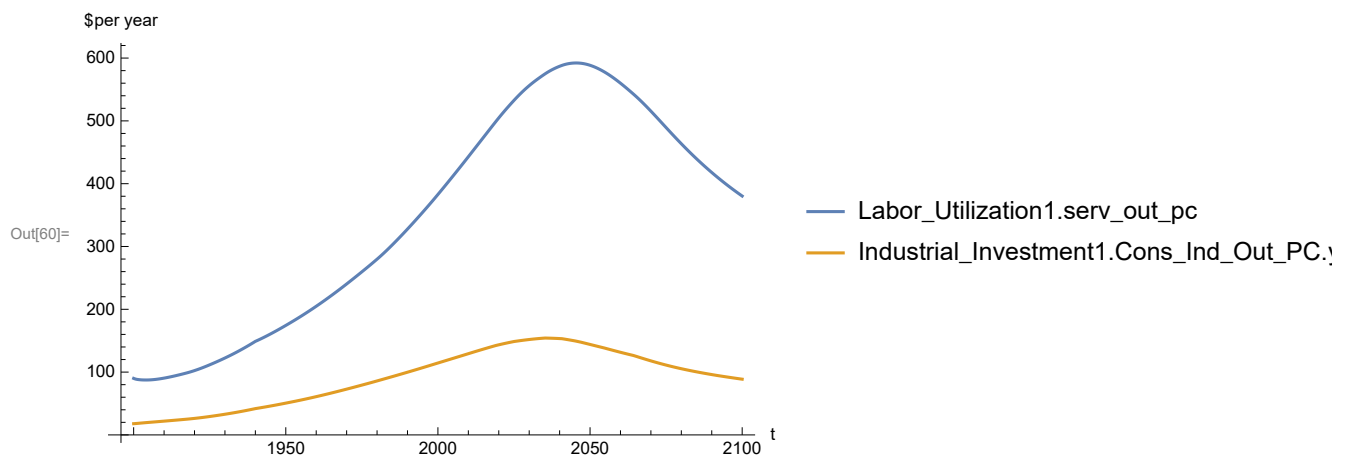
Plot total food production (kg/yr) and industrial output (in dollars).

```
In[59]:= SystemModelPlot[testsim1970, {"Food_Production1.Food.food",
  "Industrial_Investment1.Industrial_Output.industrial_output"}]
```



Plot labor utilization per capita and consolidated industrial output per capita (dollars/year).

```
In[60]:= SystemModelPlot[testsim1970,
  {"Labor_Utilization1.serv_out_pc", "Industrial_Investment1.Cons_Ind_Out_PC.y"}]
```



Find max and min of y values.

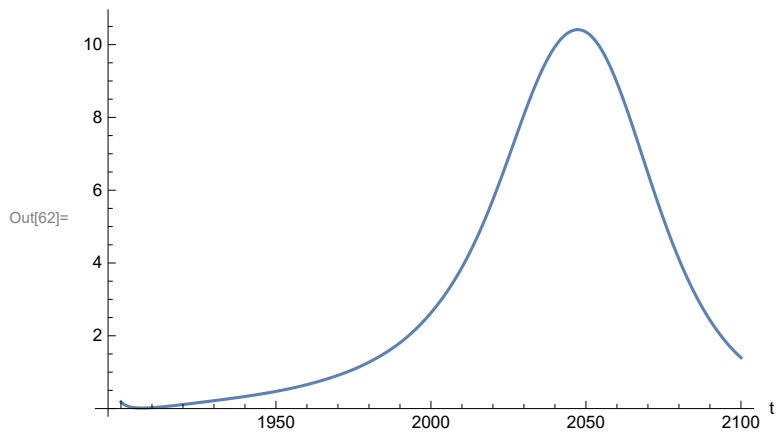
```
In[61]:= MinAndMax[testsim1970[{"Labor_Utilization1.serv_out_pc"}]]
```

Maximum is 592.186

Minimum is 87.4451

Plot persistent pollution index (normalized to 1970 value).

```
In[62]:= SystemModelPlot[testsim1970, {"Pollution_Dynamics1.PPoll_Index.y"}]
```



Find max and min of y values.

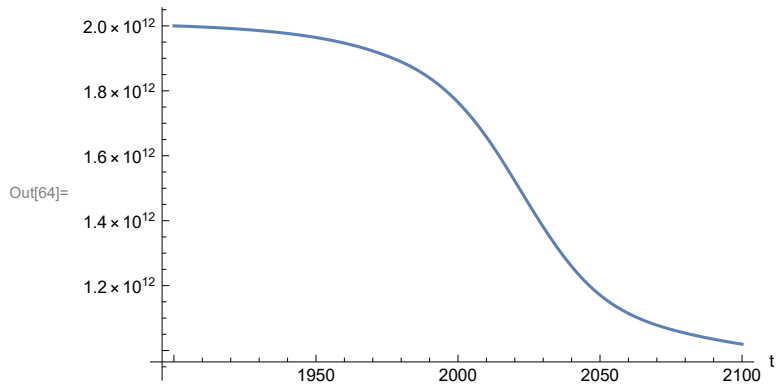
```
In[63]:= MinAndMax[testsim1970[{"Pollution_Dynamics1.PPoll_Index.y"}]]
```

Maximum is 10.4113

Minimum is 0.0150765

Plot non-renewable resources remaining.

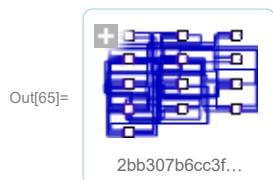
```
In[64]:= SystemModelPlot[testsim1970, {"NR_Resource_Utilization1.NR_Resources.y"}]
```



APPENDIX 29. "STRONG AIR POLLUTION" EFFECTS SCENARIO, Scenario 6, Experiment 4

Scenario 2 with air pollution effect on land yield changed as noted.

```
In[65]:= strsim = SystemModel[mysim, <|"ParameterValues" ->
      {"Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals" -> {0.7, 0.5, 0.3, 0.1}}|>]
```



```
In[66]:= basestrsim = SystemModelSimulate[strsim]
```

Out[66]= SystemModelSimulationData [ Model: W2bb307b6cc3f4d869cabdbe72ce6498d
Time: 1.90×10^3 to 2.10×10^3]

Show Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals.

```
In[67]:= SystemModel[strsim] [
      {"ParameterValues", "Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[1]"}]
```

Out[67]= {Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[1] → 0.7}

```
In[68]:= SystemModel[strsim] [
      {"ParameterValues", "Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[2]"}]
```

Out[68]= {Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[2] → 0.5}

```
In[69]:= SystemModel[strsim] [
      {"ParameterValues", "Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[3]"}]
```

Out[69]= {Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[3] → 0.3}

```
In[70]:= SystemModel[strsim] [
      {"ParameterValues", "Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[4]"}]
```

Out[70]= {Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[4] → 0.1}

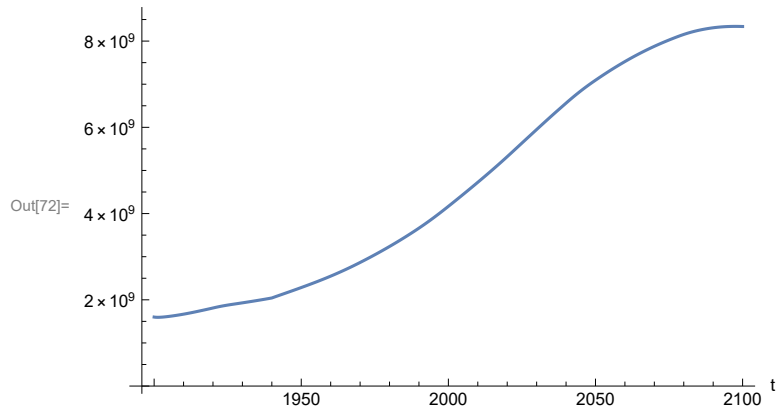
Show the value of t_air_poll_time (calendar year).

```
In[71]:= SystemModel[strsim] [{"ParameterValues", "t_air_poll_time"}]
```

Out[71]= {t_air_poll_time → 4000}

Plot the world population, people.

```
In[72]:= SystemModelPlot[basestransim, {"Population_Dynamics1.Birth_Rate.pop"}]
```



Find max and min of y values.

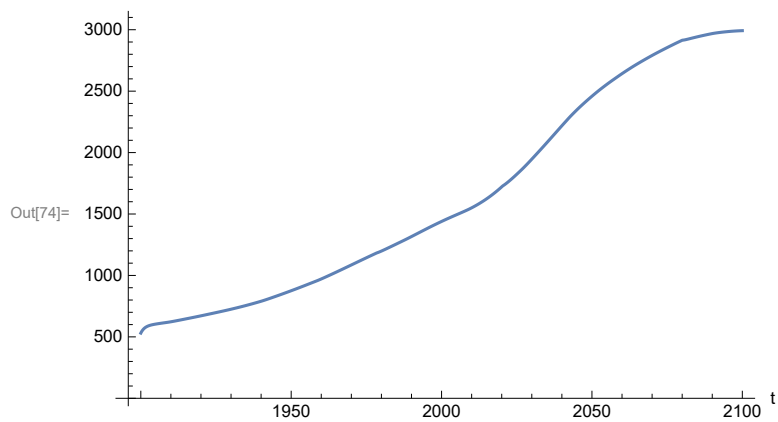
```
In[73]:= MinAndMax[basestransim[{"Population_Dynamics1.Birth_Rate.pop"}]]
```

Maximum is 8.34087×10^9

Minimum is 1.59431×10^9

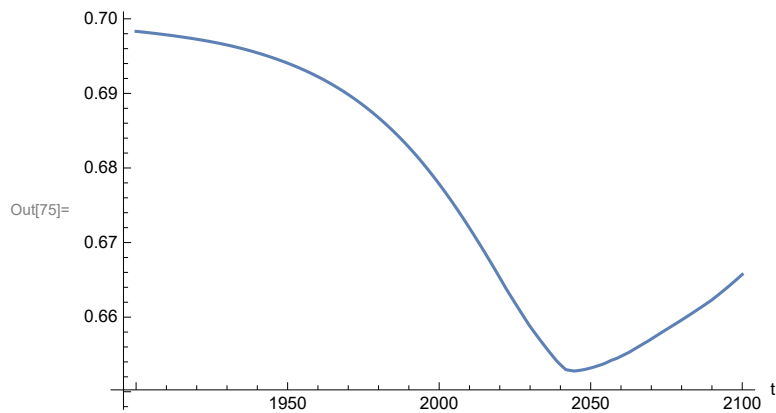
Plot land yield.

```
In[74]:= SystemModelPlot[basestransim, {"Food_Production1.Land_Yield.y"}]
```



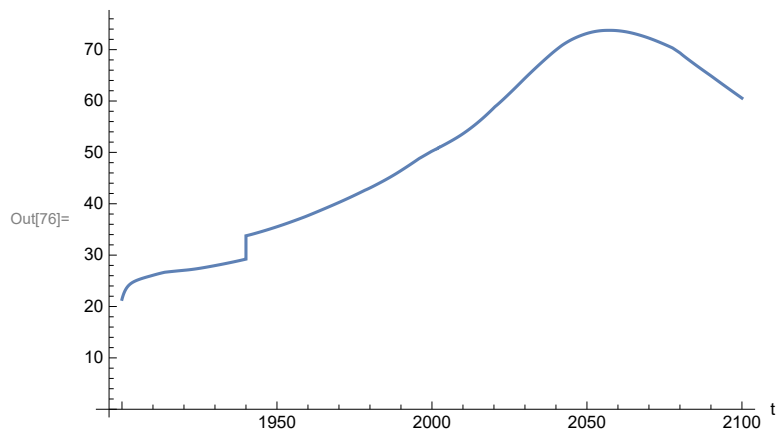
Plot multiplier of air pollution on land yield.


```
In[75]:= SystemModelPlot[basestransim, {"Food_Production1.s_yield_mlt_air_poll"}]
```



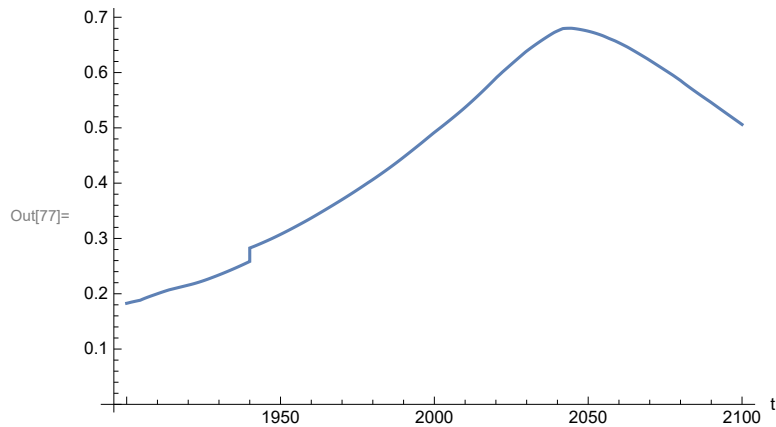
Plot life expectancy, in years.

```
In[76]:= SystemModelPlot[basestransim, {"Life_Expectancy1.Life_Expectancy.y"}]
```



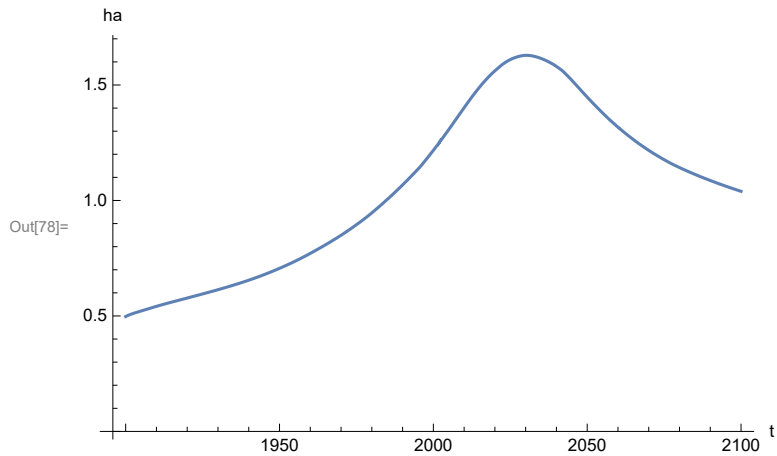
Plot the human welfare index.

```
In[77]:= SystemModelPlot[basestransim, {"Human_Welfare_Index1.HWI_Human_Welfare_Index.hwi_human_welfare_index"}]
```



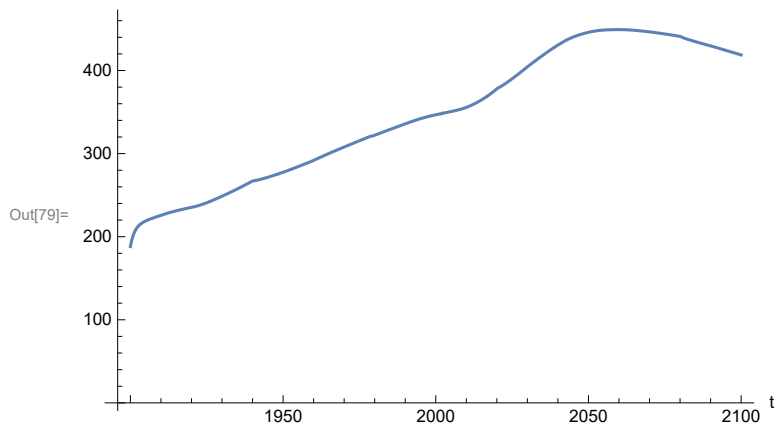
Plot the human ecological footprint, in hectares.

```
In[78]:= SystemModelPlot[basestrsim,
  {"Human_Ecological_Footprint1.HEF_Human_Ecological_Footprint.hef_human_ecological_
    _footprint"}]
```



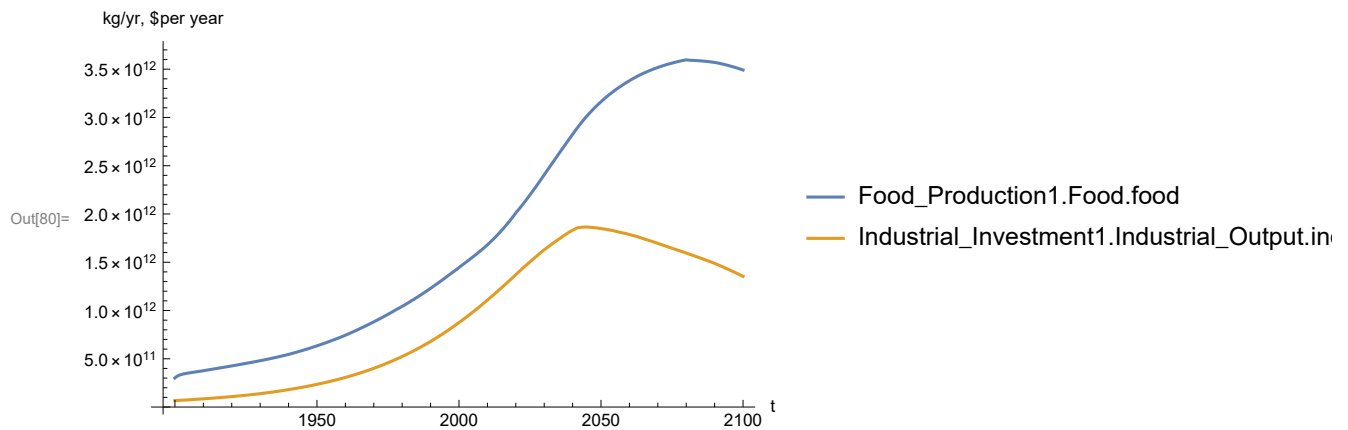
Plot per capita food production, kg/year.

```
In[79]:= SystemModelPlot[basestrsim, {"Food_Production1.Food_PC.y"}]
```



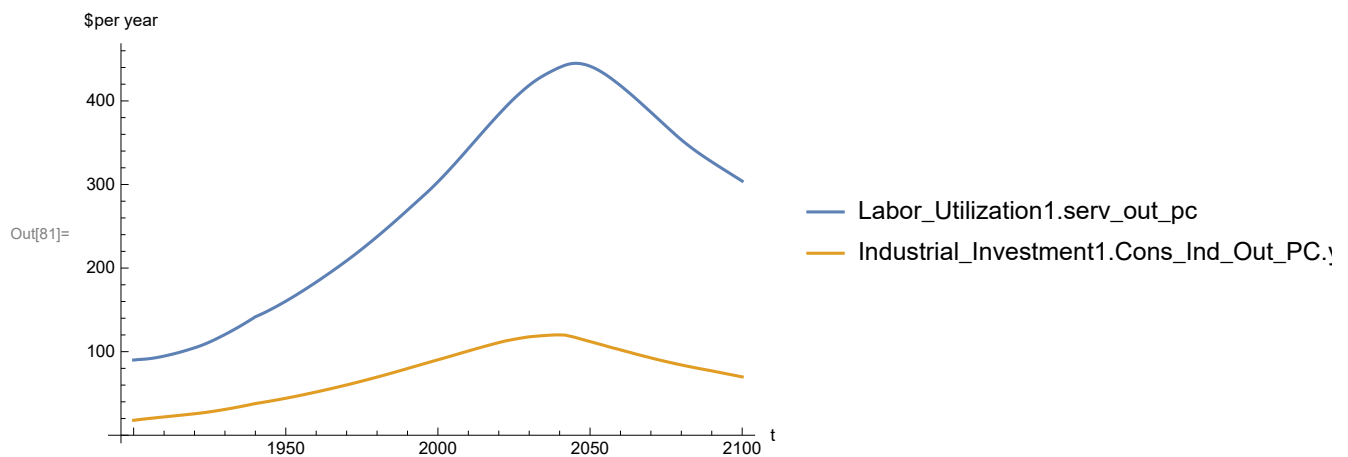
Plot total food production (kg/yr) and industrial output (in dollars).

```
In[80]:= SystemModelPlot[basestransim, {"Food_Production1.Food.food",
  "Industrial_Investment1.Industrial_Output.industrial_output"}]
```



Plot labor utilization per capita and consolidated industrial output per capita (dollars/year).

```
In[81]:= SystemModelPlot[basestransim,
  {"Labor_Utilization1.serv_out_pc", "Industrial_Investment1.Cons_Ind_Out_PC.y"}]
```



Find max and min of y values.

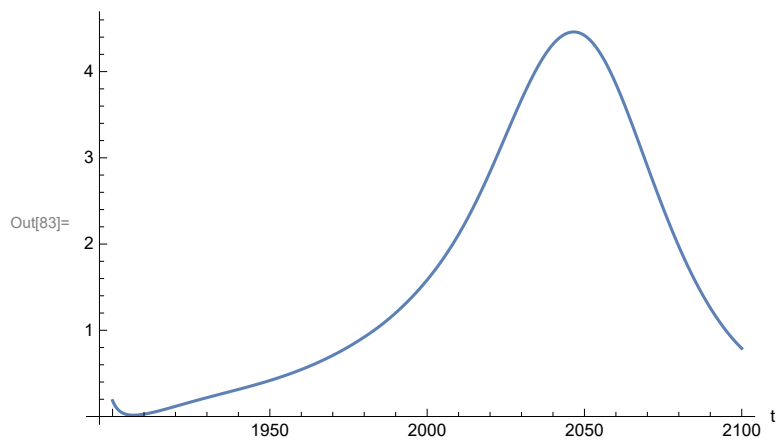
```
In[82]:= MinAndMax[basestransim[{"Labor_Utilization1.serv_out_pc"}]]
```

Maximum is 444.994

Minimum is 89.9974

Plot persistent pollution index (normalized to 1970 value).

```
In[83]:= SystemModelPlot[basestransim, {"Pollution_Dynamics1.PPoll_Index.y"}]
```



Find max and min of y values.

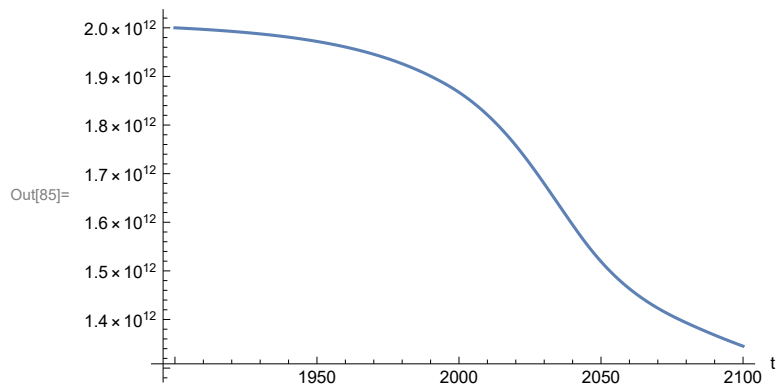
```
In[84]:= MinAndMax[basestransim[{"Pollution_Dynamics1.PPoll_Index.y"}]]
```

Maximum is 4.45998

Minimum is 0.0157768

Plot non-renewable resources remaining.

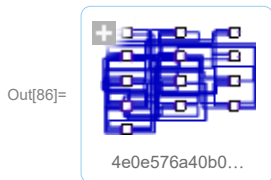
```
In[85]:= SystemModelPlot[basestransim, {"NR_Resource_Utilization1.NR_Resources.y"}]
```



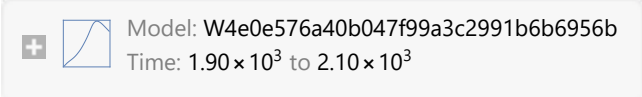
APPENDIX 30. SEVERE LAND LOSS DUE TO AIR POLLUTION, Scenario 6, Experiment 5

Scenario 6 with air pollution effect on land yield changed as noted.

```
In[86]:= sevsim = SystemModel[mysim, <|"ParameterValues" ->
      {"Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals" -> {0.7, 0.1, 0.1, 0.1}}|>]
```



```
In[87]:= basesevsim = SystemModelSimulate[sevsim]
```

Out[87]= SystemModelSimulationData [

Show Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals.

```
In[88]:= SystemModel[sevsim] [
      {"ParameterValues", "Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[1]"}]
```

Out[88]= {Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[1] → 0.7}

```
In[89]:= SystemModel[sevsim] [
      {"ParameterValues", "Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[2]"}]
```

Out[89]= {Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[2] → 0.1}

```
In[90]:= SystemModel[sevsim] [
      {"ParameterValues", "Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[3]"}]
```

Out[90]= {Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[3] → 0.1}

```
In[91]:= SystemModel[sevsim] [
      {"ParameterValues", "Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[4]"}]
```

Out[91]= {Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[4] → 0.1}

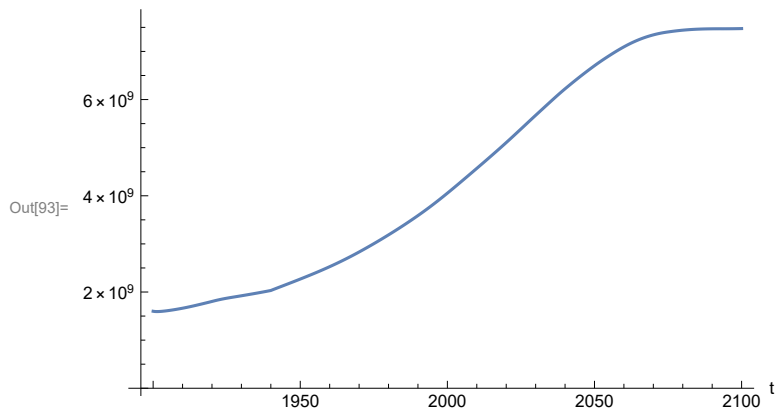
Show the value of t_air_poll_time (calendar year).

```
In[92]:= SystemModel[sevsim][{"ParameterValues", "t_air_poll_time"}]
```

```
Out[92]:= {t_air_poll_time → 4000}
```

Plot the world population, people.

```
In[93]:= SystemModelPlot[basesevsim, {"Population_Dynamics1.Birth_Rate.pop"}]
```



Find max and min of y values.

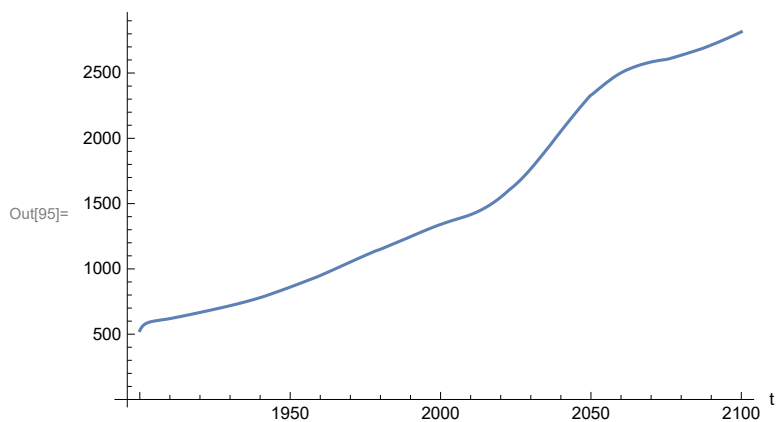
```
In[94]:= MinAndMax[basesevsim[{"Population_Dynamics1.Birth_Rate.pop"}]]
```

```
Maximum is 7.47517 × 109
```

```
Minimum is 1.59367 × 109
```

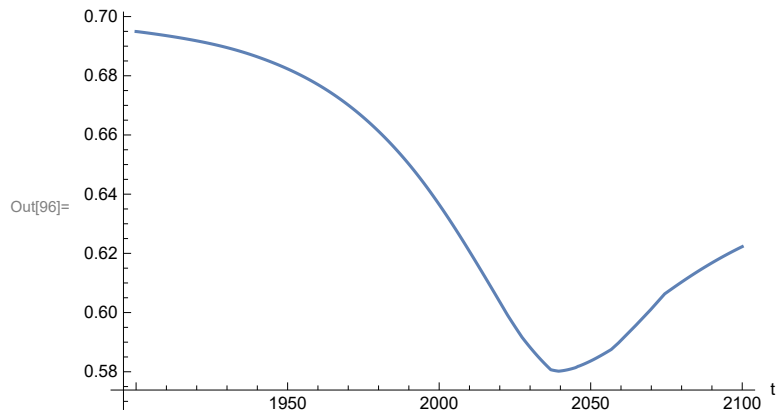
Plot land yield.

```
In[95]:= SystemModelPlot[basesevsim, {"Food_Production1.Land_Yield.y"}]
```



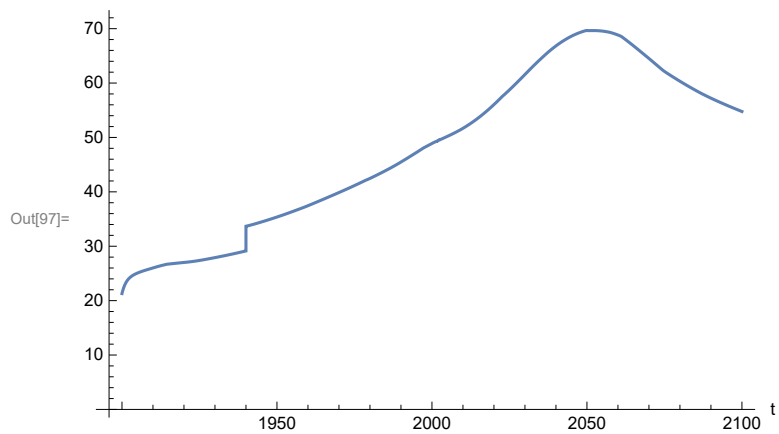
Plot multiplier of air pollution on land yield.

```
In[96]:= SystemModelPlot[basesevsim, {"Food_Production1.s_yield_mlt_air_poll"}]
```



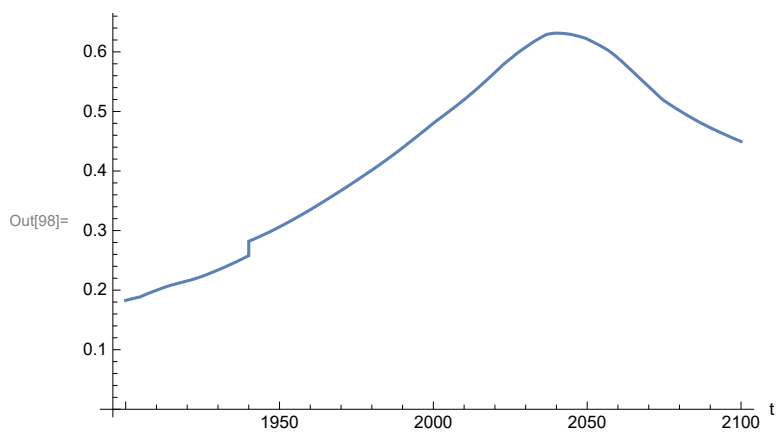
Plot life expectancy, in years.

```
In[97]:= SystemModelPlot[basesevsim, {"Life_Expectancy1.Life_Expectancy.y"}]
```



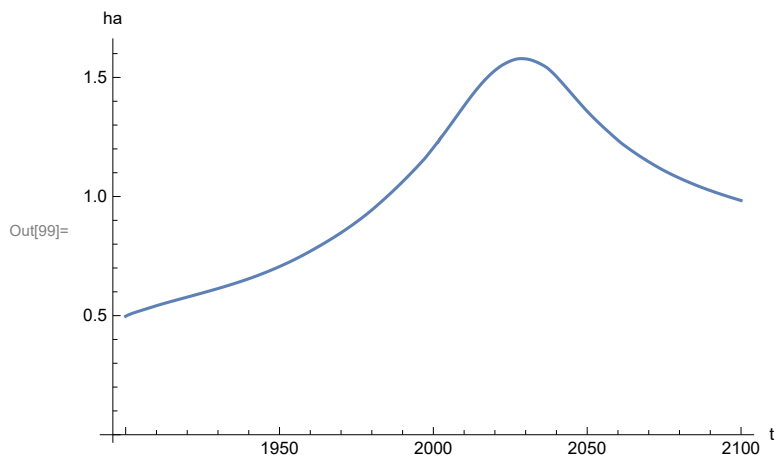
Plot the human welfare index.

```
In[98]:= SystemModelPlot[basesevsim,
  {"Human_Welfare_Index1.HWI_Human_Welfare_Index.hwi_human_welfare_index"}]
```



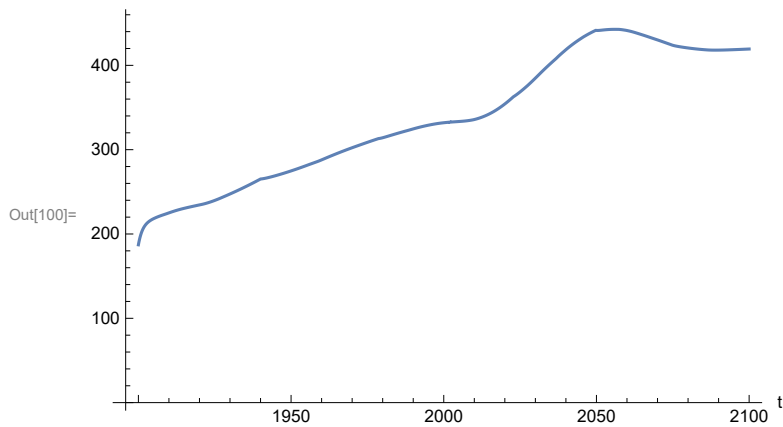
Plot the human ecological footprint, in hectares.

```
In[99]:= SystemModelPlot[basesevsim,
  {"Human_Ecological_Footprint1.HEF_Human_Ecological_Footprint.hef_human_ecological_
    _footprint"}]
```



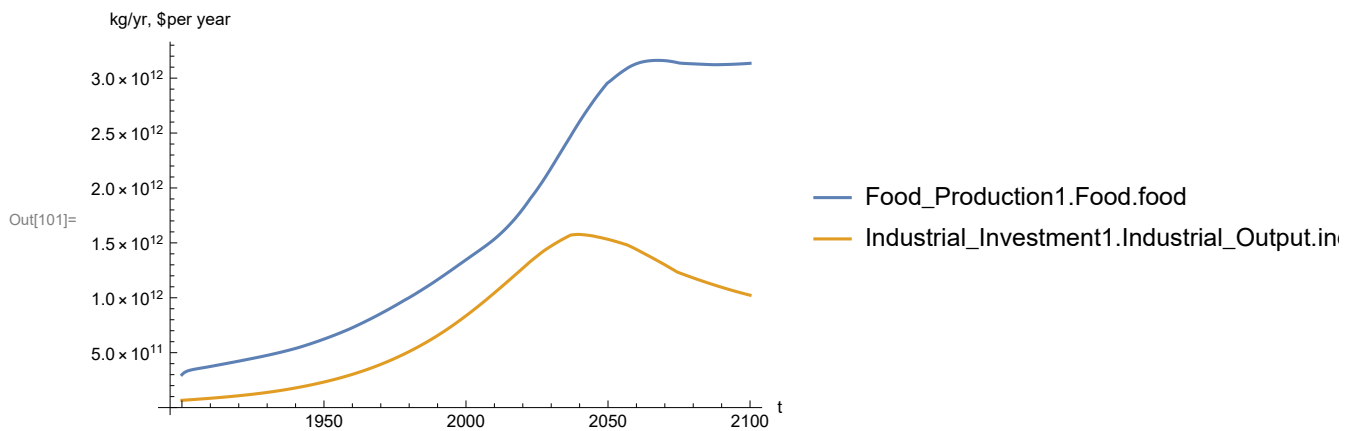
Plot per capita food production, kg/year. Note that food production per capita in 2100 has fallen to approximately the level it had in 1900 (before the rise of mechanized agriculture).


```
In[100]:= SystemModelPlot[basesevsim, {"Food_Production1.Food_PC.y"}]
```



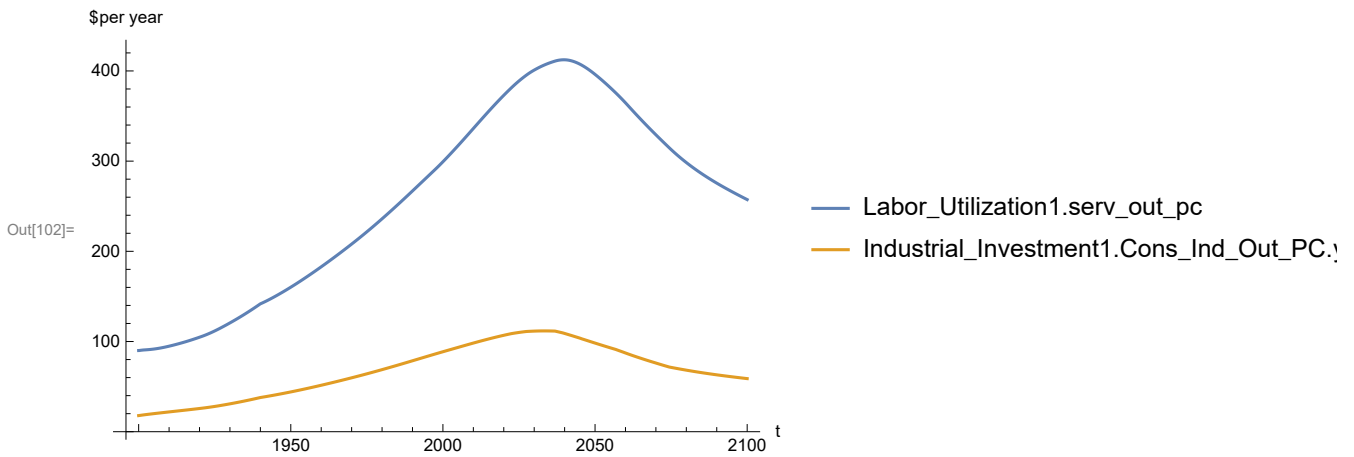
Plot total food production (kg/yr) and industrial output (in dollars).

```
In[101]:= SystemModelPlot[basesevsim, {"Food_Production1.Food.food",
  "Industrial_Investment1.Industrial_Output.industrial_output"}]
```



Plot labor utilization per capita and consolidated industrial output per capita (dollars/year).

```
In[102]:= SystemModelPlot[basesevsim,
  {"Labor_Utilization1.serv_out_pc", "Industrial_Investment1.Cons_Ind_Out_PC.y"}]
```



Find max and min of y values.

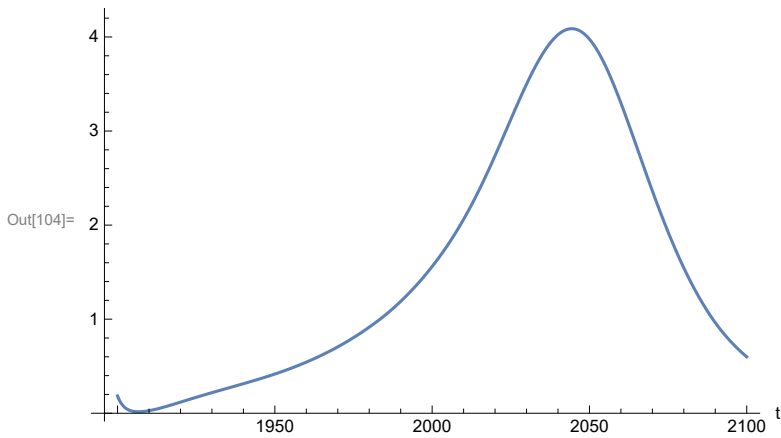
```
In[103]:= MinAndMax[basesevsim[{"Labor_Utilization1.serv_out_pc"}]]
```

Maximum is 412.371

Minimum is 90.

Plot persistent pollution index (normalized to 1970 value).

```
In[104]:= SystemModelPlot[basesevsim, {"Pollution_Dynamics1.PPoll_Index.y"}]
```



Find max and min of y values.

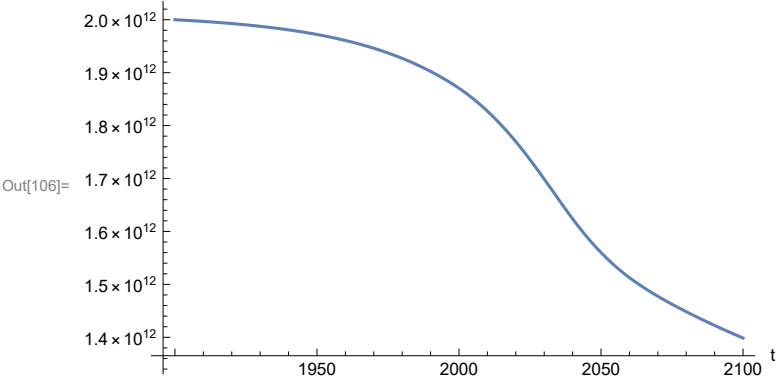
```
In[105]:= MinAndMax[basesevsim[{"Pollution_Dynamics1.PPoll_Index.y"}]]
```

Maximum is 4.08794

Minimum is 0.0157849

Plot non-renewable resources remaining.

```
In[106]:= SystemModelPlot[basesevsim, {"NR_Resource_Utilization1.NR_Resources.y"}]
```



APPENDIX 31. BENCHMARK SCENARIO 7 SIMULATIONS, Experiment 1

Define a function that extracts range data from scenario data. (The right-hand-side of this definition is specific to a *World3* data structure and assumes that the function whose range is being extracted is globally (i.e., not piecewise) defined.)

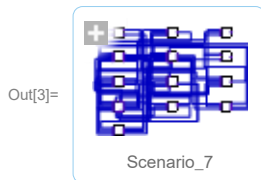
```
In[1]:= RangeData[data_] := data[[1]][[4]][[3]];
```

Define a procedure to determine and print minimum and maximum of “y” values.

```
In[2]:= MinAndMax[data_] := (myscenseries = RangeData[data];
  Print["Maximum is ", Max[myscenseries]]; Print["Minimum is ", Min[myscenseries]])
```

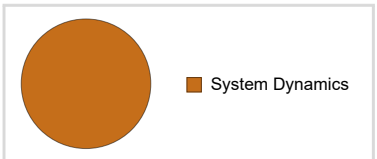
Here are some high-level properties of Benchmark Scenario 7.

```
In[3]:= mysim = SystemModel["SystemDynamics.WorldDynamics.World3.Scenario_7"]
```



```
In[4]:= mysummary = mysim["Summary"]
```

Out[4]=

ModelName	SystemDynamics.WorldDynamics.World3.Scenario_7
Description	More abundant non-recoverable natural resources and birth control
SimulationModel	True
Plots	0
Components	106
Balanced	True
SystemEquations	1583
SystemVariables	1583
Domain	

Show the value of `t_air_poll_time`.

```
In[5]= SystemModel[mysim][{"ParameterValues", "t_air_poll_time"}]
```

```
Out[5]= {t_air_poll_time → 4000}
```

Show Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals.

```
In[6]= SystemModel[mysim][
  {"ParameterValues", "Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[1]"}]
```

```
Out[6]= {Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[1] → 1}
```

```
In[7]= SystemModel[mysim][
  {"ParameterValues", "Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[2]"}]
```

```
Out[7]= {Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[2] → 1}
```

```
In[8]= SystemModel[mysim][
  {"ParameterValues", "Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[3]"}]
```

```
Out[8]= {Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[3] → 0.7}
```

```
In[9]= SystemModel[mysim][
  {"ParameterValues", "Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[4]"}]
```

```
Out[9]= {Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[4] → 0.4}
```

Show Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_2.y_vals.

```
In[10]= SystemModel[mysim][
  {"ParameterValues", "Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_2.y_vals[1]"}]
```

```
Out[10]= {Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_2.y_vals[1] → 1}
```

```
In[11]= SystemModel[mysim][
  {"ParameterValues", "Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_2.y_vals[2]"}]
```

```
Out[11]= {Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_2.y_vals[2] → 1}
```

```
In[12]= SystemModel[mysim][
  {"ParameterValues", "Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_2.y_vals[3]"}]
```

```
Out[12]= {Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_2.y_vals[3] → 0.98}
```

```
In[13]= SystemModel[mysim][
  {"ParameterValues", "Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_2.y_vals[4]"}]
```

```
Out[13]= {Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_2.y_vals[4] → 0.95}
```

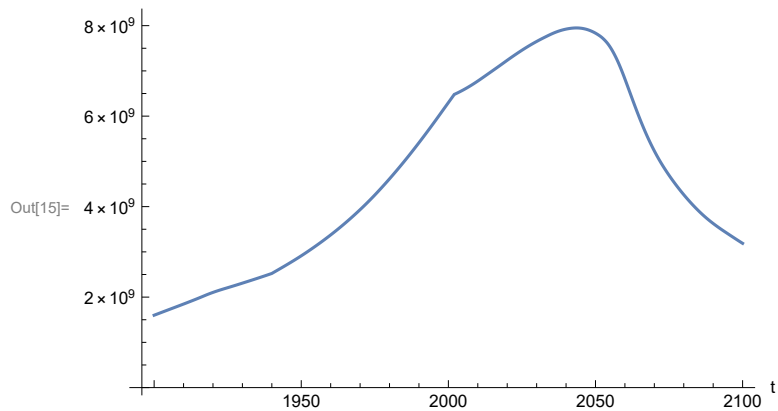
Execute Benchmark Simulation 7 and plot the variables shown in Figure 2.

In[14]:= **basesim = SystemModelSimulate[mysim]**

Out[14]= SystemModelSimulationData [ Model: Scenario_7
Time: 1.90×10^3 to 2.10×10^3]

Plot total population, people.

In[15]:= **SystemModelPlot[basesim, {"Population_Dynamics1.Birth_Rate.pop"}]**



Find max and min of population values.

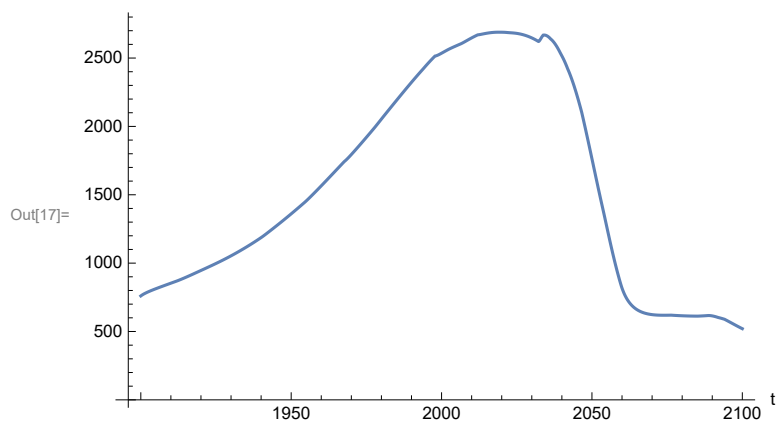
In[16]:= **MinAndMax[basesim[{"Population_Dynamics1.Birth_Rate.pop"}]]**

Maximum is 7.94948×10^9

Minimum is 1.6×10^9

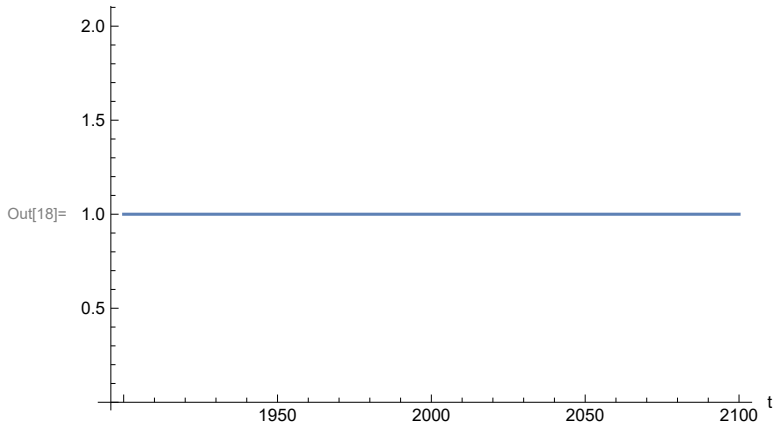
Plot land yield.

In[17]:= **SystemModelPlot[basesim, {"Food_Production1.Land_Yield.y"}]**



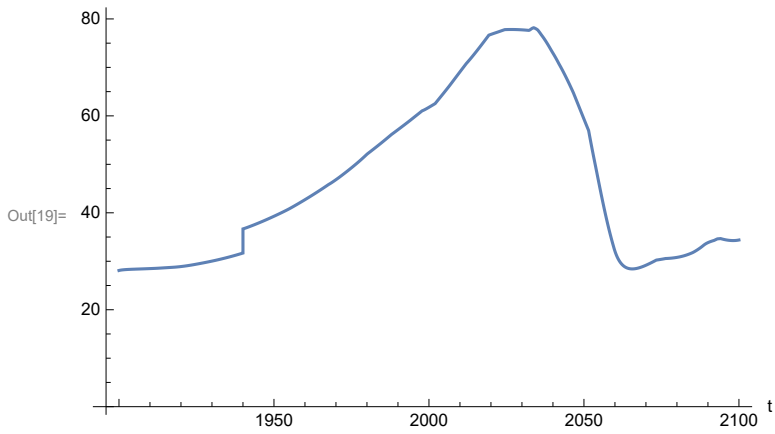
Plot multiplier of air pollution on land yield.

```
In[18]:= SystemModelPlot[basesim, {"Food_Production1.s_yield_mlt_air_poll"}]
```



Plot life expectancy, years.

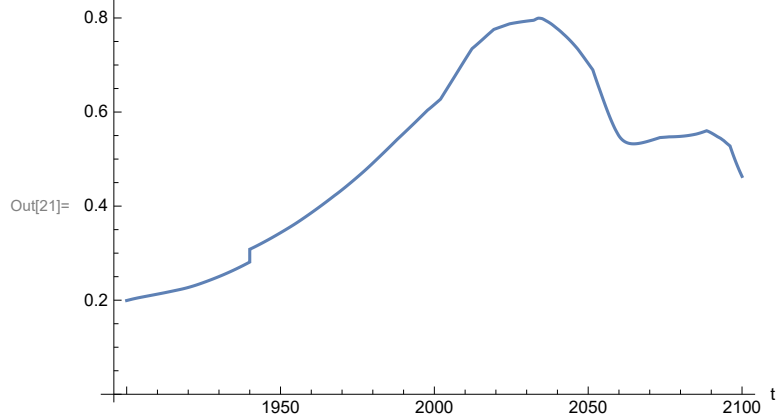
```
In[19]:= SystemModelPlot[basesim, {"Life_Expectancy1.Life_Expectancy.y"}]
```



```
In[20]:=
```

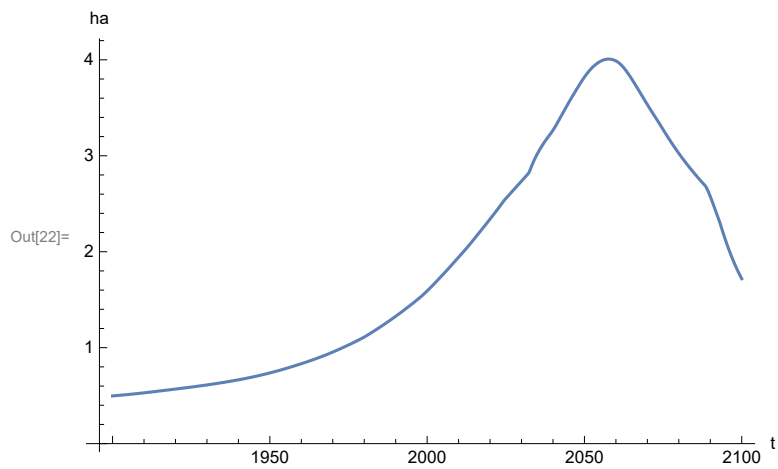
Plot human welfare index.

```
In[21]:= SystemModelPlot[basesim,
  {"Human_Welfare_Index1.HWI_Human_Welfare_Index.hwi_human_welfare_index"}]
```



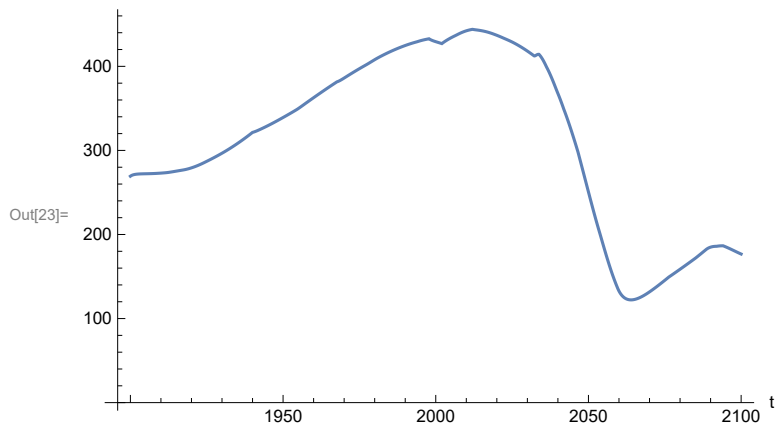
Plot per capita ecological footprint, hectares.

```
In[22]:= SystemModelPlot[basesim,
  {"Human_Ecological_Footprint1.HEF_Human_Ecological_Footprint.hef_human_ecological_footprint"}]
```



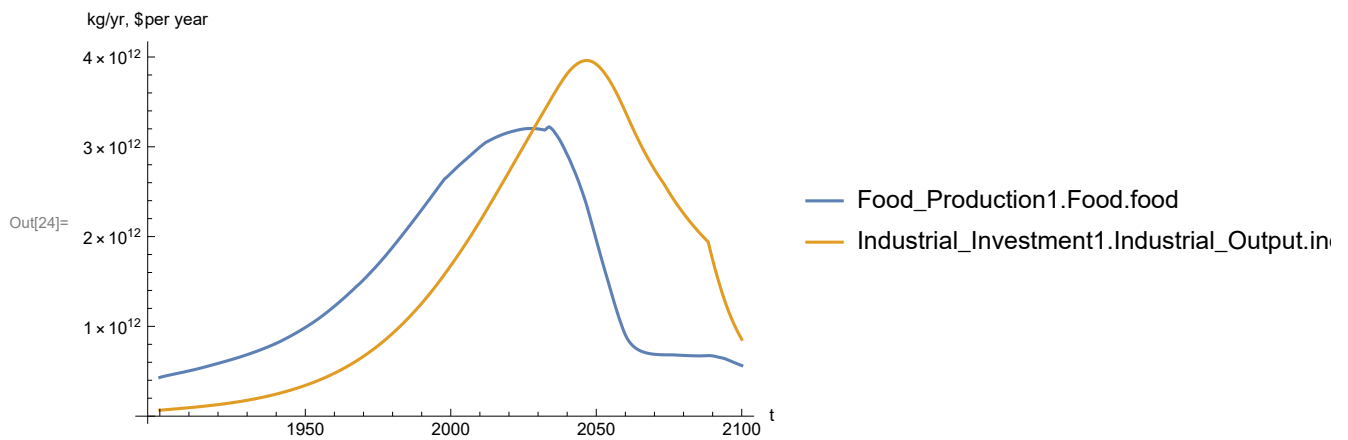
Plot food production per capita (kg/year).


```
In[23]:= SystemModelPlot[basesim, {"Food_Production1.Food_PC.y"}]
```



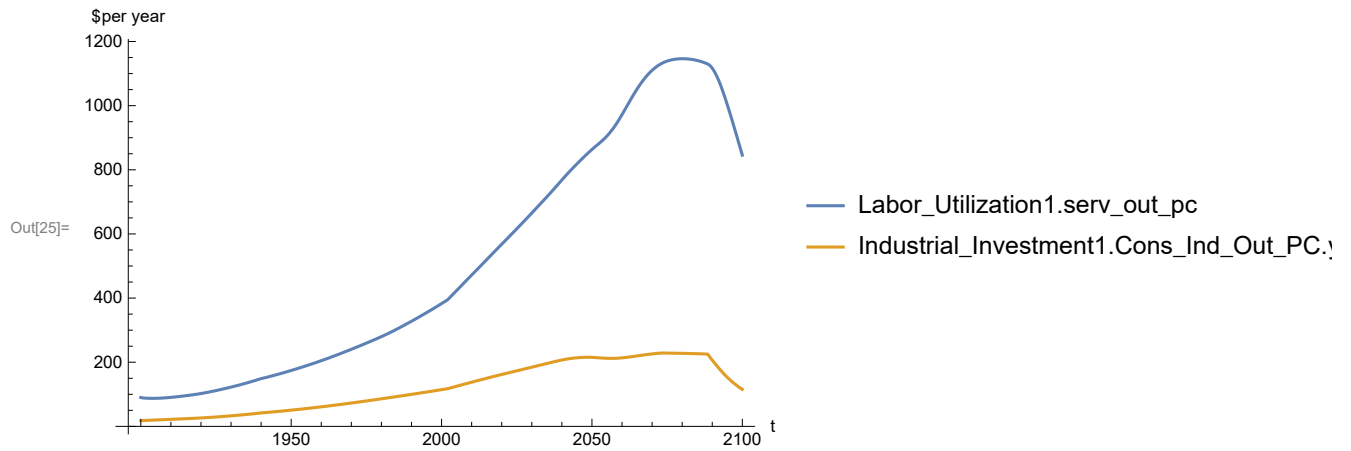
Plot total food production (kg/year), and industrial output (dollars/year).

```
In[24]:= SystemModelPlot[basesim, {"Food_Production1.Food.food",
    "Industrial_Investment1.Industrial_Output.industrial_output"}]
```



Plot labor utilization per capita (dollars/year), and consolidated industrial output per capita (dollars/year)

```
In[25]:= SystemModelPlot[basesim,
  {"Labor_Utilization1.serv_out_pc", "Industrial_Investment1.Cons_Ind_Out_PC.y"}]
```

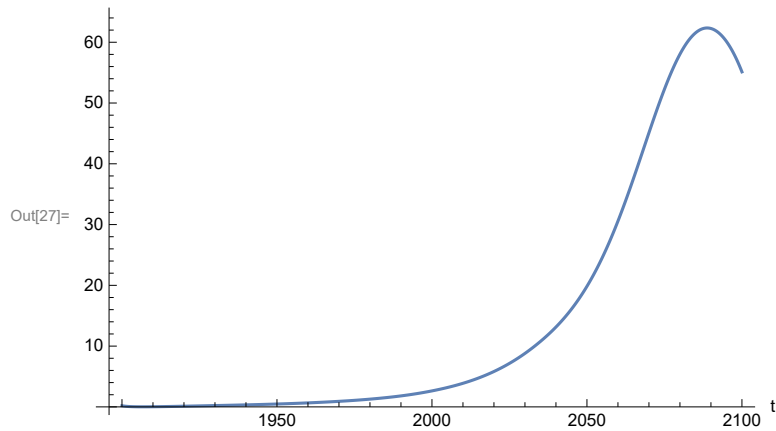


Find max and min of y values.

```
In[26]:= MinAndMax[basesim[{"Labor_Utilization1.serv_out_pc"}]]
Maximum is 1146.3
Minimum is 87.4451
```

Plot persistent pollution index.

```
In[27]:= SystemModelPlot[basesim, {"Pollution_Dynamics1.PPoll_Index.y"}]
```

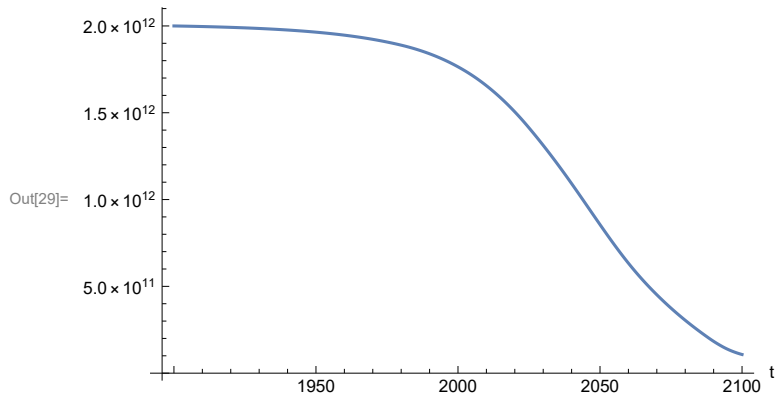


Find max and min of y values.

```
In[28]:= MinAndMax[basesim[{"Pollution_Dynamics1.PPoll_Index.y"}]]
Maximum is 62.3495
Minimum is 0.0150765
```

Plot non-renewable resources remaining.

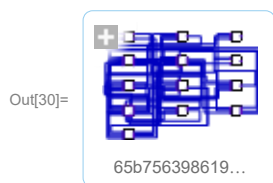
In[29]:= SystemModelPlot[basesim, {"NR_Resource_Utilization1.NR_Resources.y"}]



APPENDIX 32. Effects of mitigating the impact of air pollution on agricultural land yield, beginning calendar year 2020, Scenario 7, Experiment 2

Change the value of the air pollution effect multiplier switch time `t_air_poll_time`, to calendar year 2020, and execute the resulting scenario, plotting the variables shown in Figure 2.

```
In[30]:= newmysim = SystemModel[mysim, <|"ParameterValues" → {"t_air_poll_time" → 2020}|>]
```



```
In[31]:= testsim = SystemModelSimulate[newmysim]
```

Out[31]= SystemModelSimulationData [ Model: W65b75639861940b8805109f5335992f6
Time: 1.90×10^3 to 2.10×10^3]

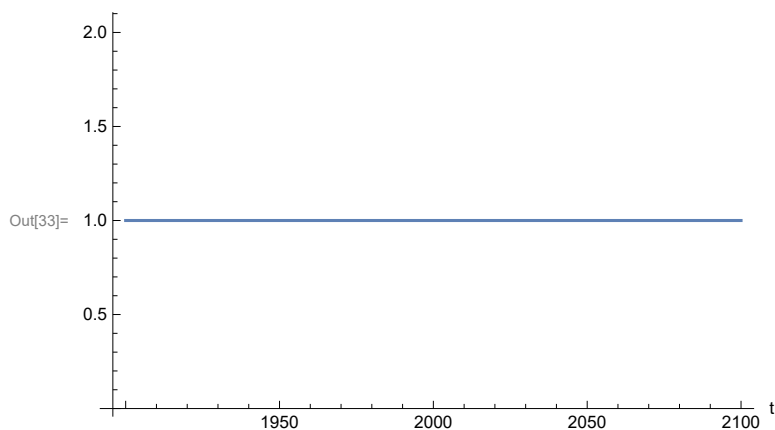
Show the value of `t_air_poll_time` (calendar year).

```
In[32]:= SystemModel[newmysim][{"ParameterValues", "t_air_poll_time"}]
```

Out[32]= {t_air_poll_time → 2020}

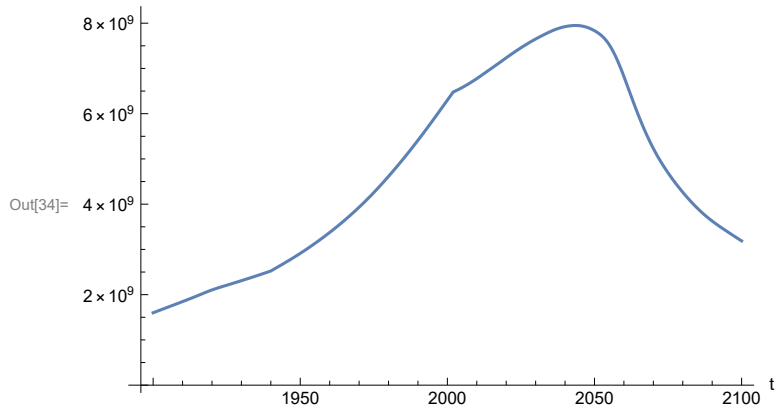
Plot air pollution multiplier of land yield.

```
In[33]:= SystemModelPlot[testsim, {"Food_Production1.s_yield_mlt_air_poll"}]
```



Plot the world population, people.

```
In[34]:= SystemModelPlot[testsim, {"Population_Dynamics1.Birth_Rate.pop"}]
```



Find max and min of y values.

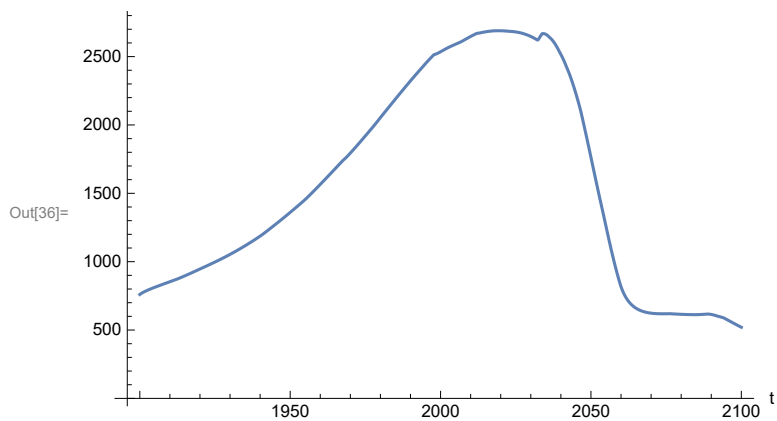
```
In[35]:= MinAndMax[testsim[{"Population_Dynamics1.Birth_Rate.pop"}]]
```

Maximum is 7.94948×10^9

Minimum is 1.6×10^9

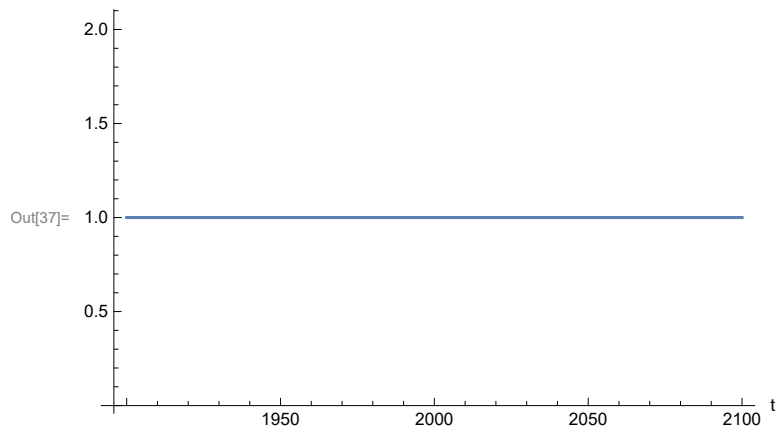
Plot land yield.

```
In[36]:= SystemModelPlot[testsim, {"Food_Production1.Land_Yield.y"}]
```



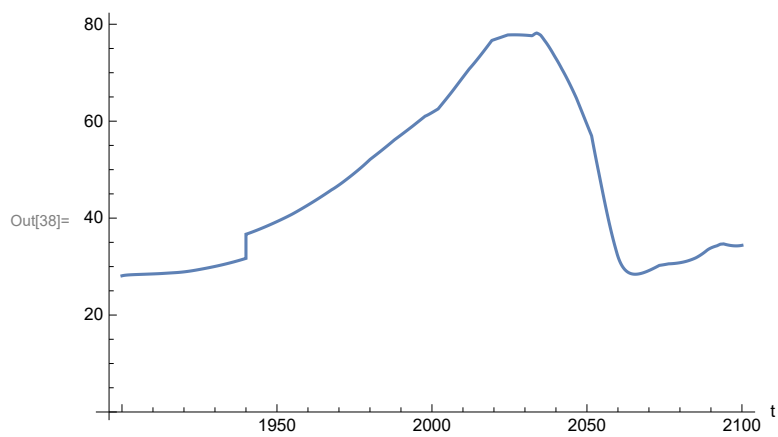
Plot multiplier of air pollution on land yield.

```
In[37]:= SystemModelPlot[testsim, {"Food_Production1.s_yield_mlt_air_poll"}]
```



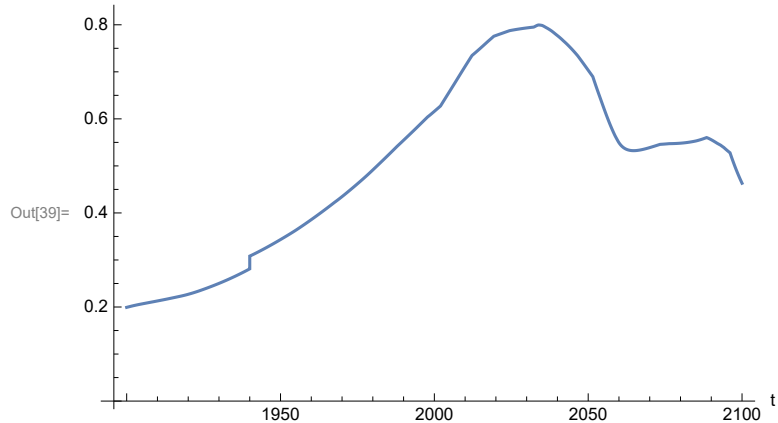
Plot life expectancy, in years.

```
In[38]:= SystemModelPlot[testsim, {"Life_Expectancy1.Life_Expectancy.y"}]
```



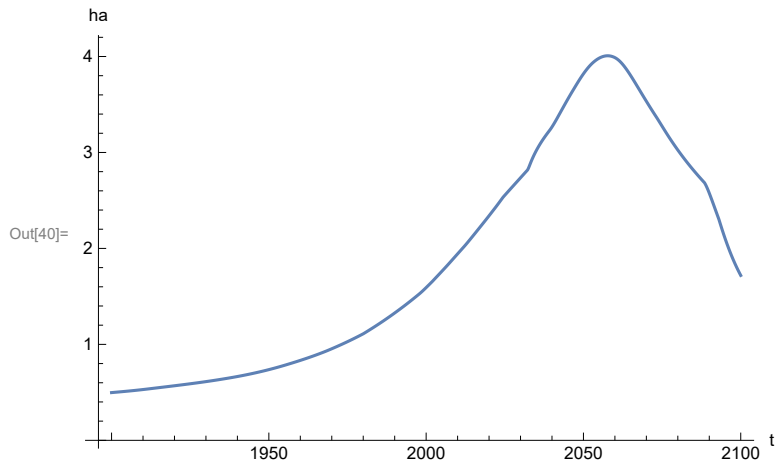
Plot the human welfare index.

```
In[39]:= SystemModelPlot[testsim, {"Human_Welfare_Index1.HWI_Human_Welfare_Index.hwi_human_welfare_index"}]
```



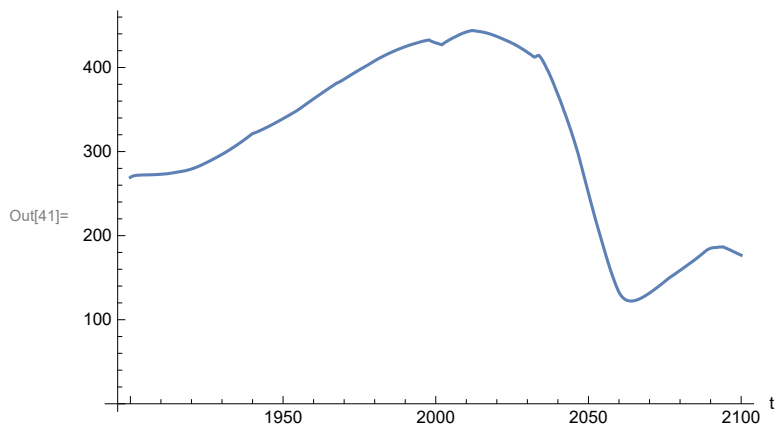
Plot the human ecological footprint, in hectares.

```
In[40]:= SystemModelPlot[testsim,
  {"Human_Ecological_Footprint1.HEF_Human_Ecological_Footprint.hef_human_ecological_
    _footprint"}]
```



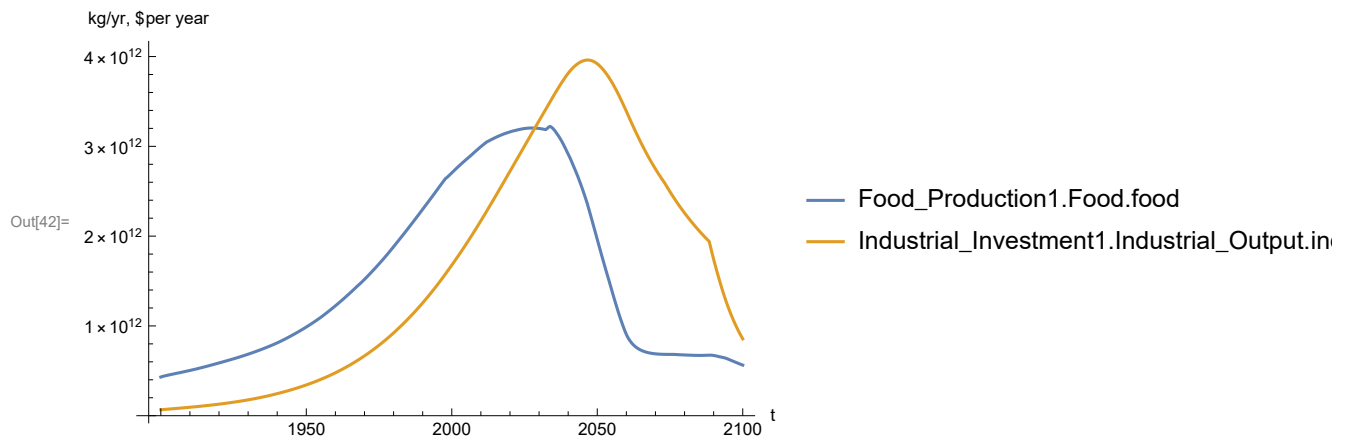
Plot per capita food production, kg/year.

```
In[41]:= SystemModelPlot[testsim, {"Food_Production1.Food_PC.y"}]
```



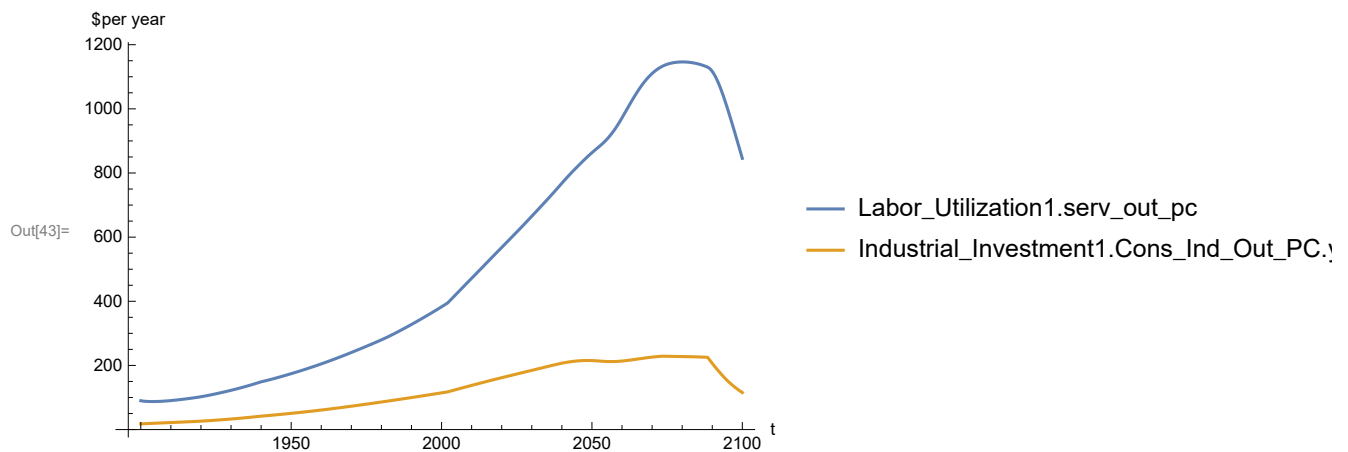
Plot total food production (kg/yr) and industrial output (in dollars).

```
In[42]:= SystemModelPlot[testsim, {"Food_Production1.Food.food",
  "Industrial_Investment1.Industrial_Output.industrial_output"}]
```



Plot labor utilization per capita consolidated industrial output per capita (dollars/year).

```
In[43]:= SystemModelPlot[testsim,
  {"Labor_Utilization1.serv_out_pc", "Industrial_Investment1.Cons_Ind_Out_PC.y"}]
```



Find max and min of y values.

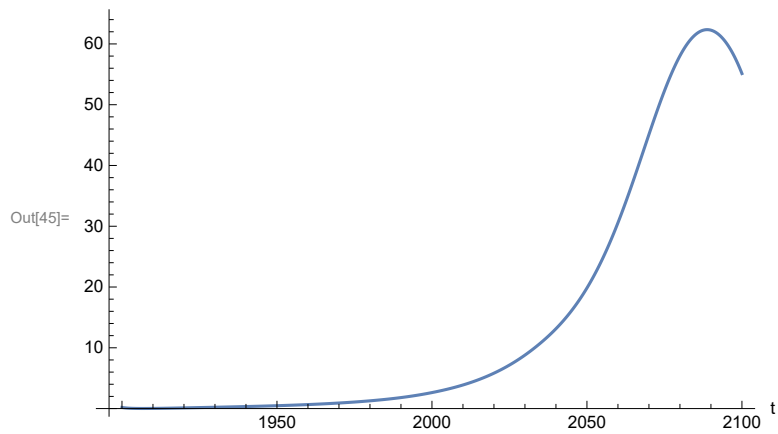
```
In[44]:= MinAndMax[testsim[{"Labor_Utilization1.serv_out_pc"}]]
```

Maximum is 1146.3

Minimum is 87.4451

Plot persistent pollution index (normalized to 1970 value).


```
In[45]:= SystemModelPlot[testsim, {"Pollution_Dynamics1.PPoll_Index.y"}]
```



Find max and min of y values.

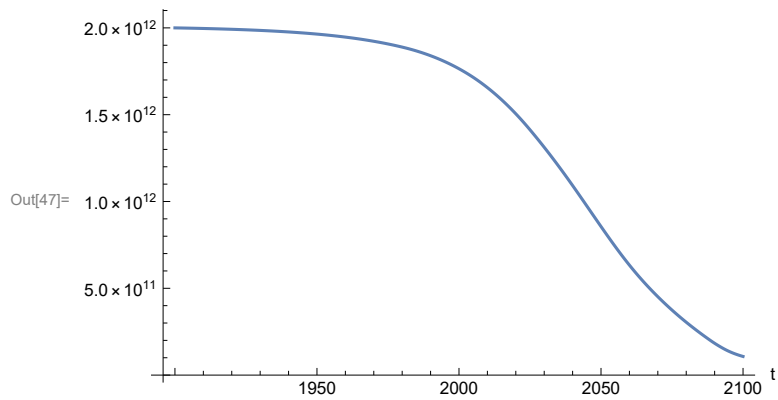
```
In[46]:= MinAndMax[testsim[{"Pollution_Dynamics1.PPoll_Index.y"}]]
```

Maximum is 62.3495

Minimum is 0.0150765

Plot non-renewable resources remaining.

```
In[47]:= SystemModelPlot[testsim, {"NR_Resource_Utilization1.NR_Resources.y"}]
```



APPENDIX 33. Effects of mitigating the impact of air pollution on agricultural land yield, beginning calendar year 1970, Scenario 7, Experiment 3

Change the value of the air pollution effect multiplier switch time `t_air_poll_time`, to calendar year 1970, and execute the resulting scenario, plotting the variables shown in Figure 2.

```
In[48]:= newmysim1970 = SystemModel[mysim, <|"ParameterValues" → {"t_air_poll_time" → 1970} |>]
```



```
In[49]:= testsim1970 = SystemModelSimulate[newmysim1970]
```

Out[49]= SystemModelSimulationData [ Model: W3f119aa823c34a4db2a429a47de7b32d
Time: 1.90×10^3 to 2.10×10^3]

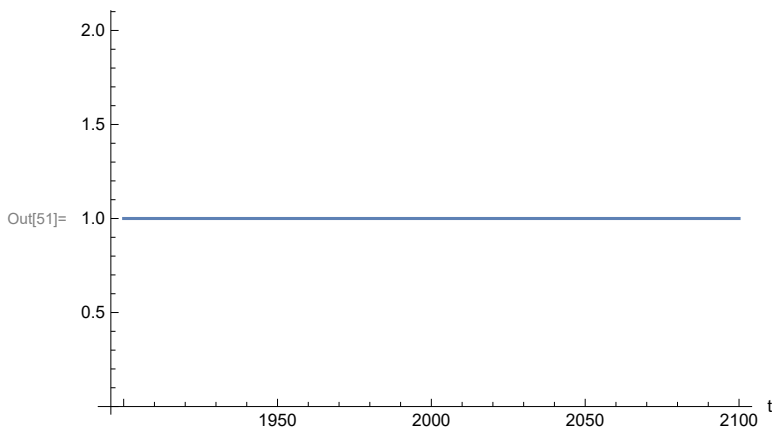
Show the value of `t_air_poll_time` (calendar year).

```
In[50]:= SystemModel[newmysim1970][{"ParameterValues", "t_air_poll_time"}]
```

Out[50]= {t_air_poll_time → 1970}

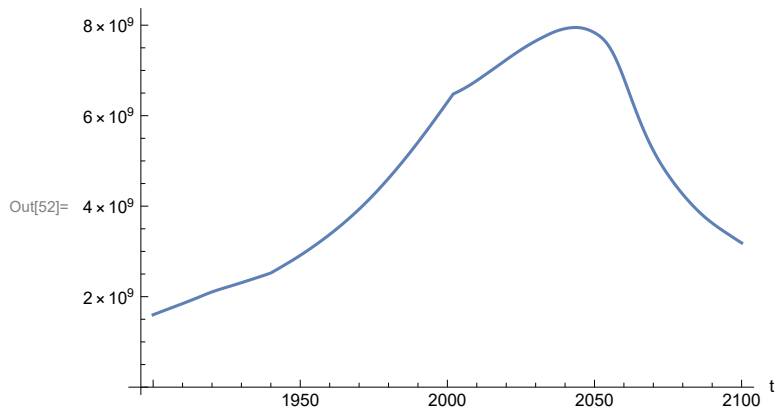
Plot air pollution multiplier of land yield.

```
In[51]:= SystemModelPlot[testsim1970, {"Food_Production1.s_yield_mlt_air_poll"}]
```



Plot the world population, people.

```
In[52]:= SystemModelPlot[testsim1970, {"Population_Dynamics1.Birth_Rate.pop"}]
```



Find max and min of y values.

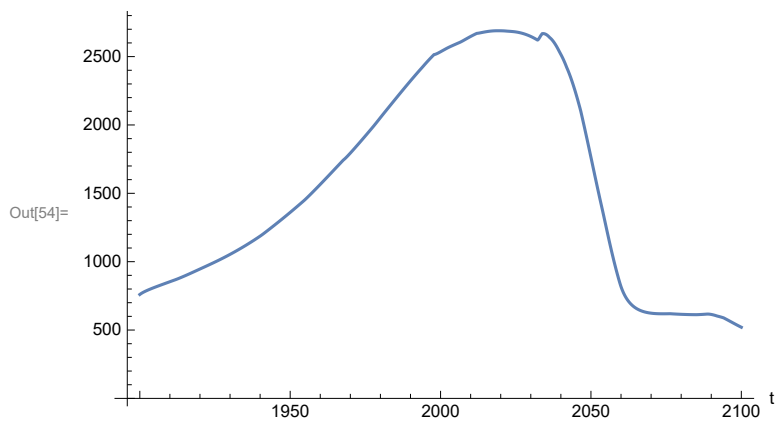
```
In[53]:= MinAndMax[testsim1970[{"Population_Dynamics1.Birth_Rate.pop"}]]
```

Maximum is 7.94948×10^9

Minimum is 1.6×10^9

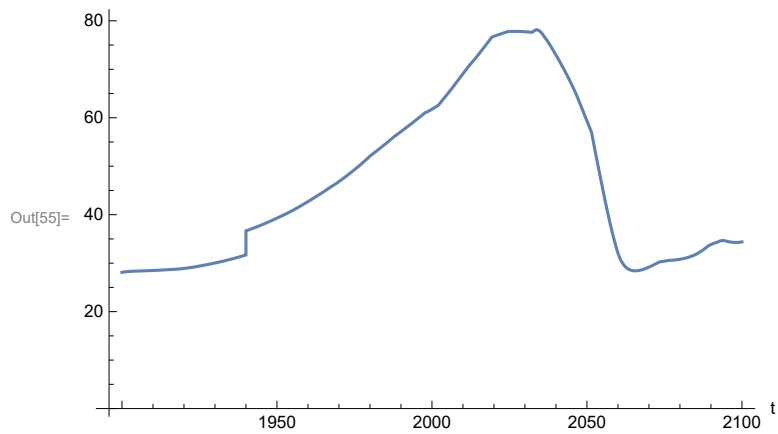
Plot land yield.

```
In[54]:= SystemModelPlot[testsim1970, {"Food_Production1.Land_Yield.y"}]
```



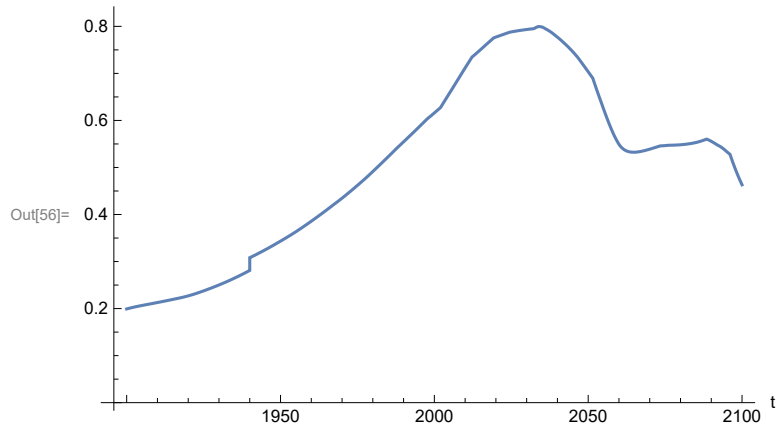
Plot life expectancy, in years.

```
In[55]:= SystemModelPlot[testsim1970, {"Life_Expectancy1.Life_Expectancy.y"}]
```



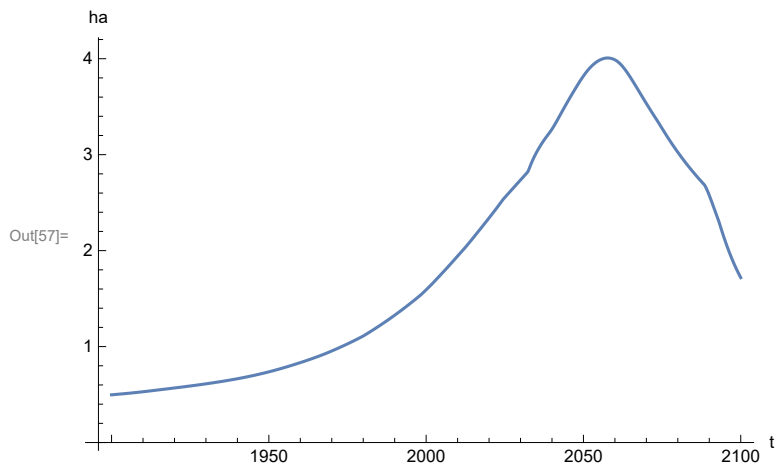
Plot the human welfare index.

```
In[56]:= SystemModelPlot[testsim1970, {"Human_Welfare_Index1.HWI_Human_Welfare_Index.hwi_human_welfare_index"}]
```



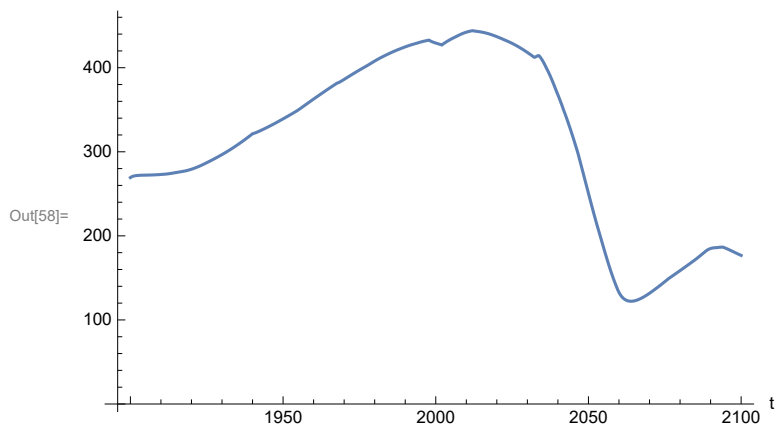
Plot the human ecological footprint, in hectares.

```
In[57]:= SystemModelPlot[testsim1970,
  {"Human_Ecological_Footprint1.HEF_Human_Ecological_Footprint.hef_human_ecological_
    _footprint"}]
```



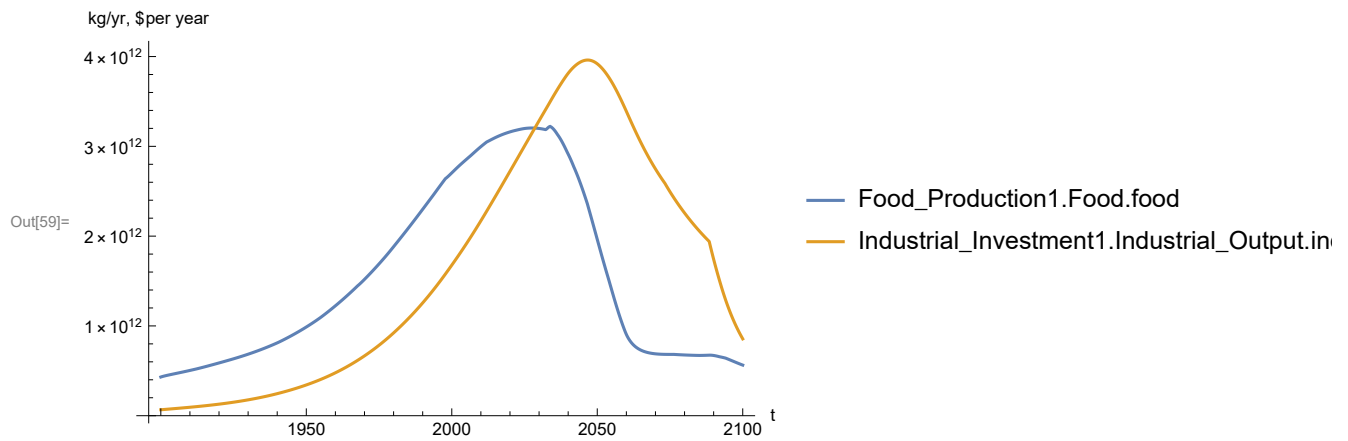
Plot per capita food production, kg/year.

```
In[58]:= SystemModelPlot[testsim1970, {"Food_Production1.Food_PC.y"}]
```



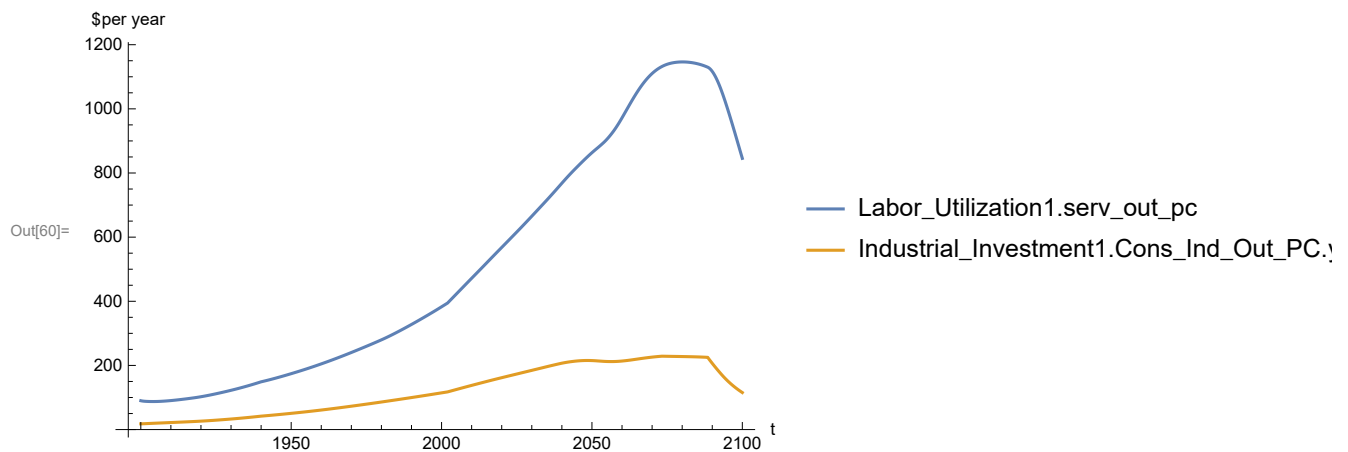
Plot total food production (kg/yr) and industrial output (in dollars).

```
In[59]:= SystemModelPlot[testsim1970, {"Food_Production1.Food.food",
  "Industrial_Investment1.Industrial_Output.industrial_output"}]
```



Plot labor utilization per capita and consolidated industrial output per capita (dollars/year).

```
In[60]:= SystemModelPlot[testsim1970,
  {"Labor_Utilization1.serv_out_pc", "Industrial_Investment1.Cons_Ind_Out_PC.y"}]
```



Find max and min of y values.

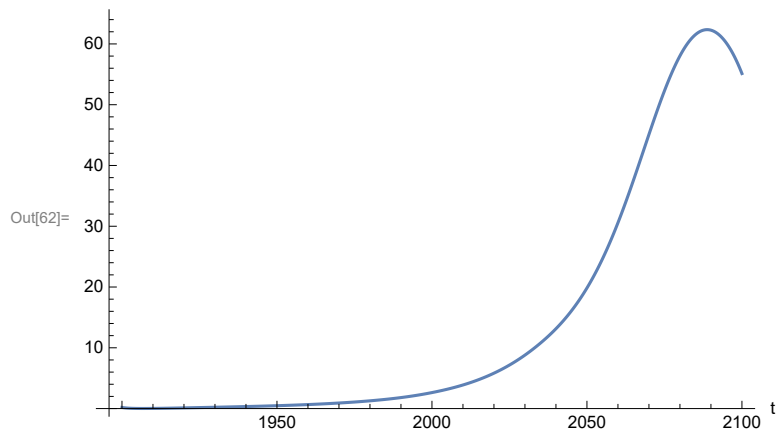
```
In[61]:= MinAndMax[testsim1970[{"Labor_Utilization1.serv_out_pc"}]]
```

Maximum is 1146.3

Minimum is 87.4451

Plot persistent pollution index (normalized to 1970 value).

```
In[62]:= SystemModelPlot[testsim1970, {"Pollution_Dynamics1.PPoll_Index.y"}]
```



Find max and min of y values.

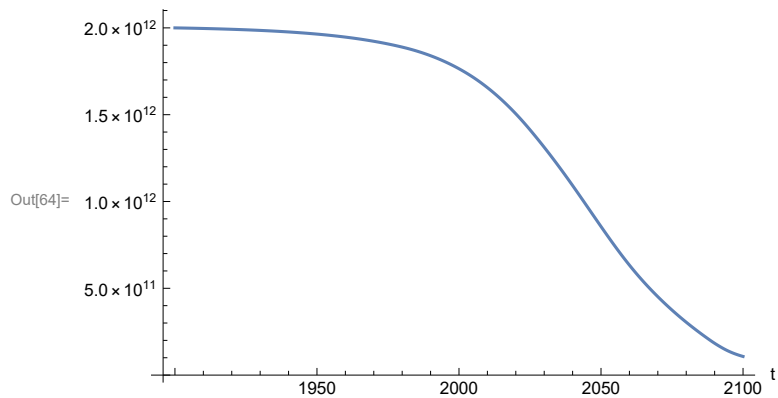
```
In[63]:= MinAndMax[testsim1970[{"Pollution_Dynamics1.PPoll_Index.y"}]]
```

Maximum is 62.3495

Minimum is 0.0150765

Plot non-renewable resources remaining.

```
In[64]:= SystemModelPlot[testsim1970, {"NR_Resource_Utilization1.NR_Resources.y"}]
```



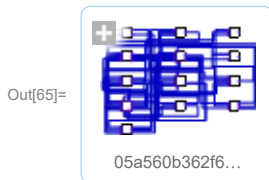
APPENDIX 34. “STRONG AIR POLLUTION” EFFECTS SCENARIO, Experiment 4

Experiment fails due to an out-of-range value in an ASSERT statement.

APPENDIX 35. SEVERE LAND LOSS DUE TO AIR POLLUTION, Scenario 7, Experiment 5

Scenario 7 with air pollution effect on land yield changed as noted.

```
In[65]:= sevsim = SystemModel[mysim, <|"ParameterValues" ->
  {"Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals" -> {0.7, 0.1, 0.1, 0.1}}|>]
```



```
In[66]:= basesevsim = SystemModelSimulate[sevsim]
```

Out[66]= SystemModelSimulationData [ Model: W05a560b362f645b396320cfc43a7e11f
Time: 1.90×10^3 to 2.10×10^3]

Show Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals.

```
In[67]:= SystemModel[sevsim] [
  {"ParameterValues", "Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[1]"}]
```

Out[67]= {Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[1] → 0.7}

```
In[68]:= SystemModel[sevsim] [
  {"ParameterValues", "Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[2]"}]
```

Out[68]= {Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[2] → 0.1}

```
In[69]:= SystemModel[sevsim] [
  {"ParameterValues", "Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[3]"}]
```

Out[69]= {Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[3] → 0.1}

```
In[70]:= SystemModel[sevsim] [
  {"ParameterValues", "Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[4]"}]
```

Out[70]= {Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[4] → 0.1}

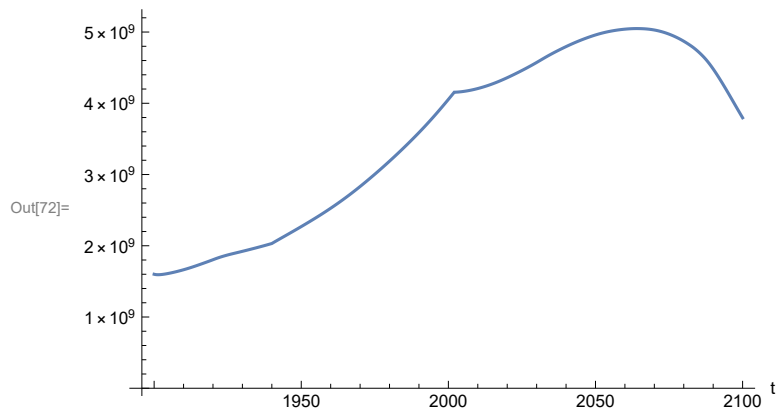
Show the value of t_air_poll_time (calendar year).

```
In[71]:= SystemModel[sevsim][{"ParameterValues", "t_air_poll_time"}]
```

```
Out[71]= {t_air_poll_time → 4000}
```

Plot the world population, people.

```
In[72]:= SystemModelPlot[basesevsim, {"Population_Dynamics1.Birth_Rate.pop"}]
```



Find max and min of y values.

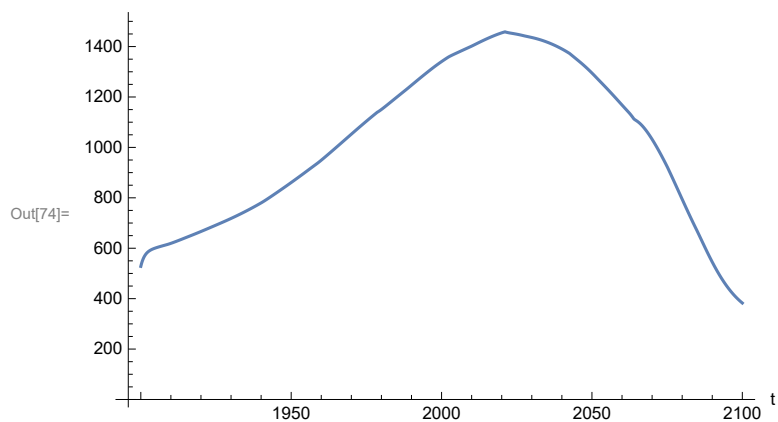
```
In[73]:= MinAndMax[basesevsim[{"Population_Dynamics1.Birth_Rate.pop"}]]
```

```
Maximum is 5.04864 × 109
```

```
Minimum is 1.59367 × 109
```

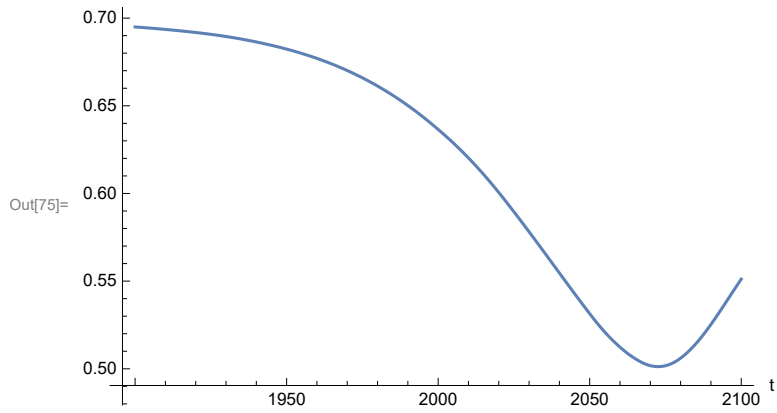
Plot land yield.

```
In[74]:= SystemModelPlot[basesevsim, {"Food_Production1.Land_Yield.y"}]
```



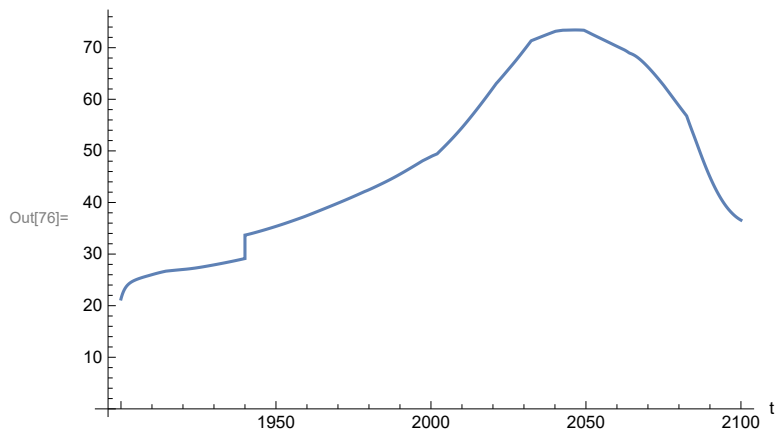
Plot multiplier of air pollution on land yield.

```
In[75]:= SystemModelPlot[basesevsim, {"Food_Production1.s_yield_mlt_air_poll"}]
```



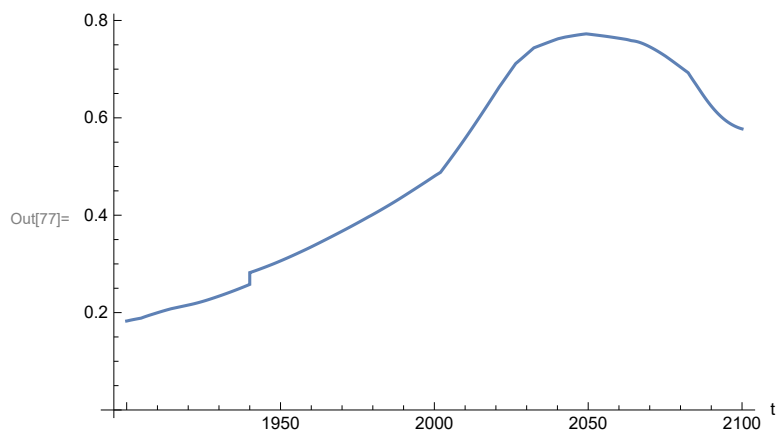
Plot life expectancy, in years.

```
In[76]:= SystemModelPlot[basesevsim, {"Life_Expectancy1.Life_Expectancy.y"}]
```



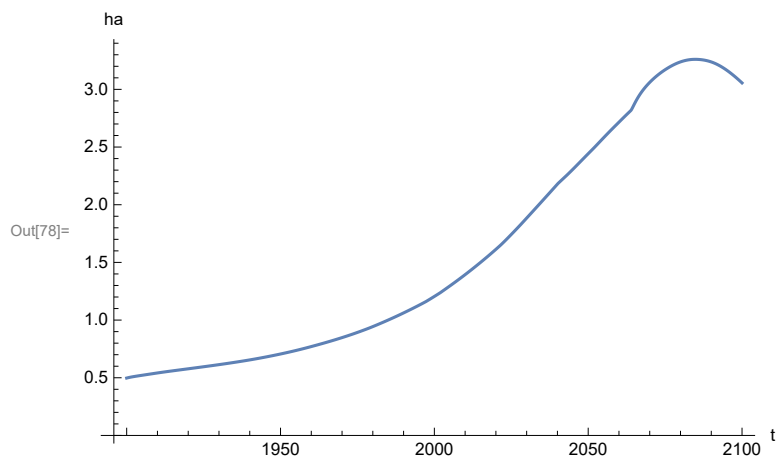
Plot the human welfare index.

```
In[77]:= SystemModelPlot[basesevsim,
  {"Human_Welfare_Index1.HWI_Human_Welfare_Index.hwi_human_welfare_index"}]
```



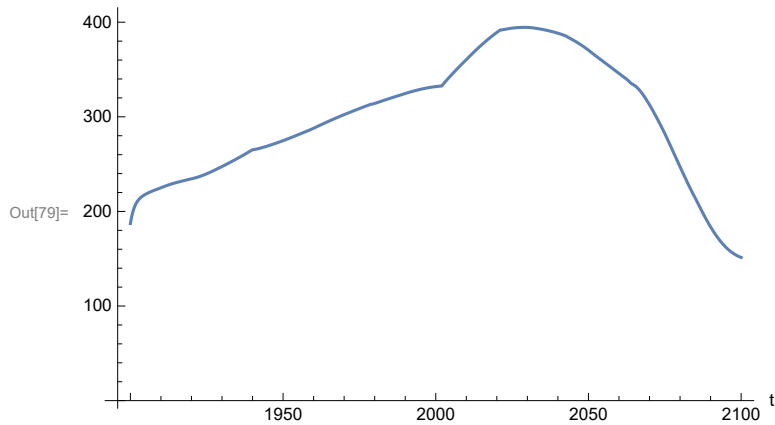
Plot the human ecological footprint, in hectares.

```
In[78]:= SystemModelPlot[basesevsim,
  {"Human_Ecological_Footprint1.HEF_Human_Ecological_Footprint.hef_human_ecological_
    _footprint"}]
```



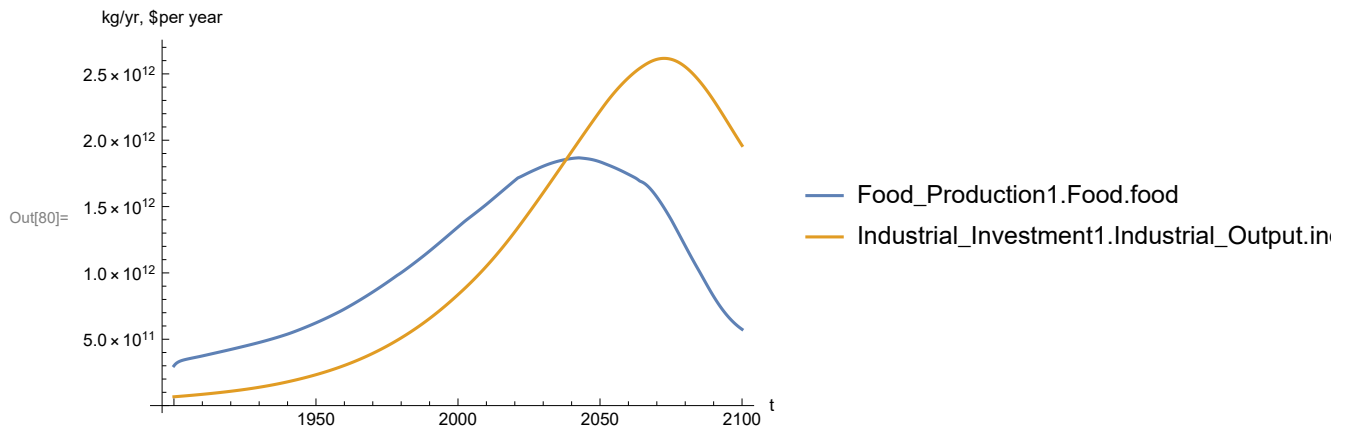
Plot per capita food production, kg/year. Note that food production per capita in 2100 has fallen to approximately the level it had in 1900 (before the rise of mechanized agriculture).

In[79]:= SystemModelPlot[basesevsim, {"Food_Production1.Food_PC.y"}]



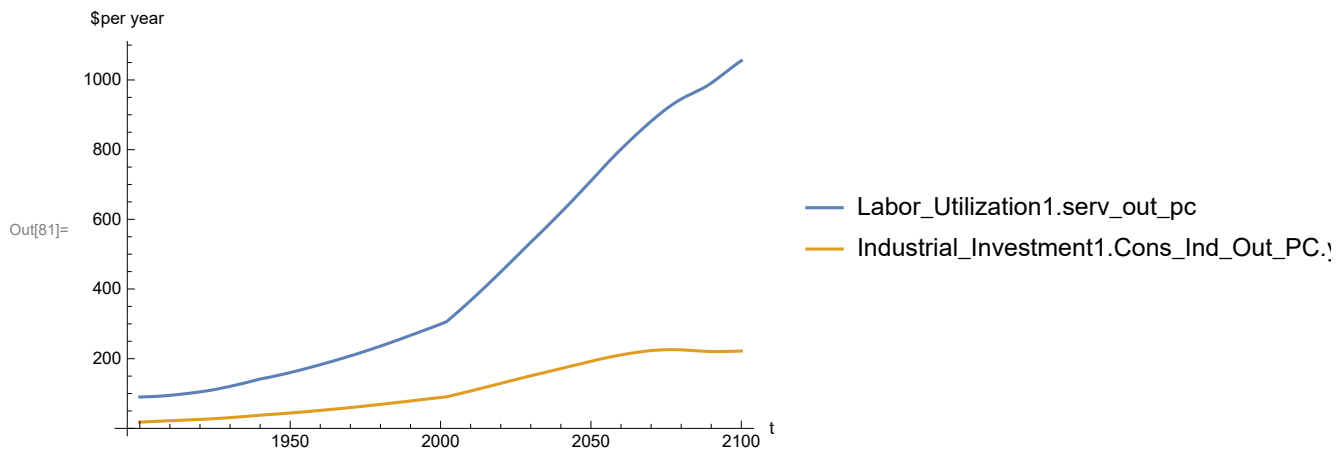
Plot total food production (kg/yr) and industrial output (in dollars).

In[80]:= SystemModelPlot[basesevsim, {"Food_Production1.Food.food", "Industrial_Investment1.Industrial_Output.industrial_output"}]



Plot labor utilization per capita and consolidated industrial output per capita (dollars/year).

```
In[81]:= SystemModelPlot[basesevsim,
  {"Labor_Utilization1.serv_out_pc", "Industrial_Investment1.Cons_Ind_Out_PC.y"}]
```



Find max and min of y values.

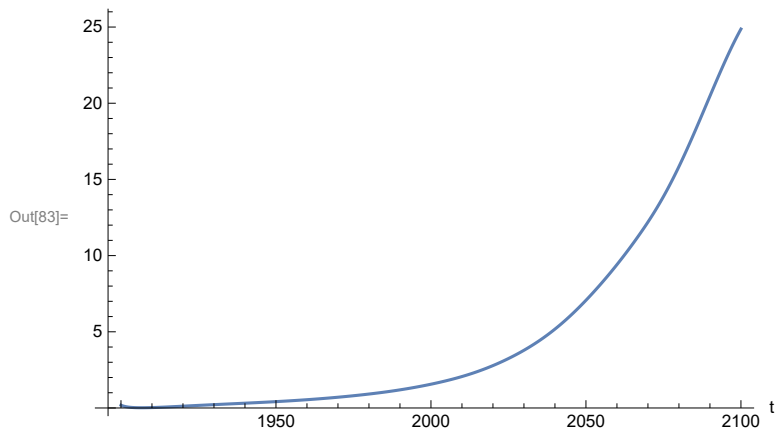
```
In[82]:= MinAndMax[basesevsim[{"Labor_Utilization1.serv_out_pc"}]]
```

Maximum is 1055.2

Minimum is 90.

Plot persistent pollution index (normalized to 1970 value).

```
In[83]:= SystemModelPlot[basesevsim, {"Pollution_Dynamics1.PPoll_Index.y"}]
```



Find max and min of y values.

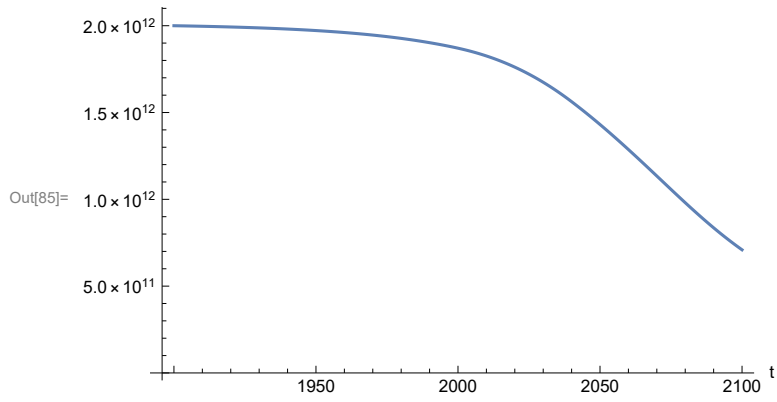
```
In[84]:= MinAndMax[basesevsim[{"Pollution_Dynamics1.PPoll_Index.y"}]]
```

Maximum is 24.8677

Minimum is 0.0157849

Plot non-renewable resources remaining.

```
In[85]:= SystemModelPlot[basesevsim, {"NR_Resource_Utilization1.NR_Resources.y"}]
```



APPENDIX 36. BENCHMARK SCENARIO 8, Experiment 1

Define a function that extracts range data from scenario data. (The right-hand-side of this definition is specific to a *World3* data structure and assumes that the function whose range is being extracted is globally (i.e., not piecewise) defined.)

```
In[86]:= RangeData[data_] := data[[1]][[4]][[3]];
```

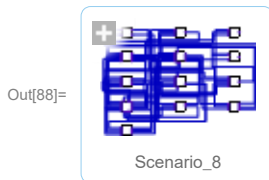
Define a procedure to determine and print minimum and maximum of “y” values.

```
In[87]:= MinAndMax[data_] := (myscenseries = RangeData[data];  
    Print["Maximum is ", Max[myscenseries]]; Print["Minimum is ", Min[myscenseries]])
```

Here are some high-level properties of Benchmark Scenario 8.

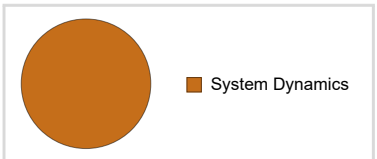
```
In[88]:=
```

```
mysim = SystemModel["SystemDynamics.WorldDynamics.World3.Scenario_8"]
```



```
In[89]:= mysummary = mysim["Summary"]
```

```
Out[89]=
```

ModelName	SystemDynamics.WorldDynamics.World3.Scenario_8
Description	More abundant non-recoverable natural resources, birth control, and stable industrial o
SimulationModel	True
Plots	0
Components	106
Balanced	True
SystemEquations	1583
SystemVariables	1583
Domain	

Show the value of `t_air_poll_time`.


```
In[90]= SystemModel[mysim][{"ParameterValues", "t_air_poll_time"}]
```

```
Out[90]= {t_air_poll_time → 4000}
```

Show Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals.

```
In[91]= SystemModel[mysim][
  {"ParameterValues", "Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[1]"}]
```

```
Out[91]= {Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[1] → 1}
```

```
In[92]= SystemModel[mysim][
  {"ParameterValues", "Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[2]"}]
```

```
Out[92]= {Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[2] → 1}
```

```
In[93]= SystemModel[mysim][
  {"ParameterValues", "Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[3]"}]
```

```
Out[93]= {Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[3] → 0.7}
```

```
In[94]= SystemModel[mysim][
  {"ParameterValues", "Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[4]"}]
```

```
Out[94]= {Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[4] → 0.4}
```

Show Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_2.y_vals.

```
In[95]= SystemModel[mysim][
  {"ParameterValues", "Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_2.y_vals[1]"}]
```

```
Out[95]= {Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_2.y_vals[1] → 1}
```

```
In[96]= SystemModel[mysim][
  {"ParameterValues", "Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_2.y_vals[2]"}]
```

```
Out[96]= {Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_2.y_vals[2] → 1}
```

```
In[97]= SystemModel[mysim][
  {"ParameterValues", "Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_2.y_vals[3]"}]
```

```
Out[97]= {Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_2.y_vals[3] → 0.98}
```

```
In[98]= SystemModel[mysim][
  {"ParameterValues", "Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_2.y_vals[4]"}]
```

```
Out[98]= {Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_2.y_vals[4] → 0.95}
```

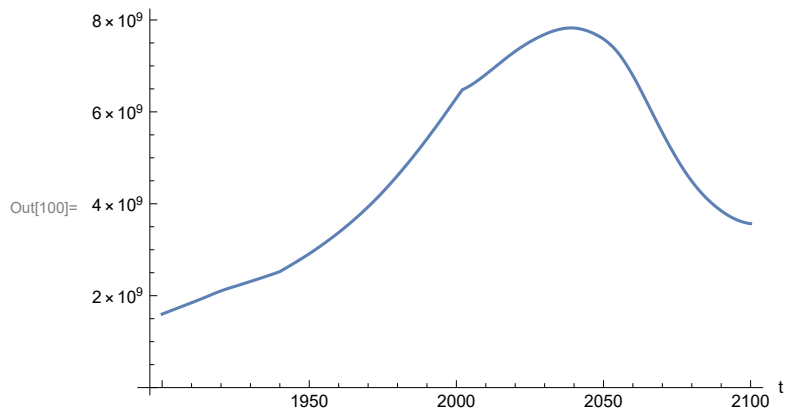
Execute Benchmark Simulation 8 and plot the variables shown in Figure 2.

```
In[99]:= basesim = SystemModelSimulate[mysim]
```

```
Out[99]= SystemModelSimulationData [  Model: Scenario_8  
Time:  $1.90 \times 10^3$  to  $2.10 \times 10^3$  ]
```

Plot total population, people.

```
In[100]:= SystemModelPlot[basesim, {"Population_Dynamics1.Birth_Rate.pop"}]
```



Find max and min of population values.

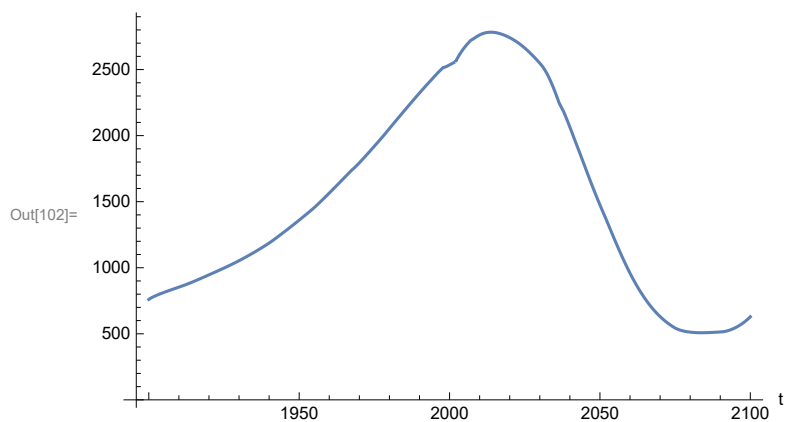
```
In[101]:= MinAndMax[basesim[{"Population_Dynamics1.Birth_Rate.pop"}]]
```

Maximum is 7.82639×10^9

Minimum is 1.6×10^9

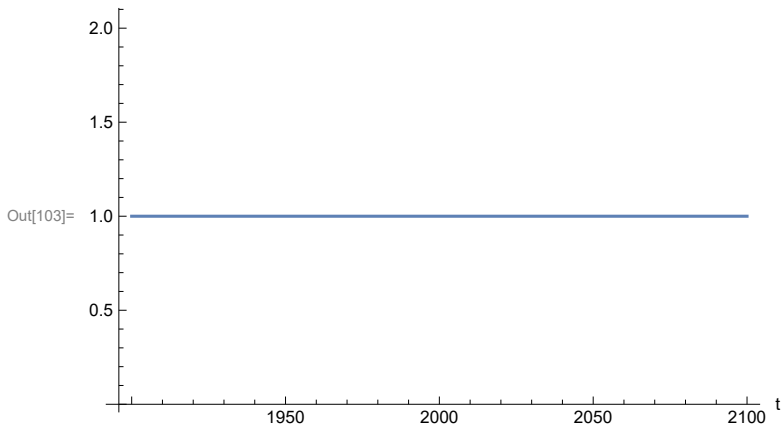
Plot land yield.

```
In[102]:= SystemModelPlot[basesim, {"Food_Production1.Land_Yield.y"}]
```



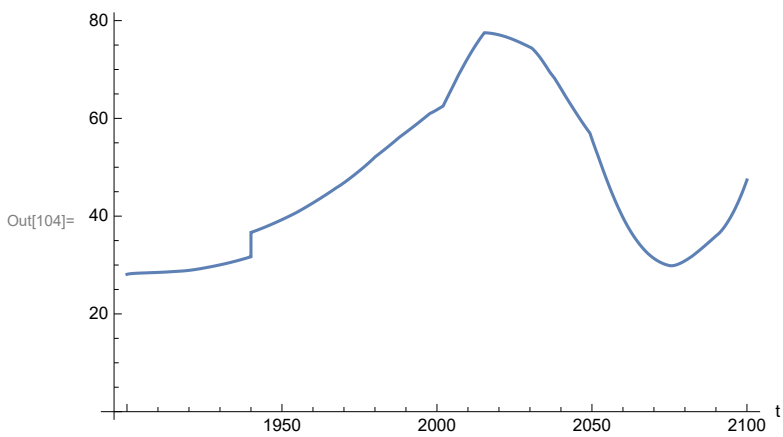
Plot multiplier of air pollution on land yield.

```
In[103]:= SystemModelPlot[basesim, {"Food_Production1.s_yield_mlt_air_poll"}]
```



Plot life expectancy, years.

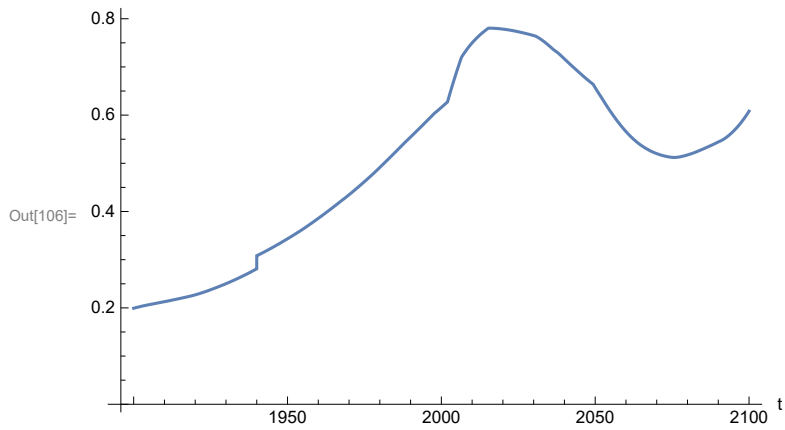
```
In[104]:= SystemModelPlot[basesim, {"Life_Expectancy1.Life_Expectancy.y"}]
```



```
In[105]:=
```

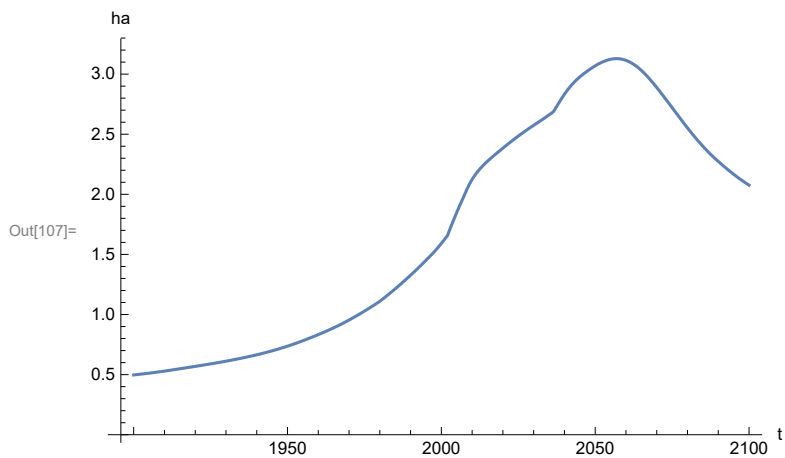
Plot human welfare index.

```
In[106]:= SystemModelPlot[basesim,
  {"Human_Welfare_Index1.HWI_Human_Welfare_Index.hwi_human_welfare_index"}]
```



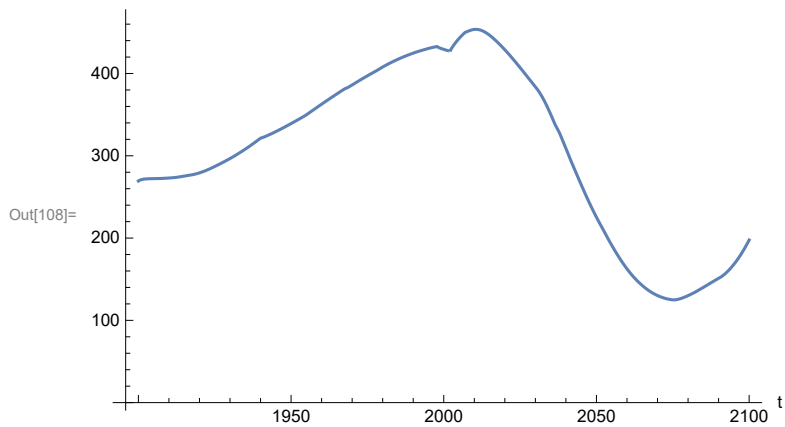
Plot per capita ecological footprint, hectares.

```
In[107]:= SystemModelPlot[basesim,
  {"Human_Ecological_Footprint1.HEF_Human_Ecological_Footprint.hef_human_ecological_footprint"}]
```



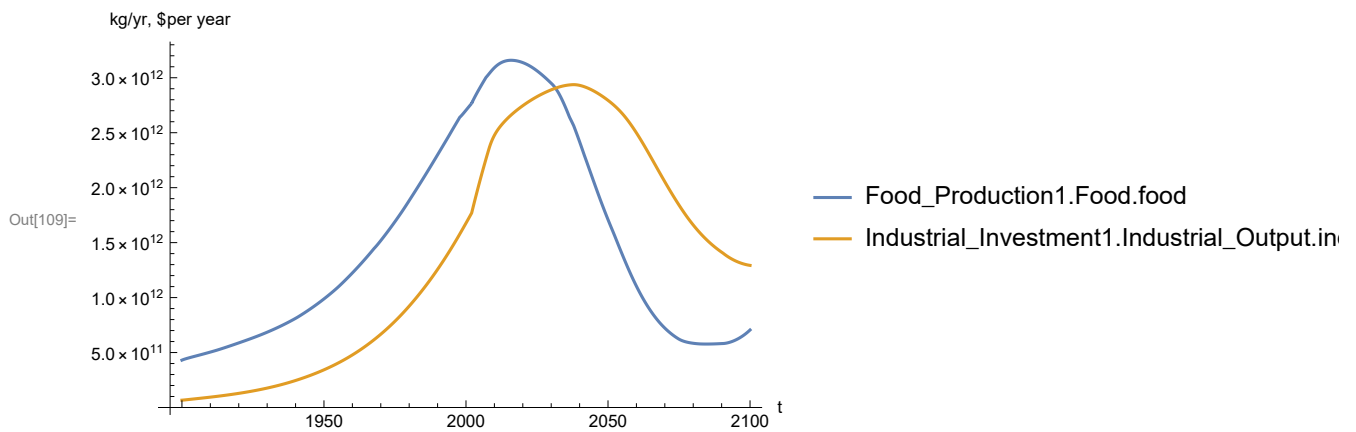
Plot food production per capita (kg/year).

```
In[108]:= SystemModelPlot[basesim, {"Food_Production1.Food_PC.y"}]
```



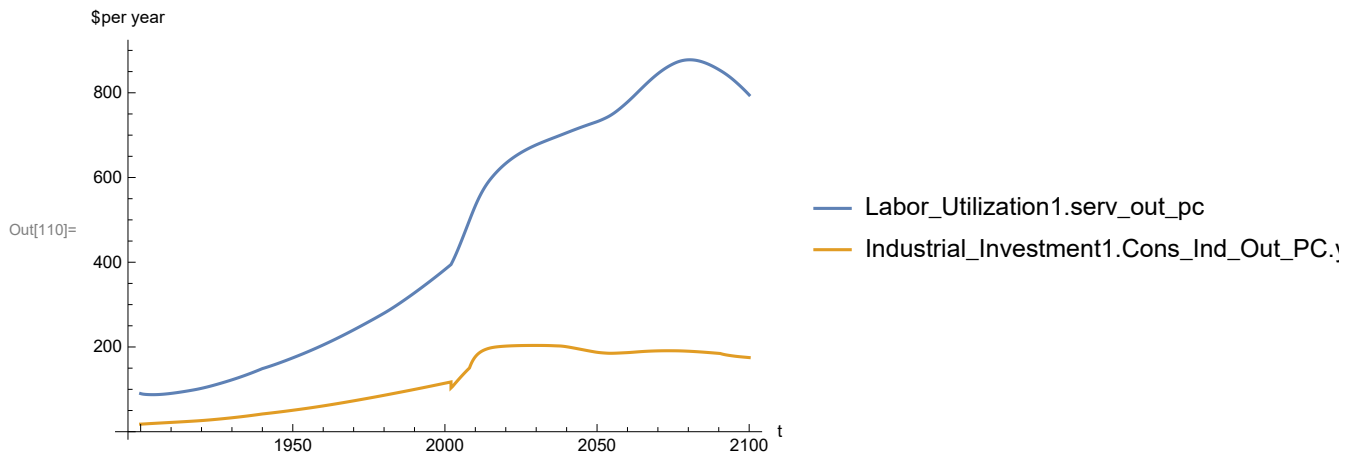
Plot total food production (kg/year), and industrial output (dollars/year).

```
In[109]:= SystemModelPlot[basesim, {"Food_Production1.Food.food",
  "Industrial_Investment1.Industrial_Output.industrial_output"}]
```



Plot labor utilization per capita (dollars/year), and consolidated industrial output per capita (dollars/year)

```
In[110]:= SystemModelPlot[basesim,
  {"Labor_Utilization1.serv_out_pc", "Industrial_Investment1.Cons_Ind_Out_PC.y"}]
```



Find max and min of y values.

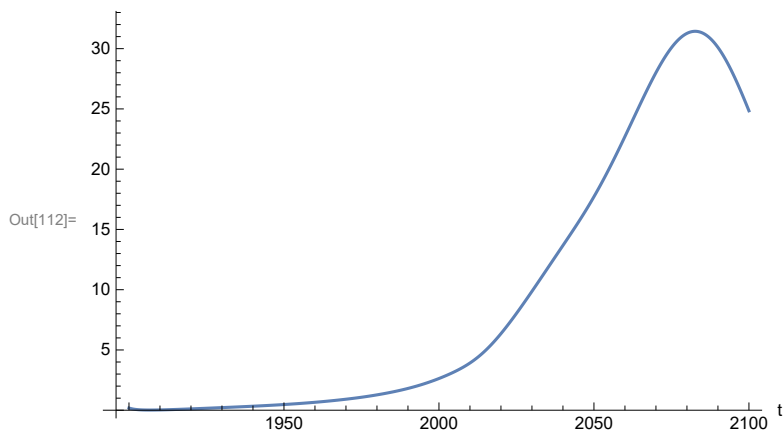
```
In[111]:= MinAndMax[basesim[{"Labor_Utilization1.serv_out_pc"}]]
```

Maximum is 877.874

Minimum is 87.4451

Plot persistent pollution index.

```
In[112]:= SystemModelPlot[basesim, {"Pollution_Dynamics1.PPoll_Index.y"}]
```



Find max and min of y values.

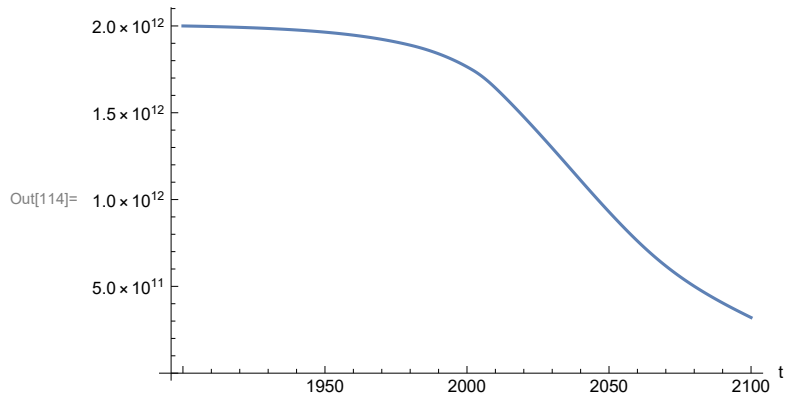
```
In[113]:= MinAndMax[basesim[{"Pollution_Dynamics1.PPoll_Index.y"}]]
```

Maximum is 31.4397

Minimum is 0.0150765

Plot non-renewable resources remaining.

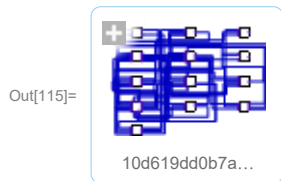
```
In[114]:= SystemModelPlot[basesim, {"NR_Resource_Utilization1.NR_Resources.y"}]
```



APPENDIX 37. Effects of mitigating the impact of air pollution on agricultural land yield, beginning calendar year 2020, Scenario 8, Experiment 2

Change the value of the air pollution effect multiplier switch time `t_air_poll_time`, to calendar year 2020, and execute the resulting scenario, plotting the variables shown in Figure 2.

```
In[115]:= newmysim = SystemModel[mysim, <|"ParameterValues" → {"t_air_poll_time" → 2020}|>]
```



```
In[116]:= testsim = SystemModelSimulate[newmysim]
```

Out[116]= SystemModelSimulationData [ Model: W10d619dd0b7a4b659538ce2364409eb0
Time: 1.90×10^3 to 2.10×10^3]

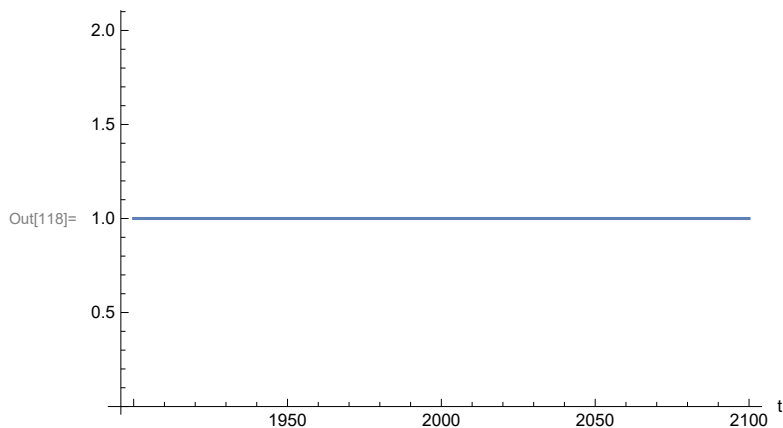
Show the value of `t_air_poll_time` (calendar year).

```
In[117]:= SystemModel[newmysim][{"ParameterValues", "t_air_poll_time"}]
```

Out[117]= {t_air_poll_time → 2020}

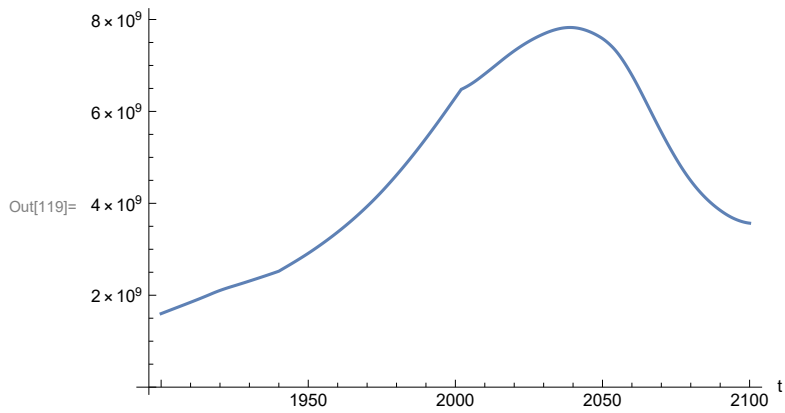
Plot air pollution multiplier of land yield.

```
In[118]:= SystemModelPlot[testsim, {"Food_Production1.s_yield_mlt_air_poll"}]
```



Plot the world population, people.

```
In[119]:= SystemModelPlot[testsim, {"Population_Dynamics1.Birth_Rate.pop"}]
```



Find max and min of y values.

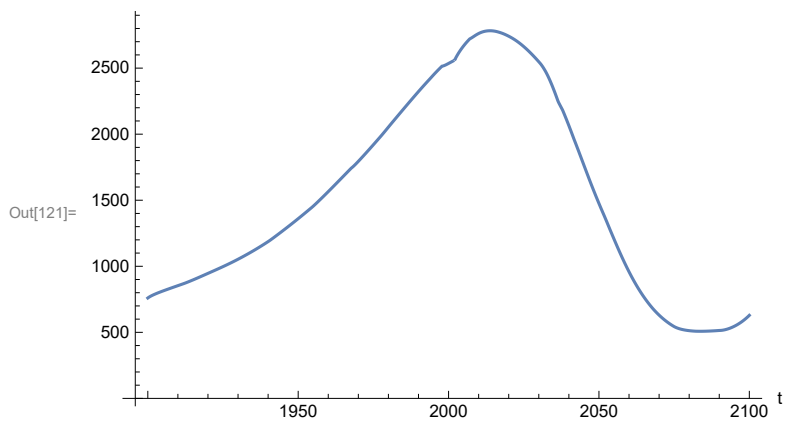
```
In[120]:= MinAndMax[testsim[{"Population_Dynamics1.Birth_Rate.pop"}]]
```

Maximum is 7.82639×10^9

Minimum is 1.6×10^9

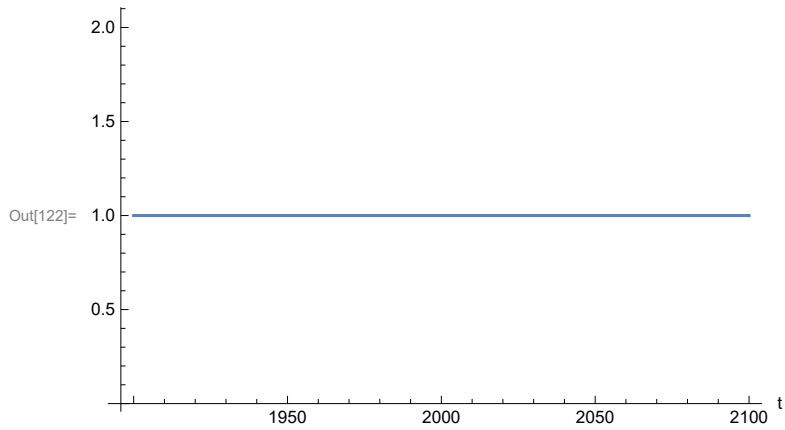
Plot land yield.

```
In[121]:= SystemModelPlot[testsim, {"Food_Production1.Land_Yield.y"}]
```



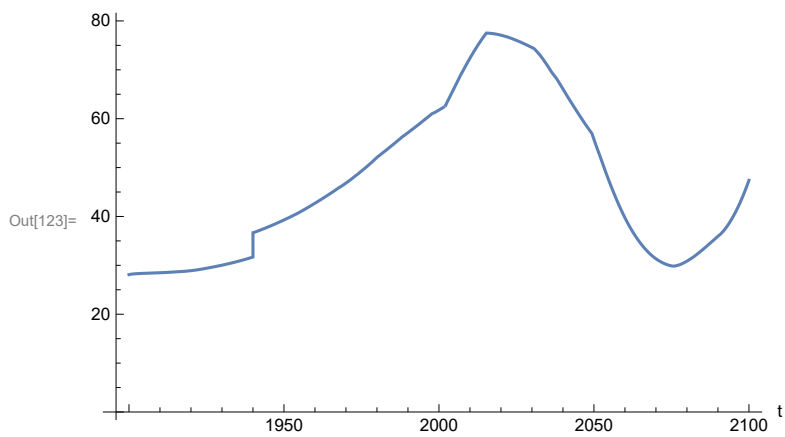
Plot multiplier of air pollution on land yield.

```
In[122]:= SystemModelPlot[testsim, {"Food_Production1.s_yield_mlt_air_poll"}]
```



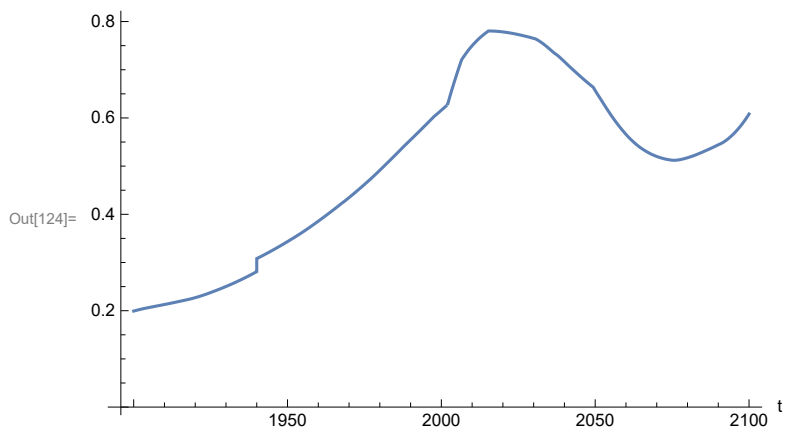
Plot life expectancy, in years.

```
In[123]:= SystemModelPlot[testsim, {"Life_Expectancy1.Life_Expectancy.y"}]
```



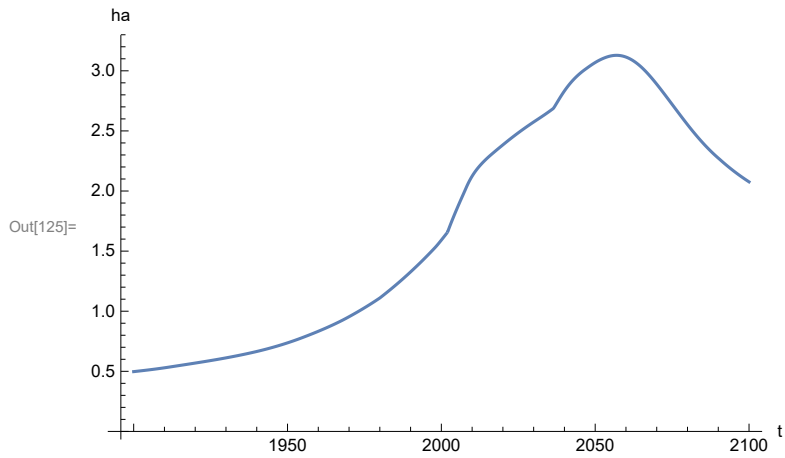
Plot the human welfare index.

```
In[124]:= SystemModelPlot[testsim, {"Human_Welfare_Index1.HWI_Human_Welfare_Index.hwi_human_welfare_index"}]
```



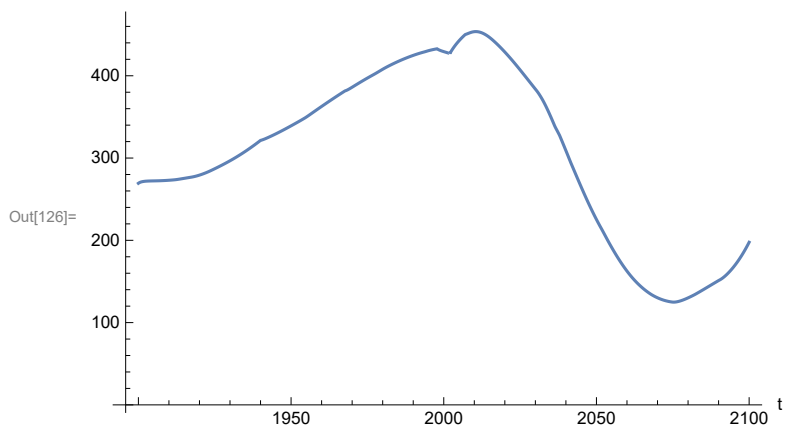
Plot the human ecological footprint, in hectares.

```
In[125]:= SystemModelPlot[testsim,
  {"Human_Ecological_Footprint1.HEF_Human_Ecological_Footprint.hef_human_ecological_
    _footprint"}]
```



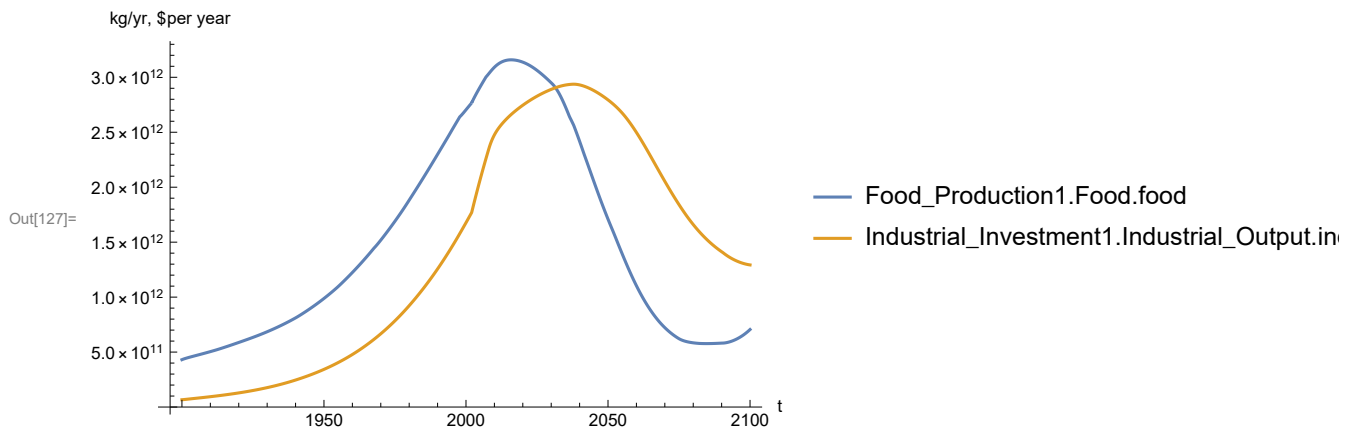
Plot per capita food production, kg/year.

```
In[126]:= SystemModelPlot[testsim, {"Food_Production1.Food_PC.y"}]
```



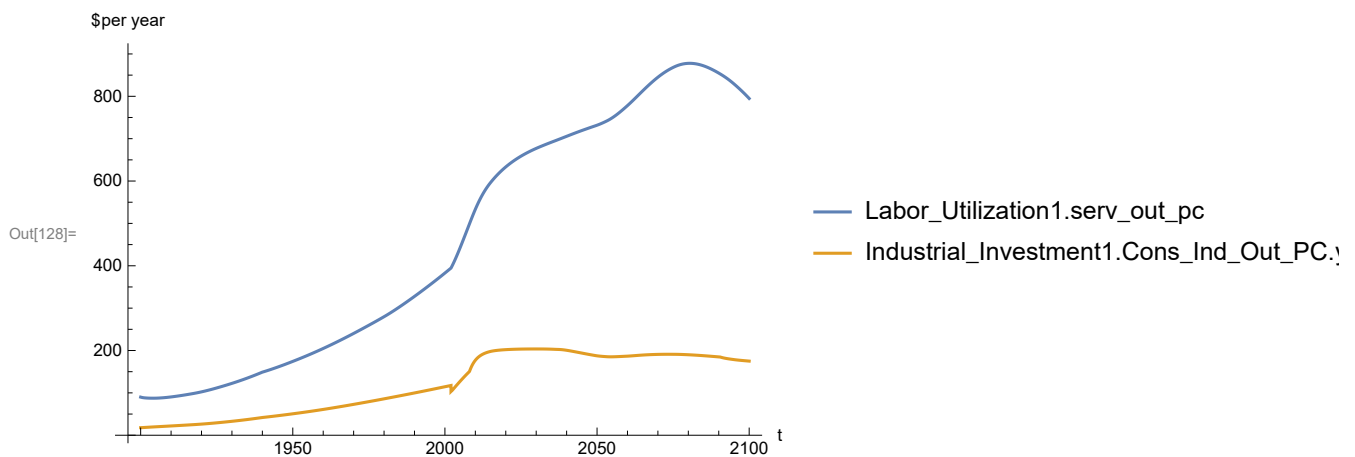
Plot total food production (kg/yr) and industrial output (in dollars).

```
In[127]:= SystemModelPlot[testsim, {"Food_Production1.Food.food",
  "Industrial_Investment1.Industrial_Output.industrial_output"}]
```



Plot labor utilization per capita and consolidated industrial output per capita (dollars/year).

```
In[128]:= SystemModelPlot[testsim,
  {"Labor_Utilization1.serv_out_pc", "Industrial_Investment1.Cons_Ind_Out_PC.y"}]
```



Find max and min of y values.

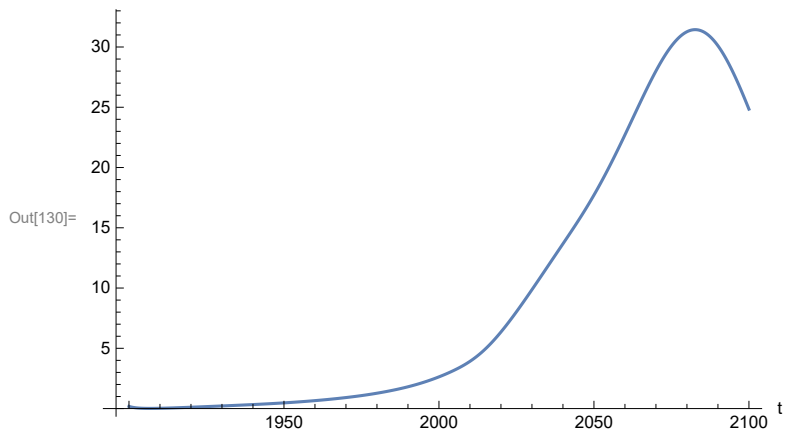
```
In[129]:= MinAndMax[testsim[{"Labor_Utilization1.serv_out_pc"}]]
```

Maximum is 877.873

Minimum is 87.4451

Plot persistent pollution index (normalized to 1970 value).

In[130]:= **SystemModelPlot**[testsim, {"Pollution_Dynamics1.PPoll_Index.y"}]



Find max and min of y values.

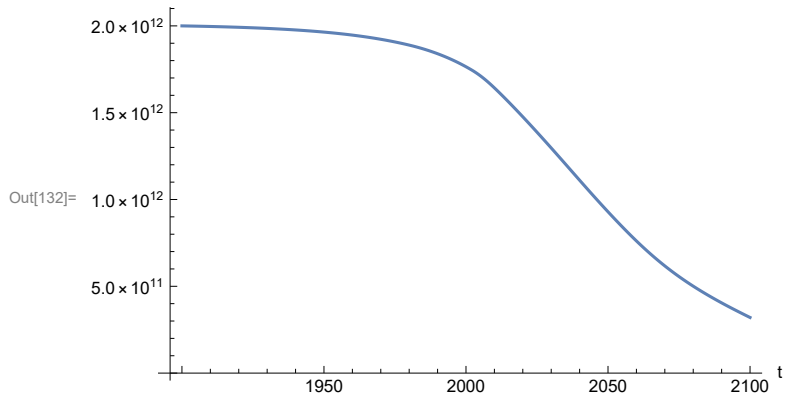
In[131]:= **MinAndMax**[testsim[{"Pollution_Dynamics1.PPoll_Index.y"}]]

Maximum is 31.4397

Minimum is 0.0150765

Plot non-renewable resources remaining.

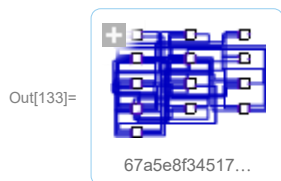
In[132]:= **SystemModelPlot**[testsim, {"NR_Resource_Utilization1.NR_Resources.y"}]



APPENDIX 38. Effects of mitigating the impact of air pollution on agricultural land yield, beginning calendar year 1970, Scenario 8, Experiment 3

Change the value of the air pollution effect multiplier switch time `t_air_poll_time`, to calendar year 1970, and execute the resulting scenario, plotting the variables shown in Figure 2.

```
In[133]:= newmysim1970 = SystemModel[mysim, <|"ParameterValues" → {"t_air_poll_time" → 1970} |>]
```



```
In[134]:= testsim1970 = SystemModelSimulate[newmysim1970]
```

Out[134]= SystemModelSimulationData [ Model: W67a5e8f345174c509bf550ba7faa5a4f
Time: 1.90×10^3 to 2.10×10^3]

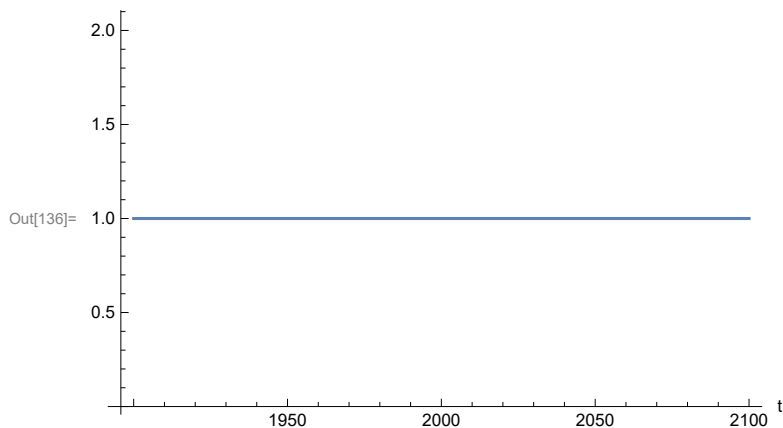
Show the value of `t_air_poll_time` (calendar year).

```
In[135]:= SystemModel[newmysim1970][{"ParameterValues", "t_air_poll_time"}]
```

Out[135]= {t_air_poll_time → 1970}

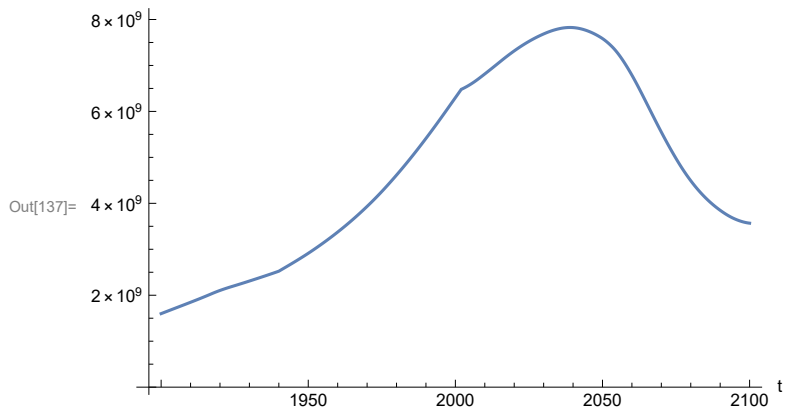
Plot air pollution multiplier of land yield.

```
In[136]:= SystemModelPlot[testsim1970, {"Food_Production1.s_yield_mlt_air_poll"}]
```



Plot the world population, people.

```
In[137]:= SystemModelPlot[testsim1970, {"Population_Dynamics1.Birth_Rate.pop"}]
```



Find max and min of y values.

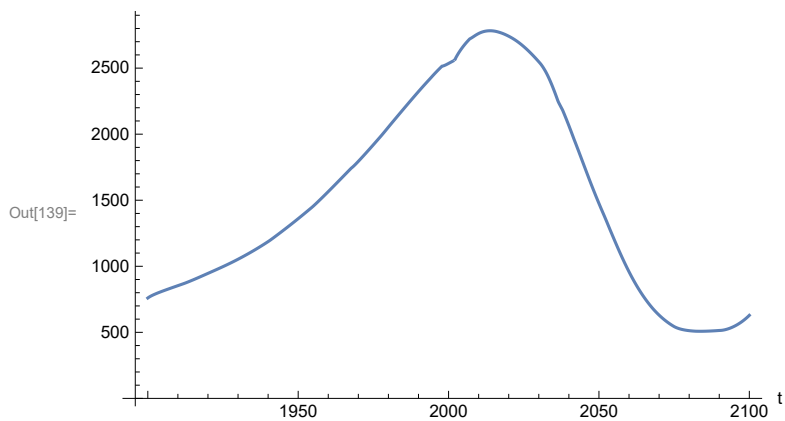
```
In[138]:= MinAndMax[testsim1970[{"Population_Dynamics1.Birth_Rate.pop"}]]
```

Maximum is 7.82639×10^9

Minimum is 1.6×10^9

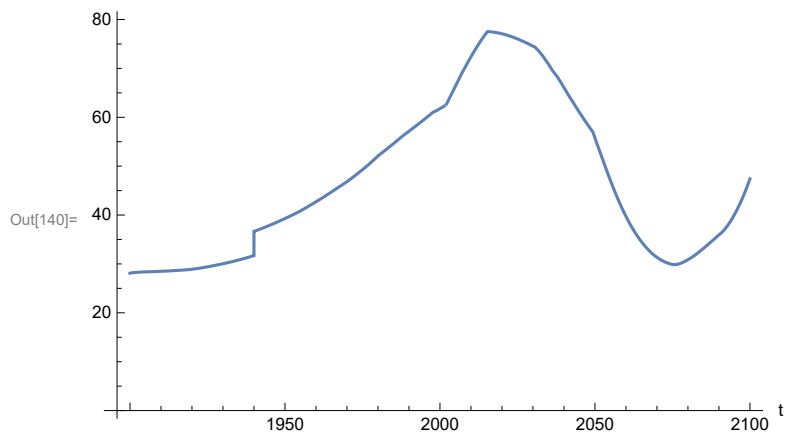
Plot land yield.

```
In[139]:= SystemModelPlot[testsim1970, {"Food_Production1.Land_Yield.y"}]
```



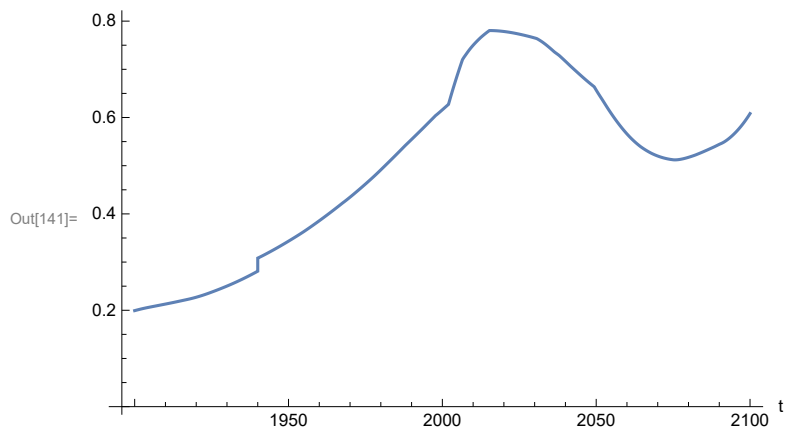
Plot life expectancy, in years.

```
In[140]:= SystemModelPlot[testsim1970, {"Life_Expectancy1.Life_Expectancy.y"}]
```



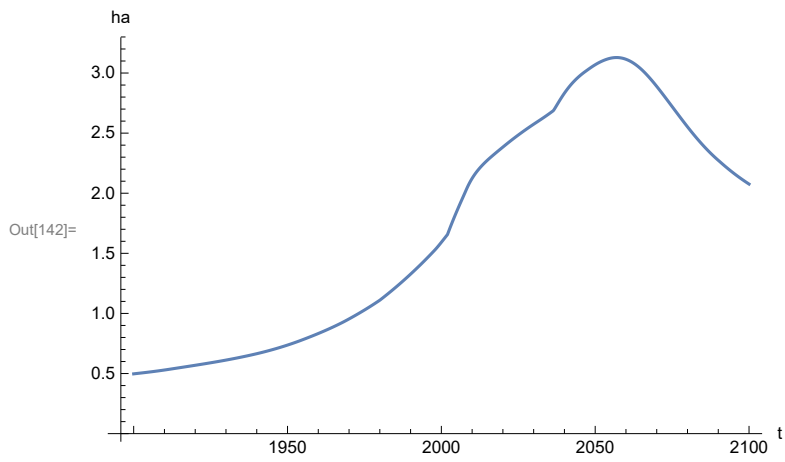
Plot the human welfare index.

```
In[141]:= SystemModelPlot[testsim1970, {"Human_Welfare_Index1.HWI_Human_Welfare_Index.hwi_human_welfare_index"}]
```



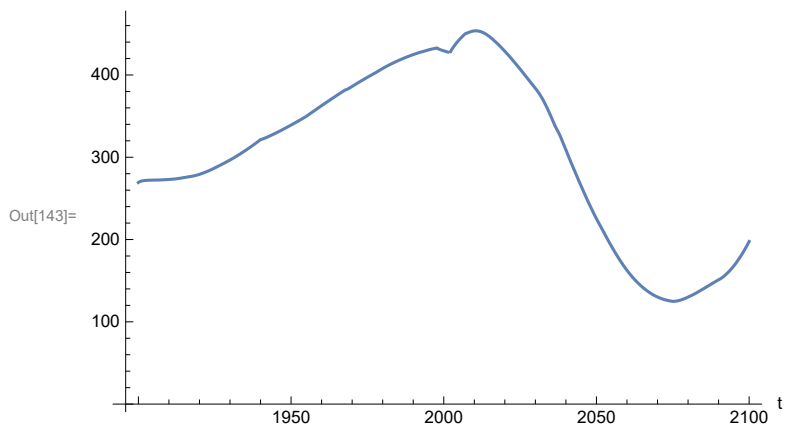
Plot the human ecological footprint, in hectares.


```
In[142]:= SystemModelPlot[testsim1970,
  {"Human_Ecological_Footprint1.HEF_Human_Ecological_Footprint.hef_human_ecological_
    _footprint"}]
```



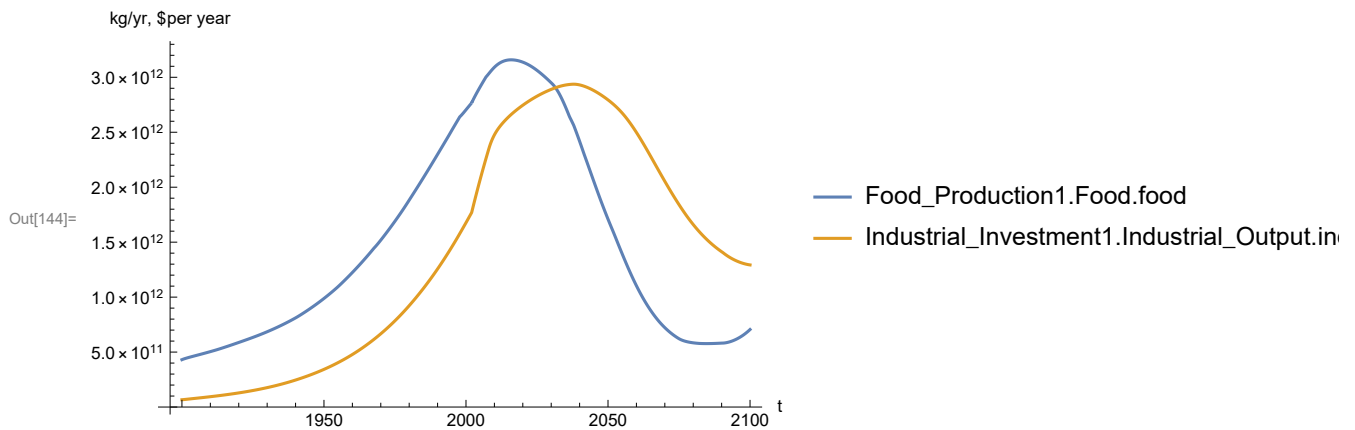
Plot per capita food production, kg/year.

```
In[143]:= SystemModelPlot[testsim1970, {"Food_Production1.Food_PC.y"}]
```



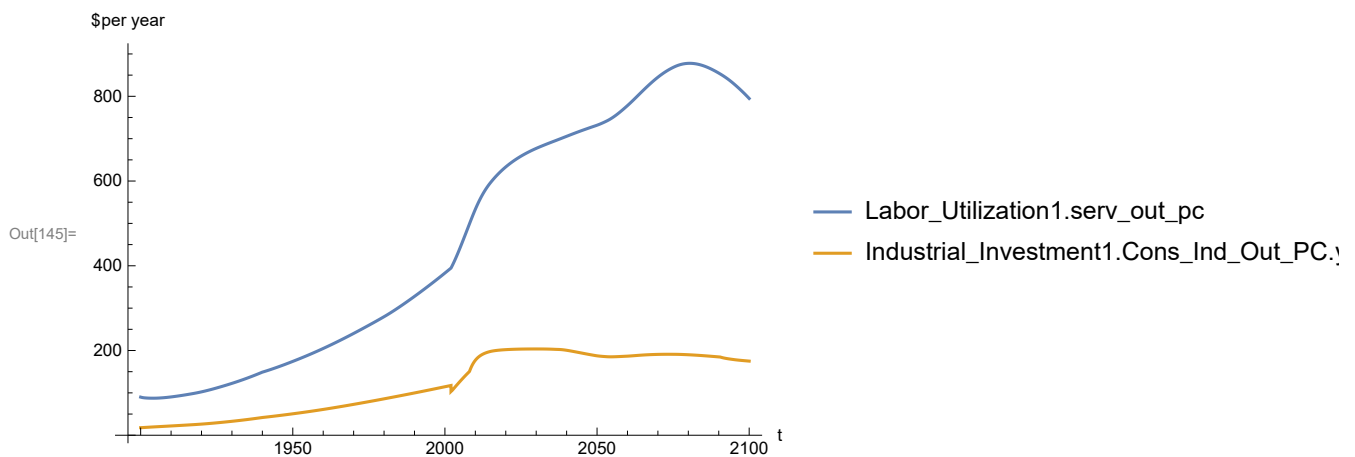
Plot total food production (kg/yr) and industrial output (in dollars).

```
In[144]:= SystemModelPlot[testsim1970, {"Food_Production1.Food.food",
  "Industrial_Investment1.Industrial_Output.industrial_output"}]
```



Plot labor utilization per capita and consolidated industrial output per capita (dollars/year).

```
In[145]:= SystemModelPlot[testsim1970,
  {"Labor_Utilization1.serv_out_pc", "Industrial_Investment1.Cons_Ind_Out_PC.y"}]
```



Find max and min of y values.

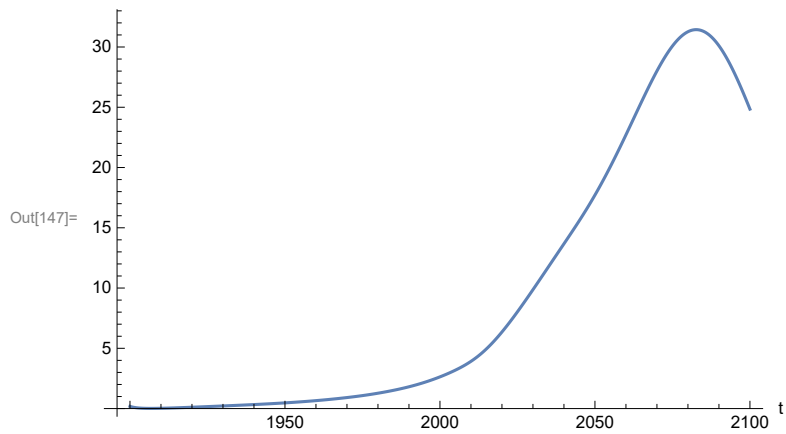
```
In[146]:= MinAndMax[testsim1970[{"Labor_Utilization1.serv_out_pc"}]]
```

Maximum is 877.873

Minimum is 87.4451

Plot persistent pollution index (normalized to 1970 value).

```
In[147]:= SystemModelPlot[testsim1970, {"Pollution_Dynamics1.PPoll_Index.y"}]
```



Find max and min of y values.

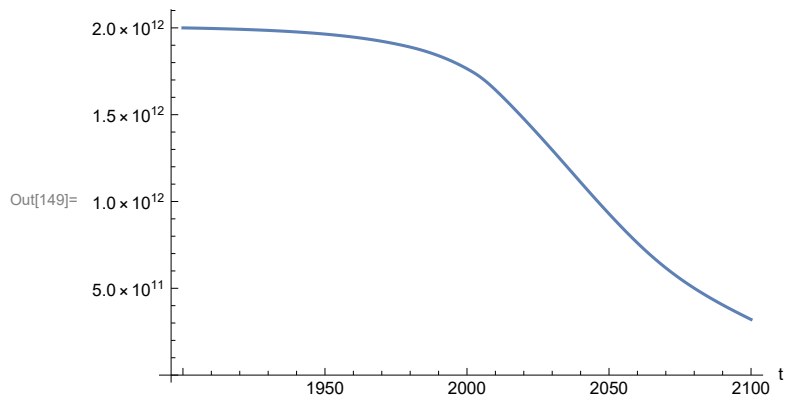
```
In[148]:= MinAndMax[testsim1970[{"Pollution_Dynamics1.PPoll_Index.y"}]]
```

Maximum is 31.4397

Minimum is 0.0150765

Plot non-renewable resources remaining.

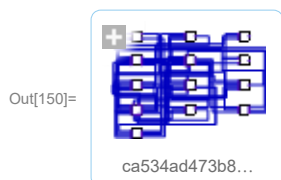
```
In[149]:= SystemModelPlot[testsim1970, {"NR_Resource_Utilization1.NR_Resources.y"}]
```



APPENDIX 39. "STRONG AIR POLLUTION" EFFECTS SCENARIO, Scenario 8, Experiment 4

Scenario 8 with air pollution effect on land yield changed as noted.

```
In[150]:= strsim = SystemModel[mysim, <|"ParameterValues" ->
  {"Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals" -> {0.7, 0.5, 0.3, 0.1}}|>]
```



```
In[151]:= basestrsim = SystemModelSimulate[strsim]
```

Out[151]= SystemModelSimulationData [ Model: Wca534ad473b84dc49b7bdf5c8f5211b
Time: 1.90×10^3 to 2.10×10^3]

Show Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals.

```
In[152]:= SystemModel[strsim] [
  {"ParameterValues", "Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[1]"}]
```

Out[152]= {Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[1] → 0.7}

```
In[153]:= SystemModel[strsim] [
  {"ParameterValues", "Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[2]"}]
```

Out[153]= {Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[2] → 0.5}

```
In[154]:= SystemModel[strsim] [
  {"ParameterValues", "Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[3]"}]
```

Out[154]= {Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[3] → 0.3}

```
In[155]:= SystemModel[strsim] [
  {"ParameterValues", "Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[4]"}]
```

Out[155]= {Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[4] → 0.1}

Show the value of t_air_poll_time (calendar year).

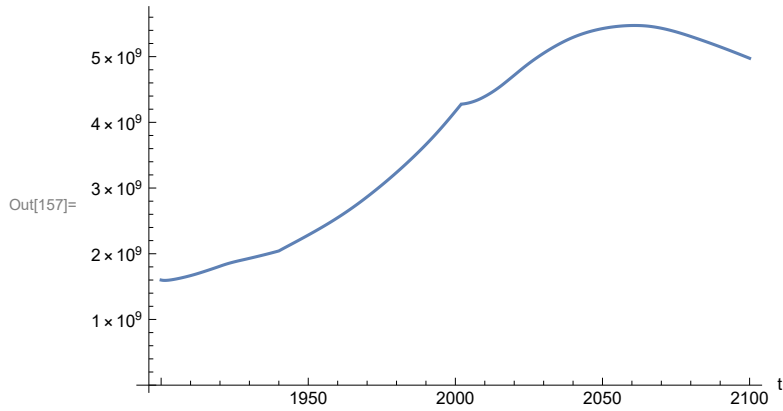
```
In[156]:= SystemModel[strsim] [{"ParameterValues", "t_air_poll_time"}]
```

Out[156]= {t_air_poll_time → 4000}

Plot the world population, people. Note that the peak population is about one billion less, and about

20 years later, than the peak population forecast by Experiments 1-3.

```
In[157]:= SystemModelPlot[basestransim, {"Population_Dynamics1.Birth_Rate.pop"}]
```

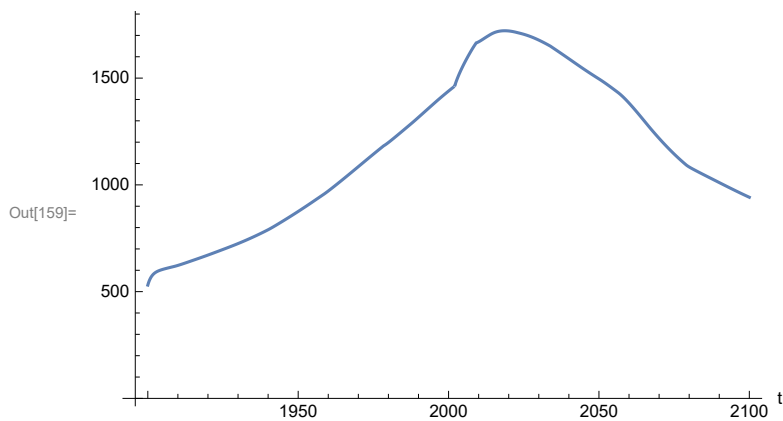


Find max and min of y values.

```
In[158]:= MinAndMax[basestransim[{"Population_Dynamics1.Birth_Rate.pop"}]]
Maximum is 5.47415 x 10^9
Minimum is 1.59431 x 10^9
```

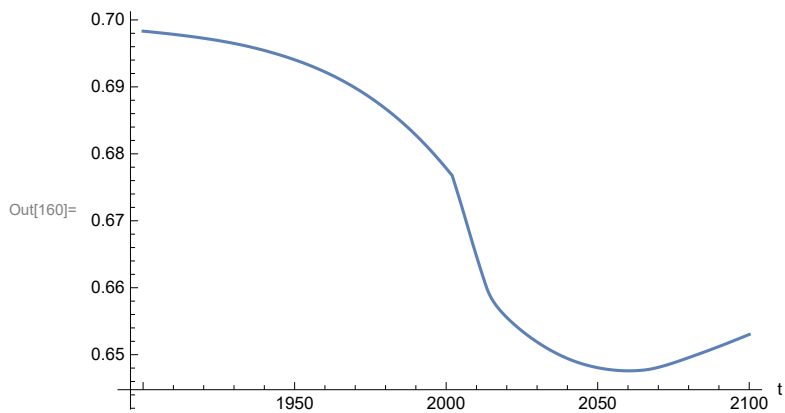
Plot land yield.

```
In[159]:= SystemModelPlot[basestransim, {"Food_Production1.Land_Yield.y"}]
```



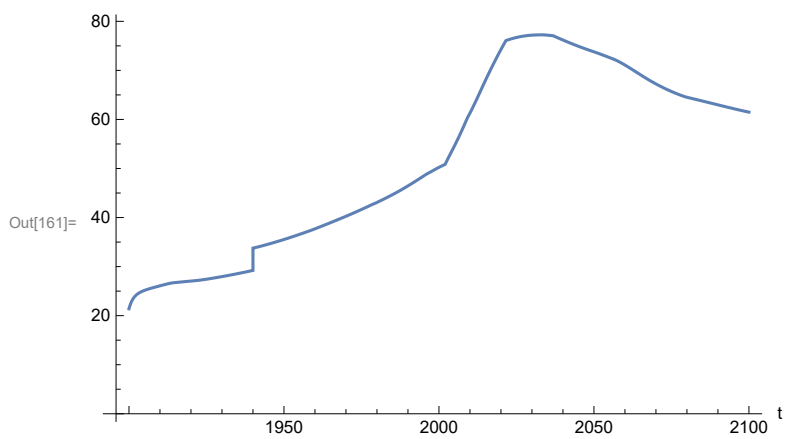
Plot multiplier of air pollution on land yield.

```
In[160]:= SystemModelPlot[basestransim, {"Food_Production1.s_yield_mlt_air_poll"}]
```



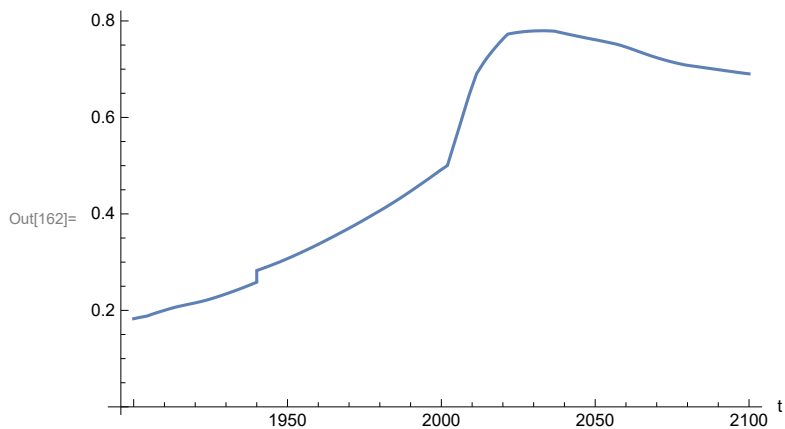
Plot life expectancy, in years.

```
In[161]:= SystemModelPlot[basestransim, {"Life_Expectancy1.Life_Expectancy.y"}]
```



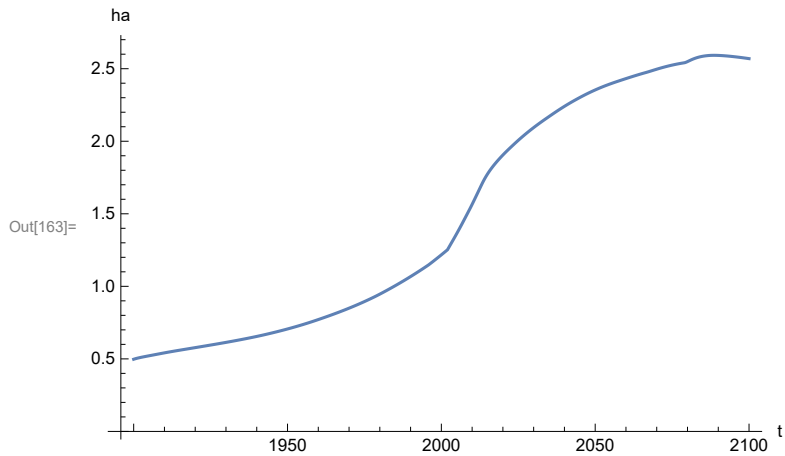
Plot the human welfare index.

```
In[162]:= SystemModelPlot[basestransim, {"Human_Welfare_Index1.HWI_Human_Welfare_Index.hwi_human_welfare_index"}]
```



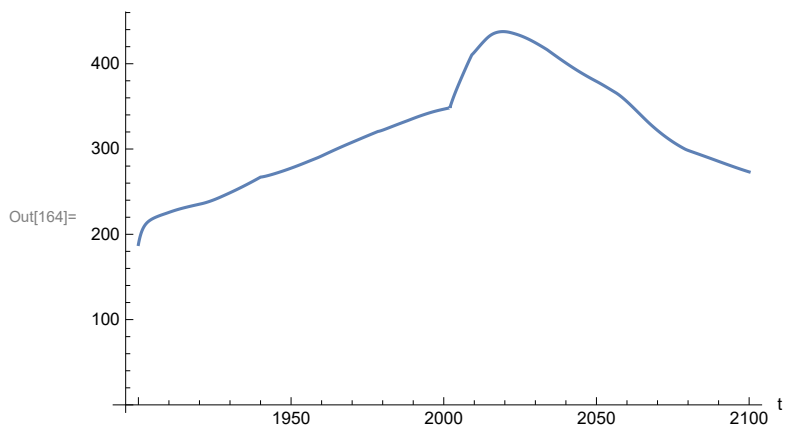
Plot the human ecological footprint, in hectares.

```
In[163]:= SystemModelPlot[basestrsim,
  {"Human_Ecological_Footprint1.HEF_Human_Ecological_Footprint.hef_human_ecological_
    _footprint"}]
```



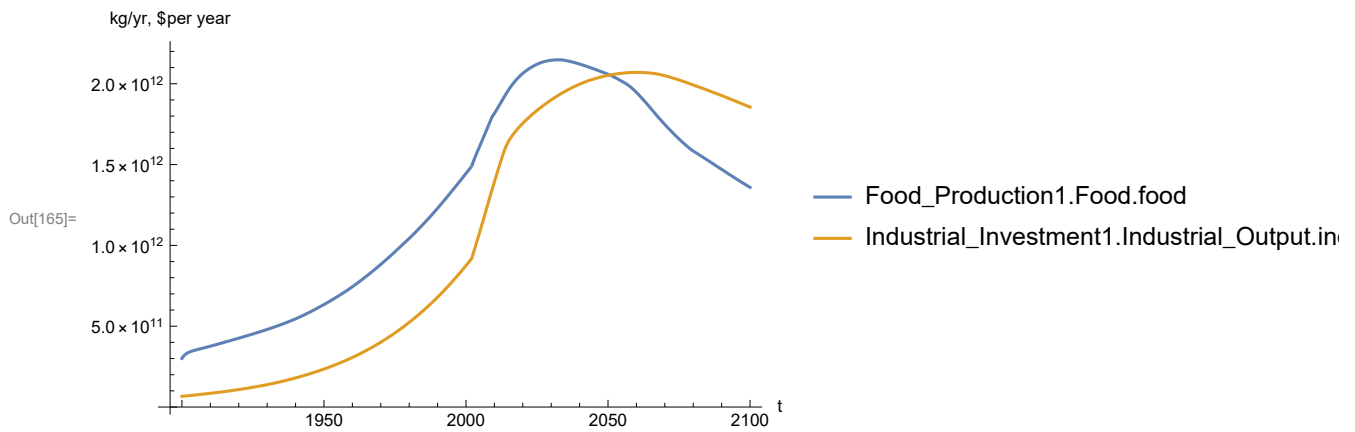
Plot per capita food production, kg/year.

```
In[164]:= SystemModelPlot[basestrsim, {"Food_Production1.Food_PC.y"}]
```



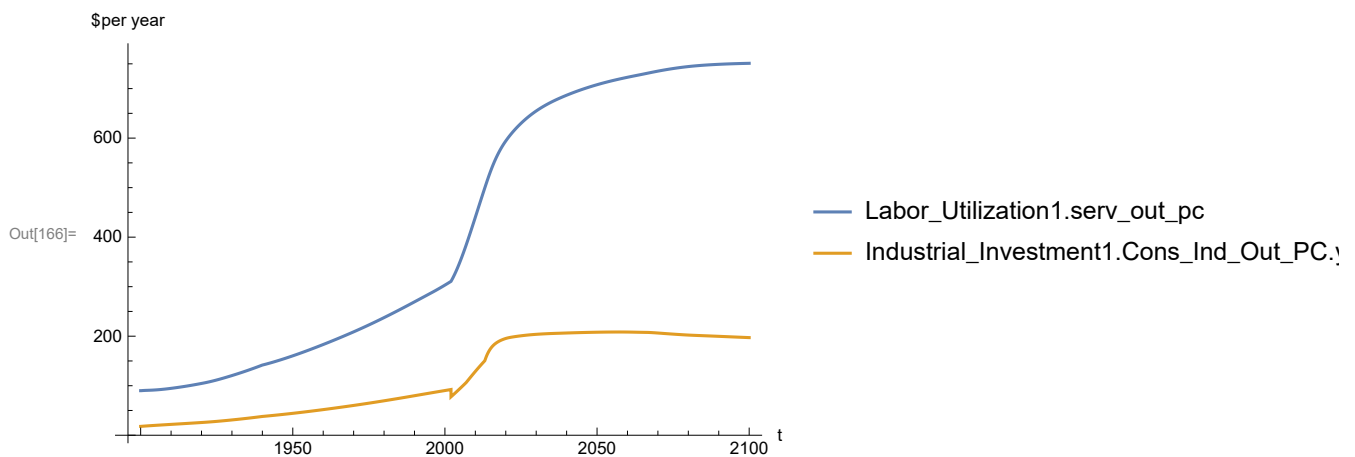
Plot total food production (kg/yr) and industrial output (in dollars).

```
In[165]:= SystemModelPlot[basestrnsim, {"Food_Production1.Food.food",
  "Industrial_Investment1.Industrial_Output.industrial_output"}]
```



Plot labor utilization per capita and consolidated industrial output per capita (dollars/year).

```
In[166]:= SystemModelPlot[basestrnsim,
  {"Labor_Utilization1.serv_out_pc", "Industrial_Investment1.Cons_Ind_Out_PC.y"}]
```



Find max and min of y values.

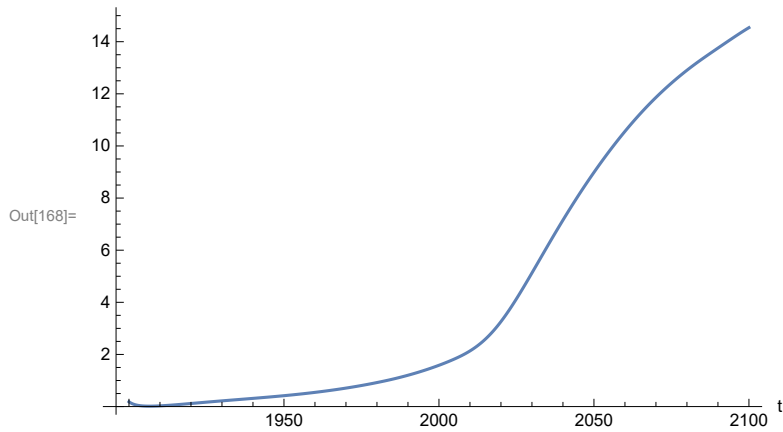
```
In[167]:= MinAndMax[basestrnsim[{"Labor_Utilization1.serv_out_pc"}]]
```

Maximum is 751.038

Minimum is 89.9974

Plot persistent pollution index (normalized to 1970 value).


```
In[168]:= SystemModelPlot[basestransim, {"Pollution_Dynamics1.PPoll_Index.y"}]
```



Find max and min of y values.

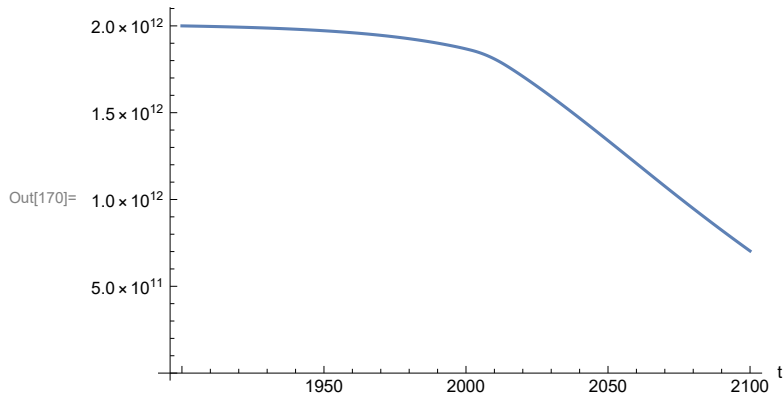
```
In[169]:= MinAndMax[basestransim[{"Pollution_Dynamics1.PPoll_Index.y"}]]
```

Maximum is 14.5389

Minimum is 0.0157768

Plot non-renewable resources remaining.

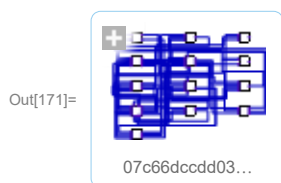
```
In[170]:= SystemModelPlot[basestransim, {"NR_Resource_Utilization1.NR_Resources.y"}]
```




APPENDIX 40. SEVERE LAND LOSS DUE TO AIR POLLUTION, Scenario 8, Experiment 5

Scenario 8 with air pollution effect on land yield changed as noted.

```
In[171]:= sevsim = SystemModel[mysim, <|"ParameterValues" ->
           {"Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals" -> {0.7, 0.1, 0.1, 0.1}}|>]
```



```
In[172]:= basesevsim = SystemModelSimulate[sevsim]
```

Out[172]= SystemModelSimulationData [ Model: W07c66dcccdd0340fba9c7dbad9e07d644
Time: 1.90×10^3 to 2.10×10^3]

Show Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals.

```
In[173]:= SystemModel[sevsim] [
           {"ParameterValues", "Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[1]"}]
```

Out[173]= {Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[1] → 0.7}

```
In[174]:= SystemModel[sevsim] [
           {"ParameterValues", "Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[2]"}]
```

Out[174]= {Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[2] → 0.1}

```
In[175]:= SystemModel[sevsim] [
           {"ParameterValues", "Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[3]"}]
```

Out[175]= {Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[3] → 0.1}

```
In[176]:= SystemModel[sevsim] [
           {"ParameterValues", "Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[4]"}]
```

Out[176]= {Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[4] → 0.1}

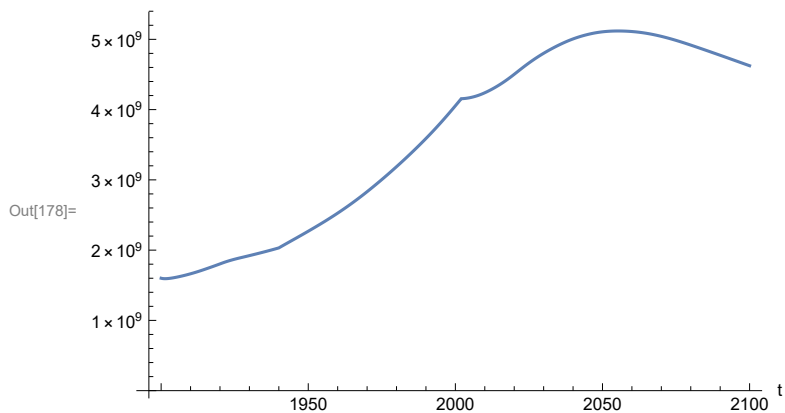
Show the value of t_air_poll_time (calendar year).

```
In[177]:= SystemModel[sevsim][{"ParameterValues", "t_air_poll_time"}]
```

```
Out[177]:= {t_air_poll_time → 4000}
```

Plot the world population, people.

```
In[178]:= SystemModelPlot[basesevsim, {"Population_Dynamics1.Birth_Rate.pop"}]
```



Find max and min of y values.

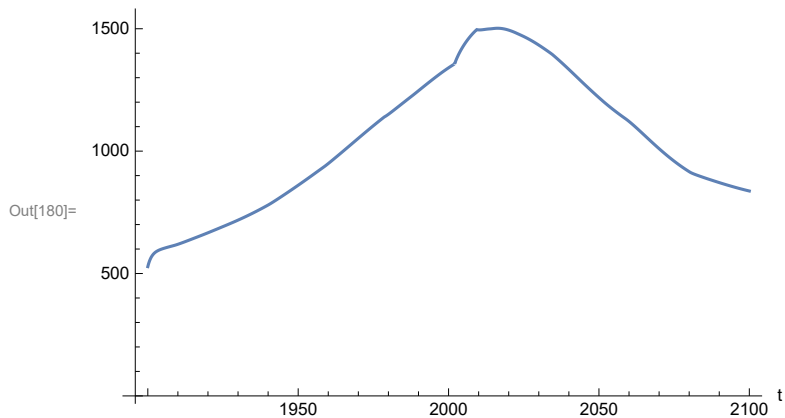
```
In[179]:= MinAndMax[basesevsim[{"Population_Dynamics1.Birth_Rate.pop"}]]
```

Maximum is 5.11896×10^9

Minimum is 1.59367×10^9

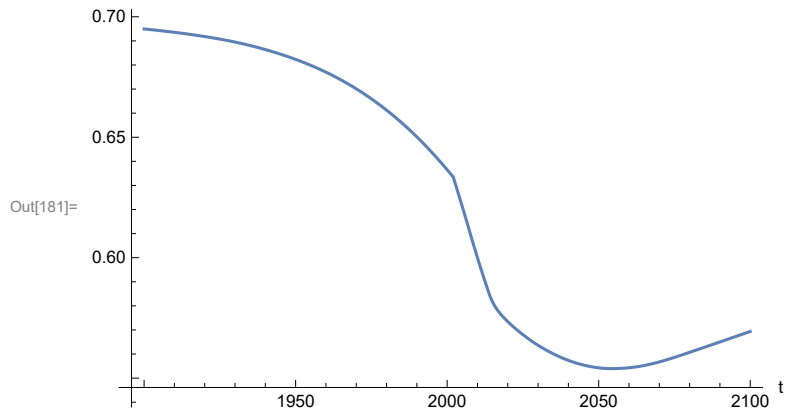
Plot land yield.

```
In[180]:= SystemModelPlot[basesevsim, {"Food_Production1.Land_Yield.y"}]
```



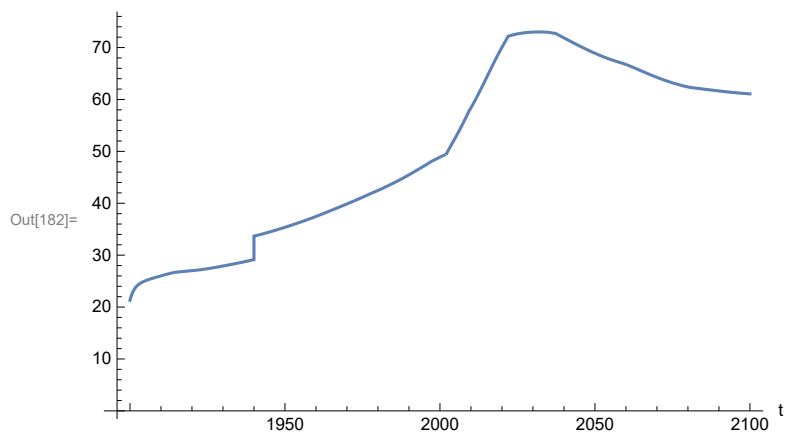
Plot multiplier of air pollution on land yield.

```
In[181]:= SystemModelPlot[basesevsim, {"Food_Production1.s_yield_mlt_air_poll"}]
```



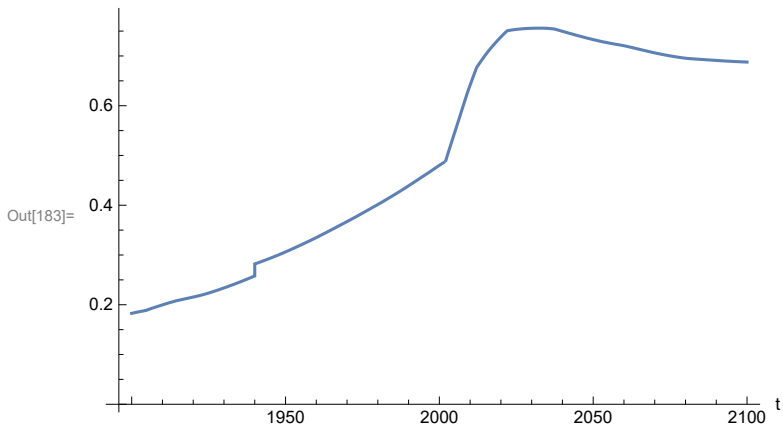
Plot life expectancy, in years.

```
In[182]:= SystemModelPlot[basesevsim, {"Life_Expectancy1.Life_Expectancy.y"}]
```



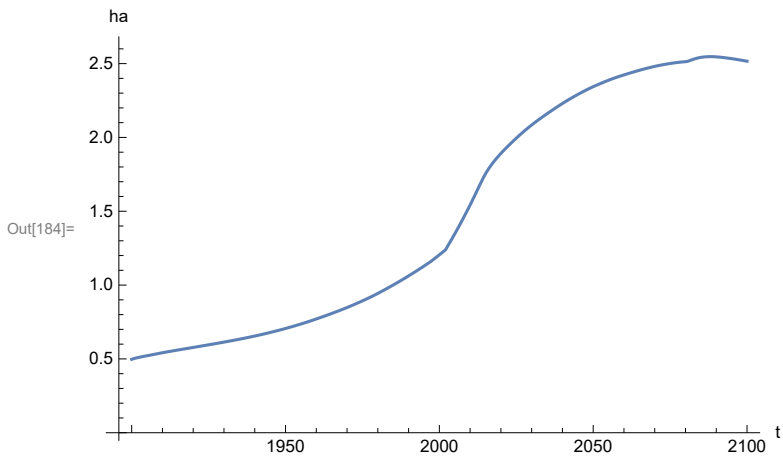
Plot the human welfare index.

```
In[183]:= SystemModelPlot[basesevsim,
  {"Human_Welfare_Index1.HWI_Human_Welfare_Index.hwi_human_welfare_index"}]
```



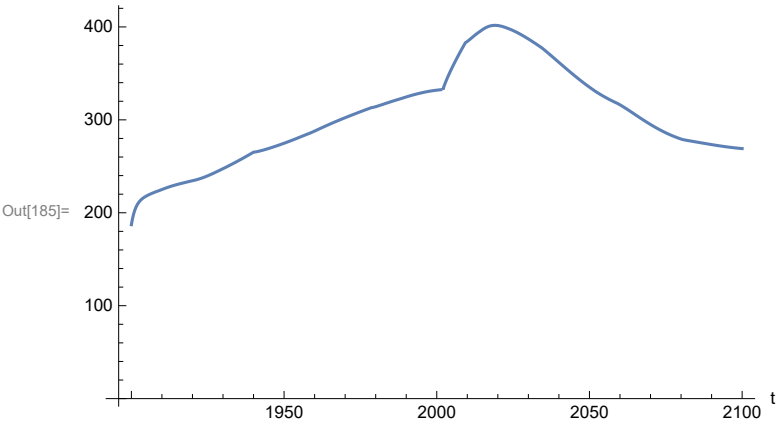
Plot the human ecological footprint, in hectares.

```
In[184]:= SystemModelPlot[basesevsim,
  {"Human_Ecological_Footprint1.HEF_Human_Ecological_Footprint.hef_human_ecological_footprint"}]
```



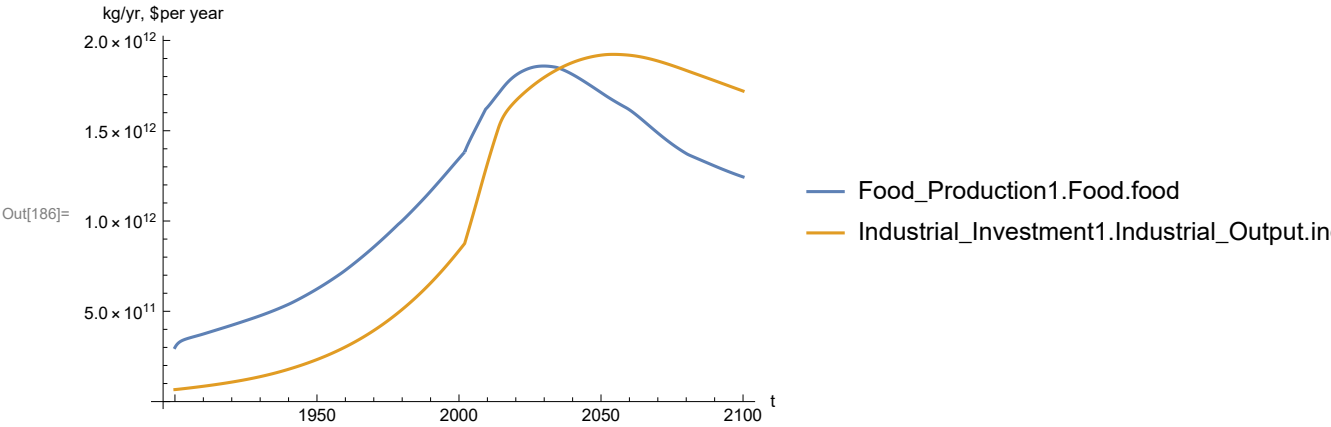
Plot per capita food production, kg/year.

```
In[185]:= SystemModelPlot[basesevsim, {"Food_Production1.Food_PC.y"}]
```



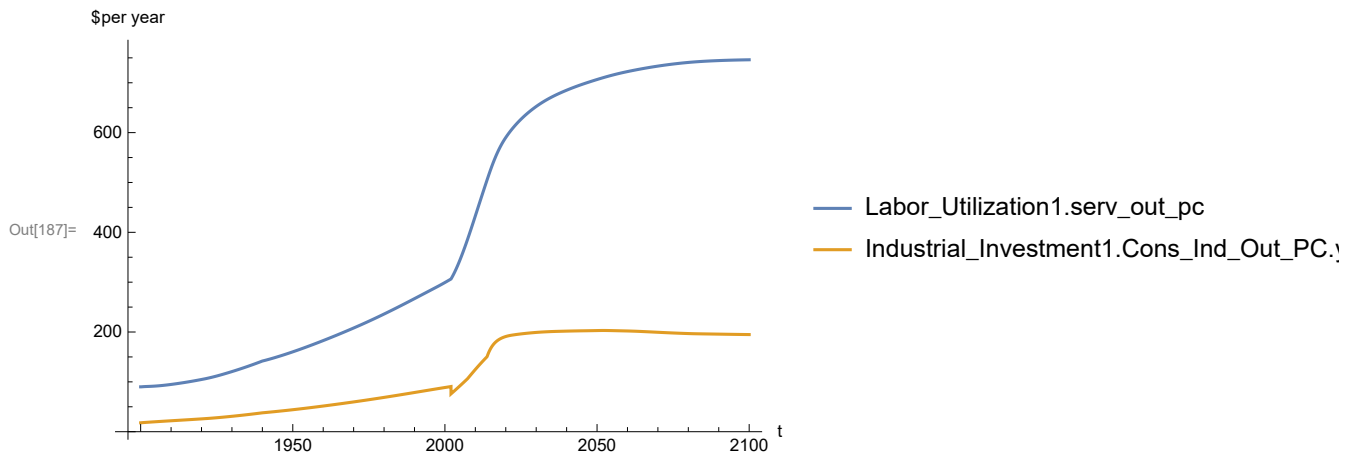
Plot total food production (kg/yr) and industrial output (in dollars).

```
In[186]:= SystemModelPlot[basesevsim, {"Food_Production1.Food.food",  
"Industrial_Investment1.Industrial_Output.industrial_output"}]
```



Plot consolidated industrial output per capita (dollars/year).

```
In[187]:= SystemModelPlot[basesevsim,
  {"Labor_Utilization1.serv_out_pc", "Industrial_Investment1.Cons_Ind_Out_PC.y"}]
```



Find max and min of y values.

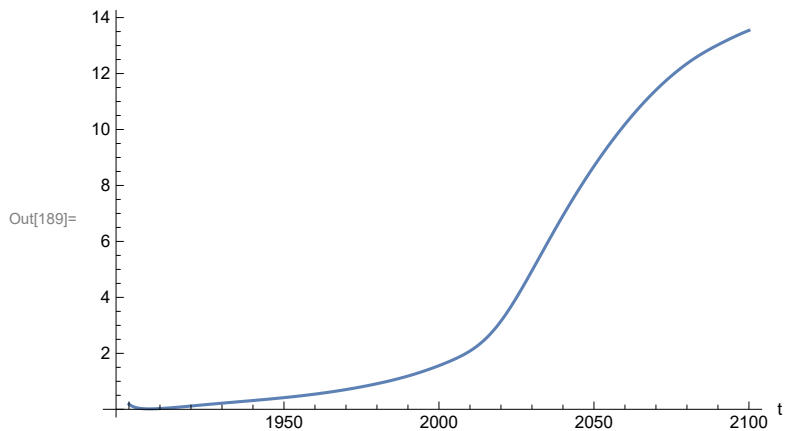
```
In[188]:= MinAndMax[basesevsim[{"Labor_Utilization1.serv_out_pc"}]]
```

Maximum is 746.123

Minimum is 90.

Plot persistent pollution index (normalized to 1970 value).

```
In[189]:= SystemModelPlot[basesevsim, {"Pollution_Dynamics1.PPoll_Index.y"}]
```



Find max and min of y values.

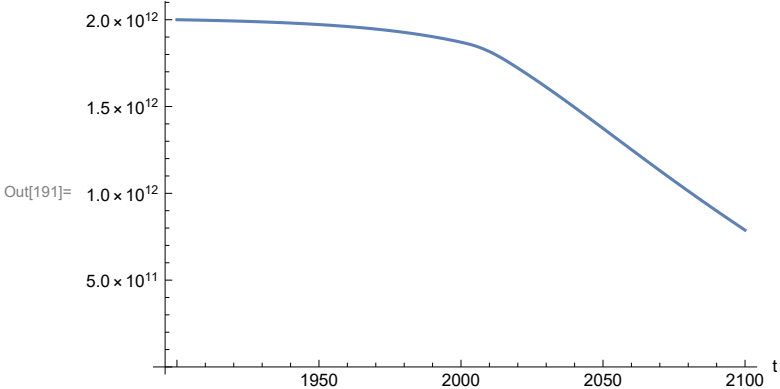
```
In[190]:= MinAndMax[basesevsim[{"Pollution_Dynamics1.PPoll_Index.y"}]]
```

Maximum is 13.5418

Minimum is 0.0157849

Plot non-renewable resources remaining.

```
In[191]:= SystemModelPlot[basesevsim, {"NR_Resource_Utilization1.NR_Resources.y"}]
```



APPENDIX 41. BENCHMARK SCENARIO 9, Experiment 1

Define a function that extracts range data from scenario data. (The right-hand-side of this definition is specific to a *World3* data structure and assumes that the function whose range is being extracted is globally (i.e., not piecewise) defined.)

```
In[1]:= RangeData[data_] := data[[1]][[4]][[3]];
```

Define a procedure to determine and print minimum and maximum of “y” values.

```
In[2]:= MinAndMax[data_] := (myscenseries = RangeData[data];  
Print["Maximum is ", Max[myscenseries]]; Print["Minimum is ", Min[myscenseries]])
```

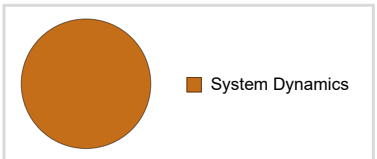
Here are some high-level properties of Benchmark Scenario 9.

```
In[3]:= mysim = SystemModel["SystemDynamics.WorldDynamics.World3.Scenario_9"]
```



```
In[4]:= mysummary = mysim["Summary"]
```

Out[4]=

ModelName	SystemDynamics.WorldDynamics.World3.Scenario_9
Description	Combining the measures of Scenarios #6 and #8
SimulationModel	True
Plots	0
Components	106
Balanced	True
SystemEquations	1583
SystemVariables	1583
Domain	

Show the value of `t_air_poll_time`.

```
In[5]= SystemModel[mysim][{"ParameterValues", "t_air_poll_time"}]
```

```
Out[5]= {t_air_poll_time → 4000}
```

Show Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals.

```
In[6]= SystemModel[mysim][
  {"ParameterValues", "Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[1]"}]
```

```
Out[6]= {Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[1] → 1}
```

```
In[7]= SystemModel[mysim][
  {"ParameterValues", "Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[2]"}]
```

```
Out[7]= {Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[2] → 1}
```

```
In[8]= SystemModel[mysim][
  {"ParameterValues", "Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[3]"}]
```

```
Out[8]= {Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[3] → 0.7}
```

```
In[9]= SystemModel[mysim][
  {"ParameterValues", "Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[4]"}]
```

```
Out[9]= {Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[4] → 0.4}
```

Show Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_2.y_vals.

```
In[10]= SystemModel[mysim][
  {"ParameterValues", "Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_2.y_vals[1]"}]
```

```
Out[10]= {Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_2.y_vals[1] → 1}
```

```
In[11]= SystemModel[mysim][
  {"ParameterValues", "Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_2.y_vals[2]"}]
```

```
Out[11]= {Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_2.y_vals[2] → 1}
```

```
In[12]= SystemModel[mysim][
  {"ParameterValues", "Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_2.y_vals[3]"}]
```

```
Out[12]= {Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_2.y_vals[3] → 0.98}
```

```
In[13]= SystemModel[mysim][
  {"ParameterValues", "Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_2.y_vals[4]"}]
```

```
Out[13]= {Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_2.y_vals[4] → 0.95}
```

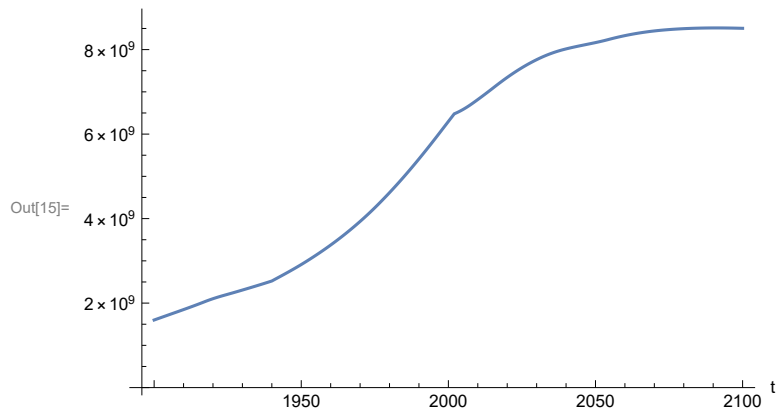
Execute Benchmark Simulation 9 and plot the variables shown in Figure 2.

In[14]:= **basesim = SystemModelSimulate[mysim]**

Out[14]= SystemModelSimulationData [ Model: Scenario_9
Time: 1.90×10^3 to 2.10×10^3]

Plot total population, people.

In[15]:= **SystemModelPlot[basesim, {"Population_Dynamics1.Birth_Rate.pop"}]**



Find max and min of population values.

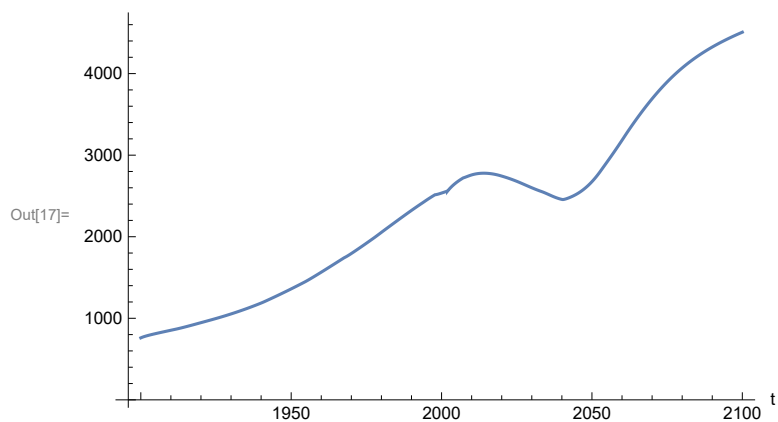
In[16]:= **MinAndMax[basesim[{"Population_Dynamics1.Birth_Rate.pop"}]]**

Maximum is 8.51279×10^9

Minimum is 1.6×10^9

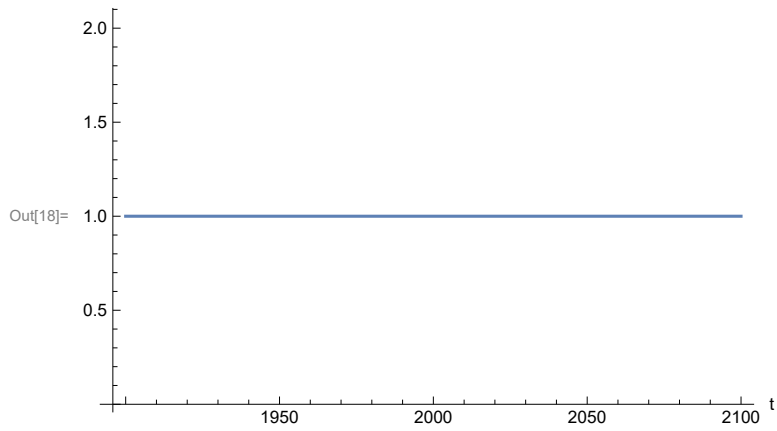
Plot land yield.

In[17]:= **SystemModelPlot[basesim, {"Food_Production1.Land_Yield.y"}]**



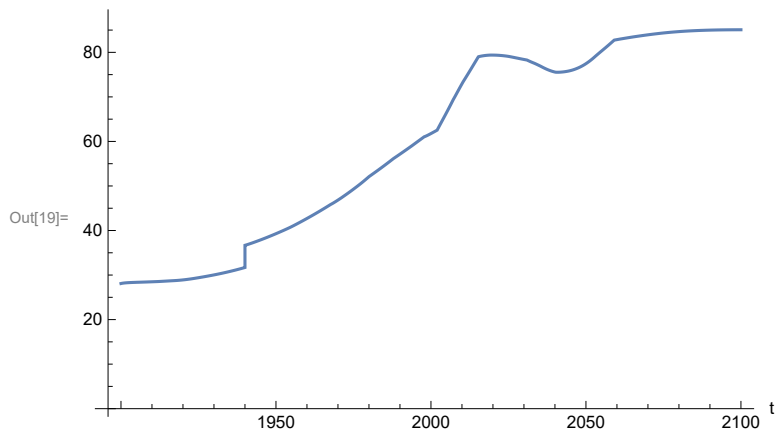
Plot multiplier of air pollution on land yield.

```
In[18]:= SystemModelPlot[basesim, {"Food_Production1.s_yield_mlt_air_poll"}]
```



Plot life expectancy, years.

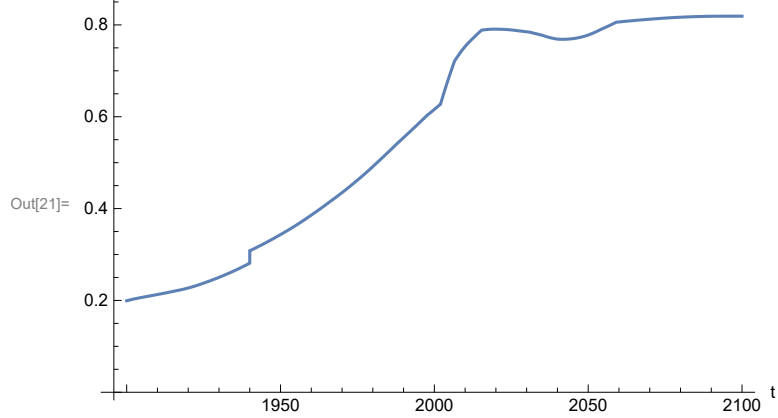
```
In[19]:= SystemModelPlot[basesim, {"Life_Expectancy1.Life_Expectancy.y"}]
```



```
In[20]:=
```

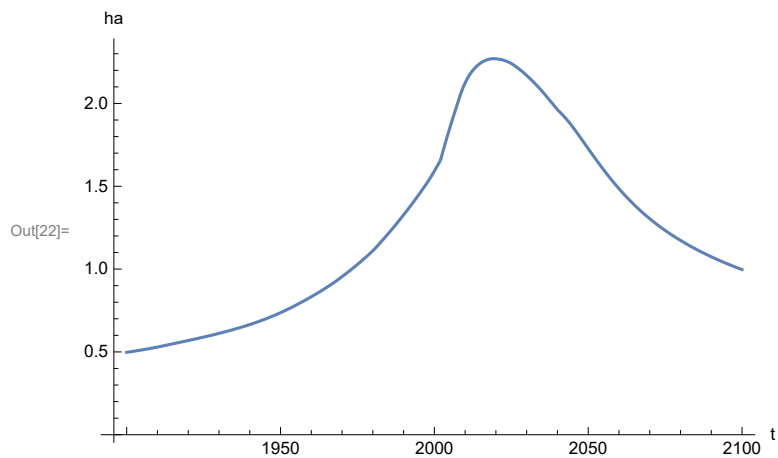
Plot human welfare index.

```
In[21]:= SystemModelPlot[basesim,
  {"Human_Welfare_Index1.HWI_Human_Welfare_Index.hwi_human_welfare_index"}]
```



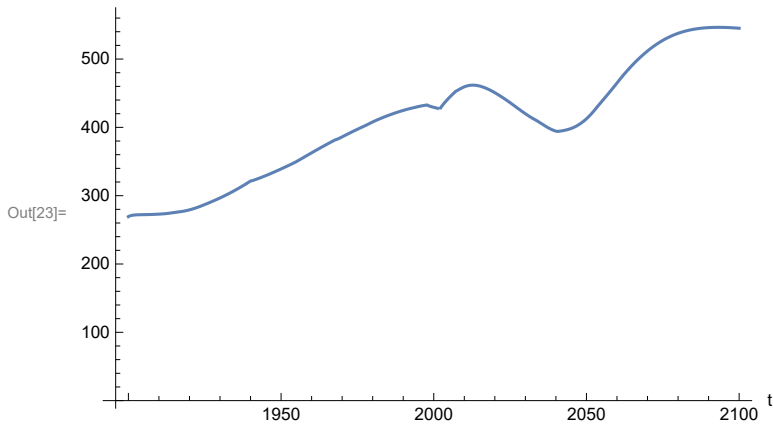
Plot per capita ecological footprint, hectares.

```
In[22]:= SystemModelPlot[basesim,
  {"Human_Ecological_Footprint1.HEF_Human_Ecological_Footprint.hef_human_ecological_footprint"}]
```



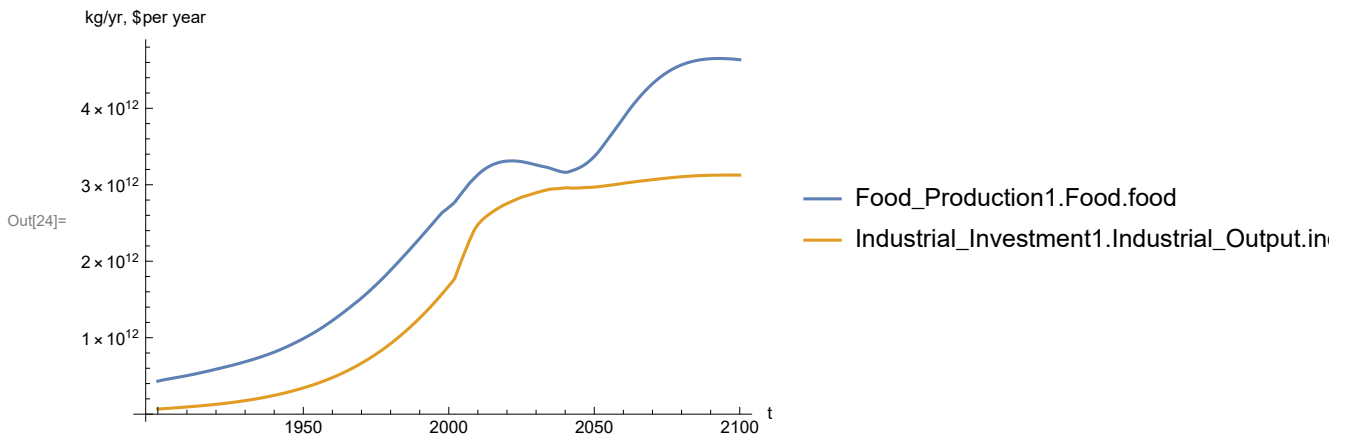
Plot food production per capita (kg/year).

In[23]:= SystemModelPlot[basesim, {"Food_Production1.Food_PC.y"}]



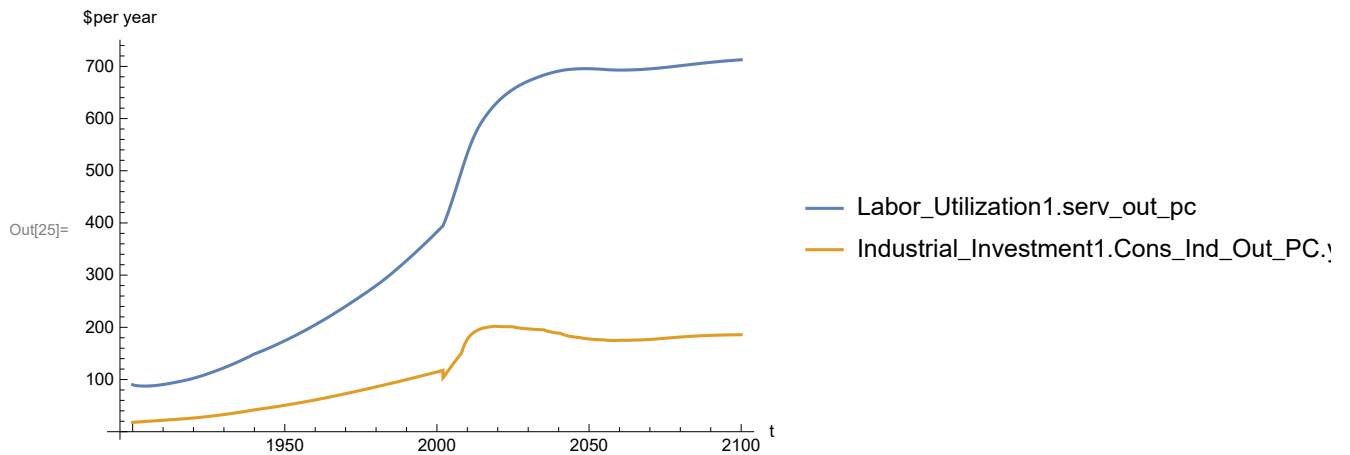
Plot total food production (kg/year), and industrial output (dollars/year).

In[24]:= SystemModelPlot[basesim, {"Food_Production1.Food.food",
"Industrial_Investment1.Industrial_Output.industrial_output"}]



Plot labor utilization per capita (dollars/year), and consolidated industrial output per capita (dollars/year)

```
In[25]:= SystemModelPlot[basesim,
  {"Labor_Utilization1.serv_out_pc", "Industrial_Investment1.Cons_Ind_Out_PC.y"}]
```



Find max and min of y values.

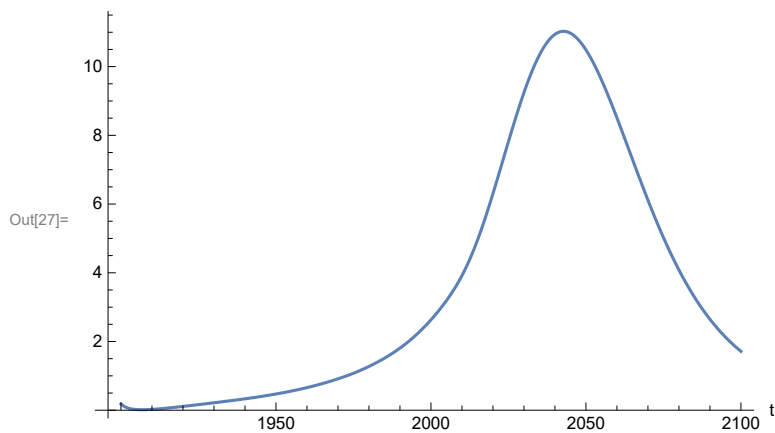
```
In[26]:= MinAndMax[basesim[{"Labor_Utilization1.serv_out_pc"}]]
```

Maximum is 712.65

Minimum is 87.4451

Plot persistent pollution index.

```
In[27]:= SystemModelPlot[basesim, {"Pollution_Dynamics1.PPoll_Index.y"}]
```



Find max and min of y values.

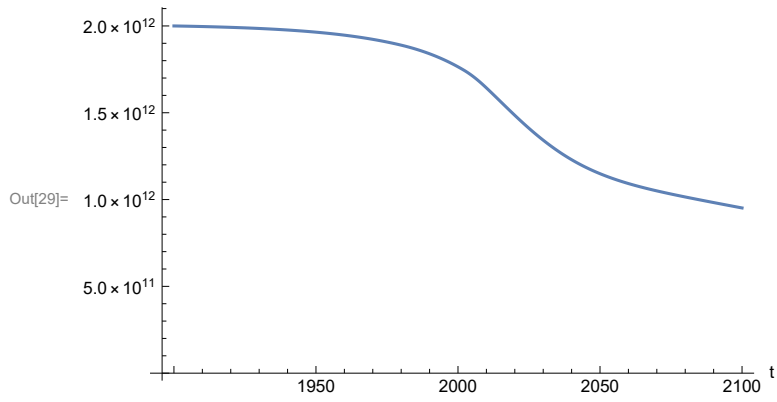
```
In[28]:= MinAndMax[basesim[{"Pollution_Dynamics1.PPoll_Index.y"}]]
```

Maximum is 11.028

Minimum is 0.0150765

Plot non-renewable resources remaining.

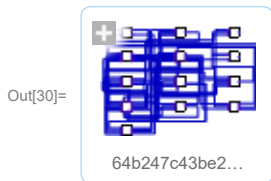
In[29]:= SystemModelPlot[basesim, {"NR_Resource_Utilization1.NR_Resources.y"}]



APPENDIX 42. Effects of mitigating the impact of air pollution on agricultural land yield, beginning calendar year 2020, Scenario 9, Experiment 2

Change the value of the air pollution effect multiplier switch time `t_air_poll_time`, to calendar year 2020, and execute the resulting scenario, plotting the variables shown in Figure 2.

```
In[30]:= newmysim = SystemModel[mysim, <|"ParameterValues" → {"t_air_poll_time" → 2020}|>]
```



```
In[31]:= testsim = SystemModelSimulate[newmysim]
```

Out[31]= SystemModelSimulationData [  Model: W64b247c43be24bcc8d206945229eb385
Time: 1.90×10^3 to 2.10×10^3]

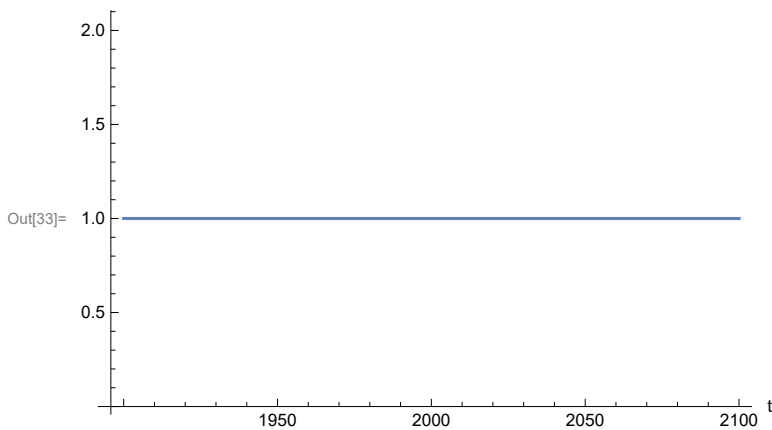
Show the value of `t_air_poll_time` (calendar year).

```
In[32]:= SystemModel[newmysim][{"ParameterValues", "t_air_poll_time"}]
```

Out[32]= {t_air_poll_time → 2020}

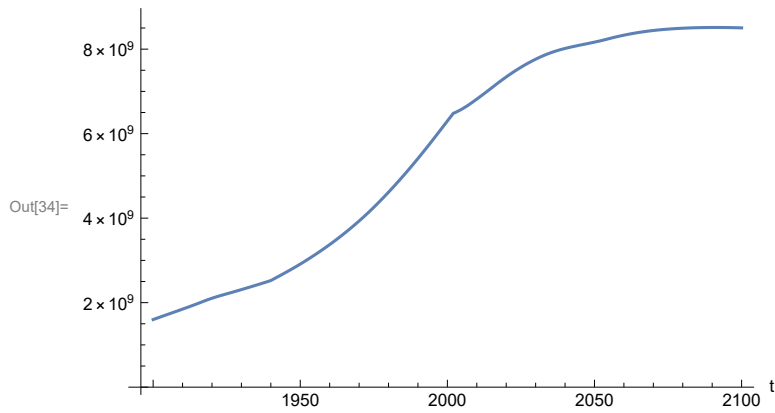
Plot air pollution multiplier of land yield.

```
In[33]:= SystemModelPlot[testsim, {"Food_Production1.s_yield_mlt_air_poll"}]
```



Plot the world population, people.

```
In[34]:= SystemModelPlot[testsim, {"Population_Dynamics1.Birth_Rate.pop"}]
```



Find max and min of y values.

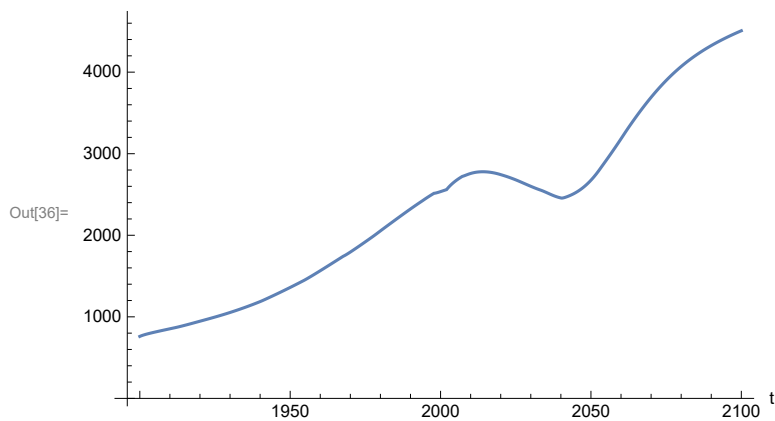
```
In[35]:= MinAndMax[testsim[{"Population_Dynamics1.Birth_Rate.pop"}]]
```

Maximum is 8.51279×10^9

Minimum is 1.6×10^9

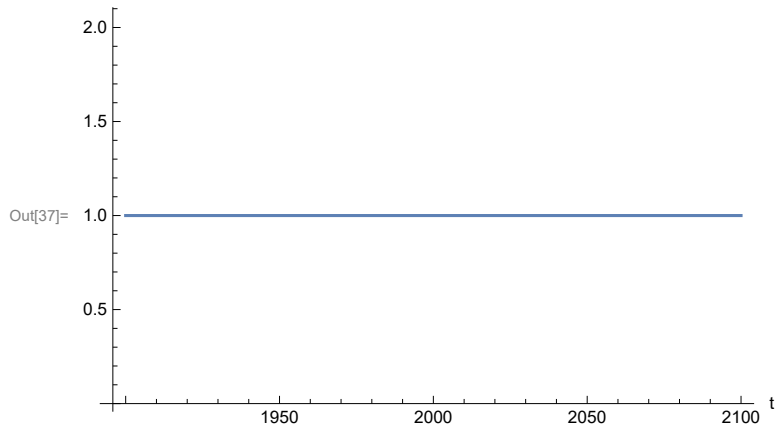
Plot land yield.

```
In[36]:= SystemModelPlot[testsim, {"Food_Production1.Land_Yield.y"}]
```



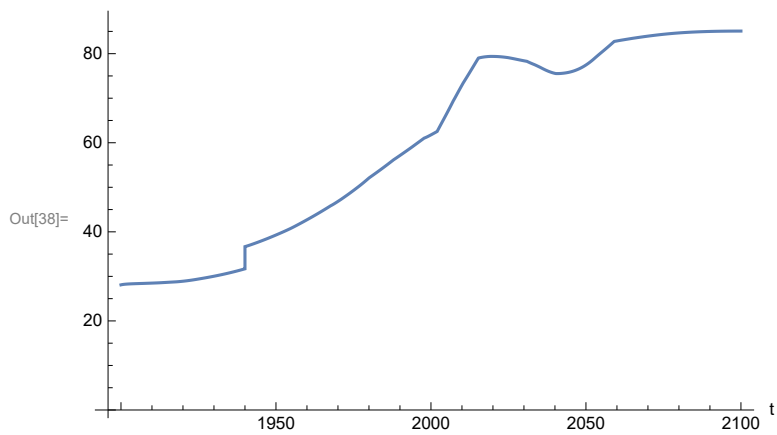
Plot multiplier of air pollution on land yield.

```
In[37]:= SystemModelPlot[testsim, {"Food_Production1.s_yield_mlt_air_poll"}]
```



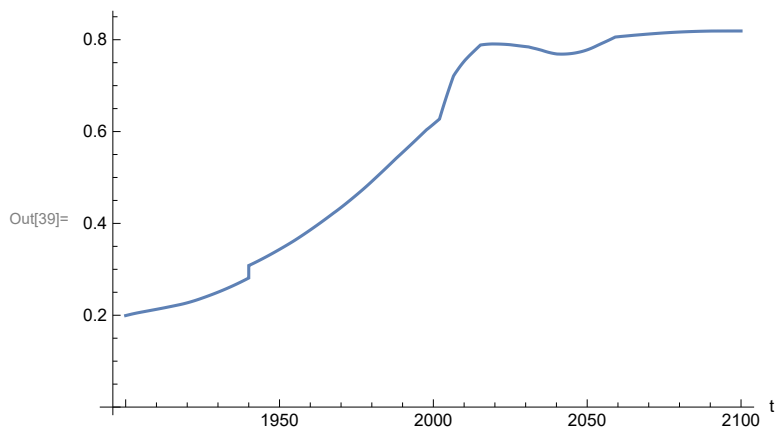
Plot life expectancy, in years.

```
In[38]:= SystemModelPlot[testsim, {"Life_Expectancy1.Life_Expectancy.y"}]
```



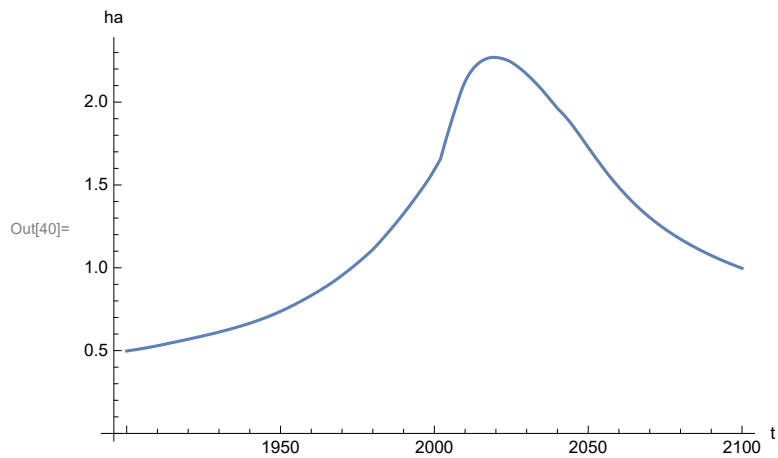
Plot the human welfare index.

```
In[39]:= SystemModelPlot[testsim, {"Human_Welfare_Index1.HWI_Human_Welfare_Index.hwi_human_welfare_index"}]
```



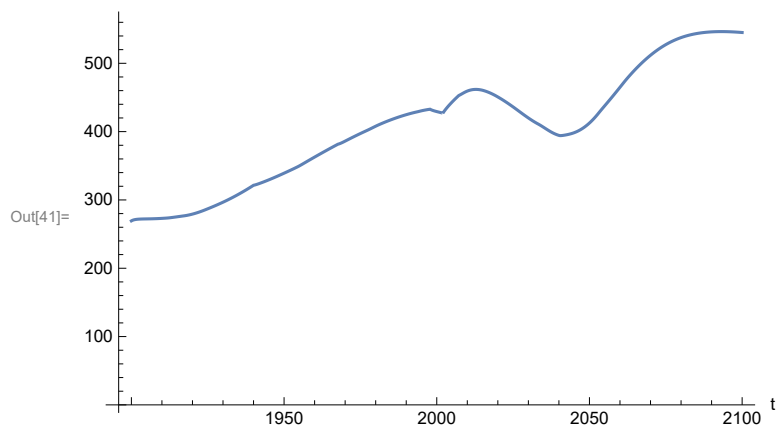
Plot the human ecological footprint, in hectares.

```
In[40]:= SystemModelPlot[testsim,
  {"Human_Ecological_Footprint1.HEF_Human_Ecological_Footprint.hef_human_ecological_
    _footprint"}]
```



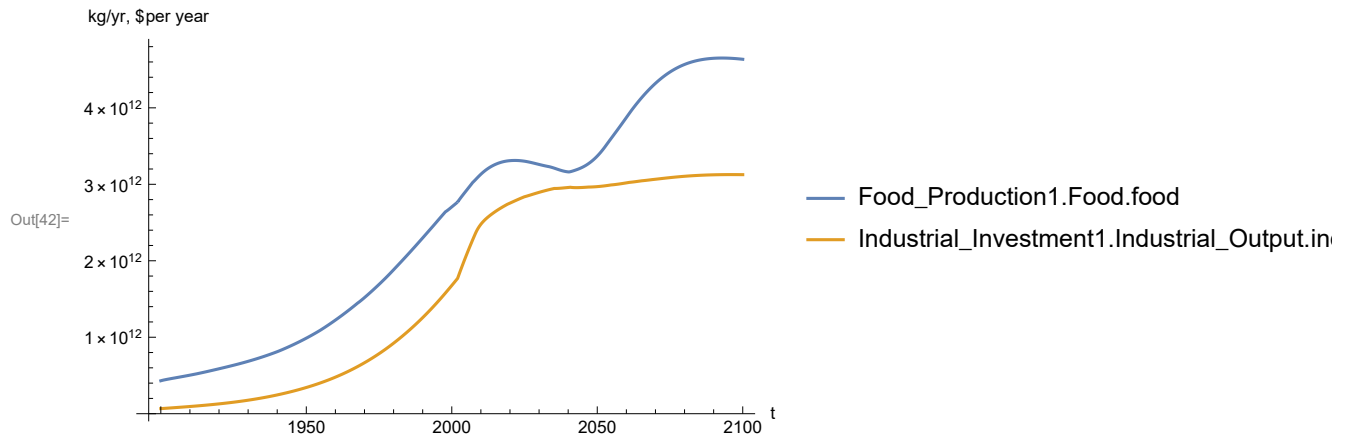
Plot per capita food production, kg/year.

```
In[41]:= SystemModelPlot[testsim, {"Food_Production1.Food_PC.y"}]
```



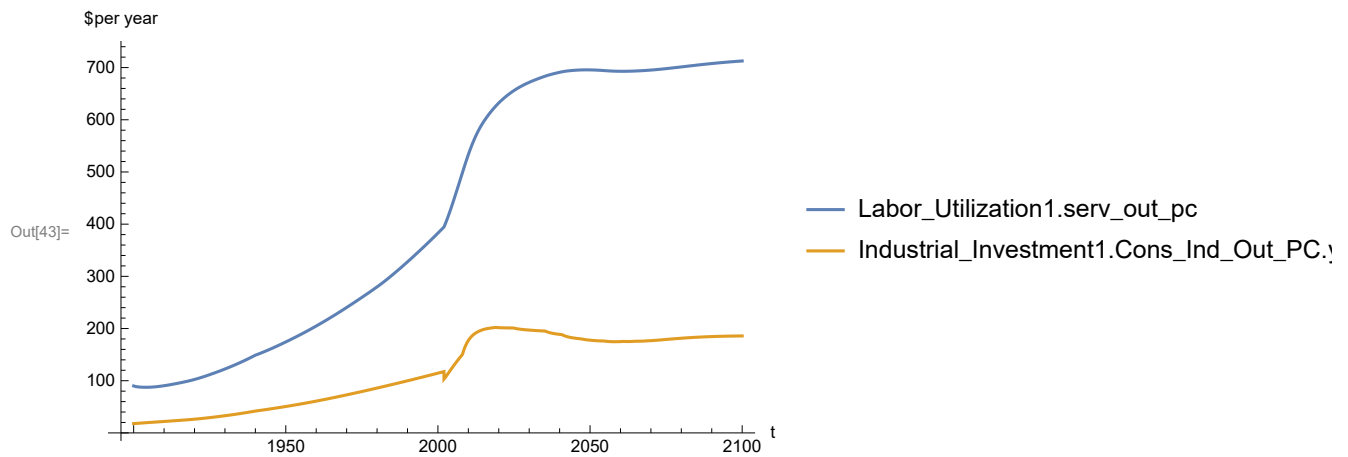
Plot total food production (kg/yr) and industrial output (in dollars).

```
In[42]:= SystemModelPlot[testsim, {"Food_Production1.Food.food",
  "Industrial_Investment1.Industrial_Output.industrial_output"}]
```



Plot consolidated industrial output per capita (dollars/year).

```
In[43]:= SystemModelPlot[testsim,
  {"Labor_Utilization1.serv_out_pc", "Industrial_Investment1.Cons_Ind_Out_PC.y"}]
```



Find max and min of y values.

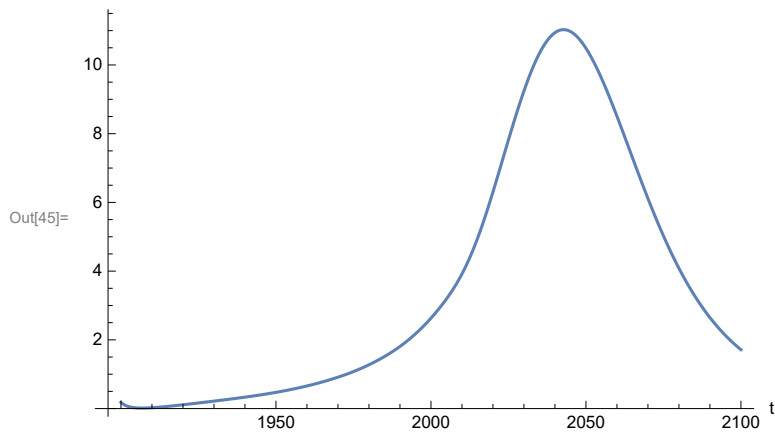
```
In[44]:= MinAndMax[testsim[{"Labor_Utilization1.serv_out_pc"}]]
```

Maximum is 712.65

Minimum is 87.4451

Plot persistent pollution index (normalized to 1970 value).

```
In[45]:= SystemModelPlot[testsim, {"Pollution_Dynamics1.PPoll_Index.y"}]
```



Find max and min of y values.

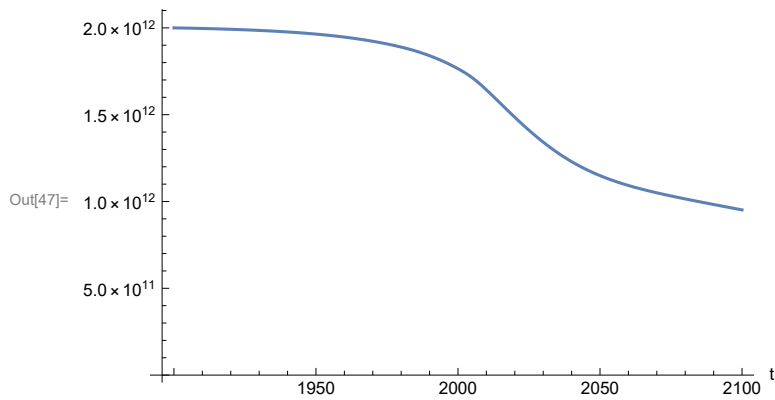
```
In[46]:= MinAndMax[testsim[{"Pollution_Dynamics1.PPoll_Index.y"}]]
```

Maximum is 11.028

Minimum is 0.0150765

Plot non-renewable resources remaining.

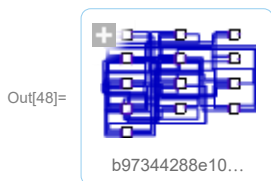
```
In[47]:= SystemModelPlot[testsim, {"NR_Resource_Utilization1.NR_Resources.y"}]
```



APPENDIX 43. Effects of mitigating the impact of air pollution on agricultural land yield, beginning calendar year 1970, Scenario 9, Experiment 3

Change the value of the air pollution effect multiplier switch time `t_air_poll_time`, to calendar year 1970, and execute the resulting scenario, plotting the variables shown in Figure 2.

```
In[48]:= newmysim1970 = SystemModel[mysim, <|"ParameterValues" → {"t_air_poll_time" → 1970} |>]
```



```
In[49]:= testsim1970 = SystemModelSimulate[newmysim1970]
```

Out[49]= SystemModelSimulationData [ Model: Wb97344288e104e7fa086392890e56f4a
Time: 1.90×10^3 to 2.10×10^3]

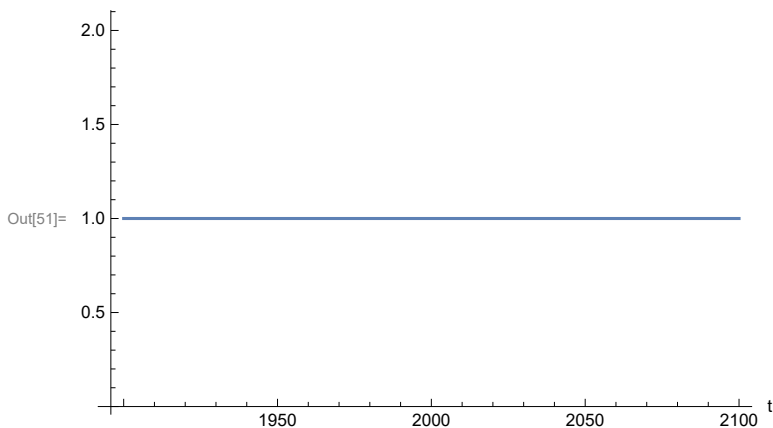
Show the value of `t_air_poll_time` (calendar year).

```
In[50]:= SystemModel[newmysim1970][{"ParameterValues", "t_air_poll_time"}]
```

Out[50]= {t_air_poll_time → 1970}

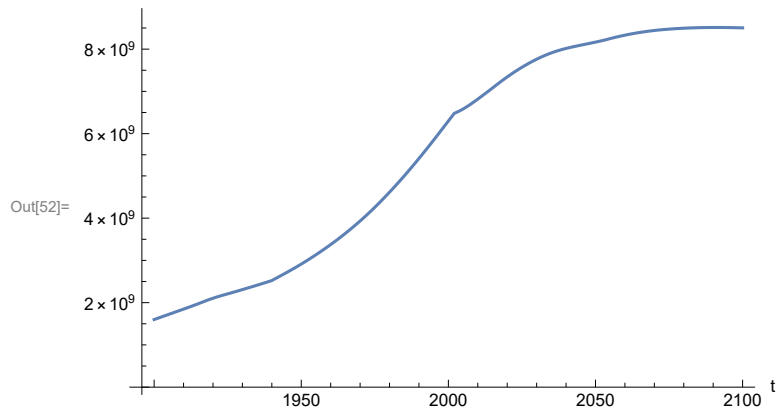
Plot air pollution multiplier of land yield.

```
In[51]:= SystemModelPlot[testsim1970, {"Food_Production1.s_yield_mlt_air_poll"}]
```



Plot the world population, people.

```
In[52]:= SystemModelPlot[testsim1970, {"Population_Dynamics1.Birth_Rate.pop"}]
```



Find max and min of y values.

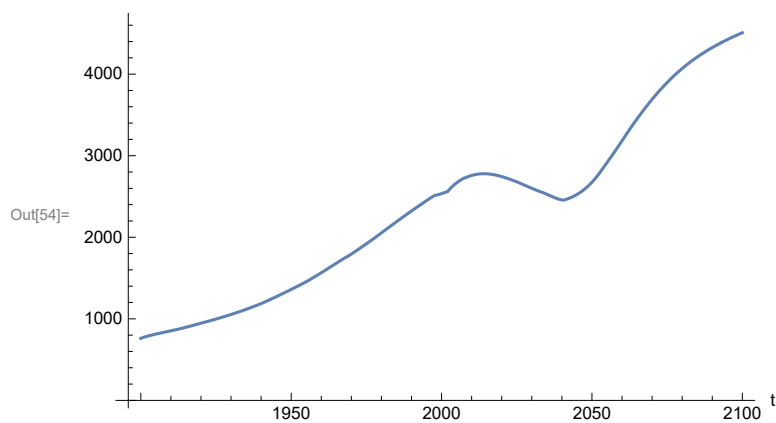
```
In[53]:= MinAndMax[testsim1970[{"Population_Dynamics1.Birth_Rate.pop"}]]
```

Maximum is 8.51278×10^9

Minimum is 1.6×10^9

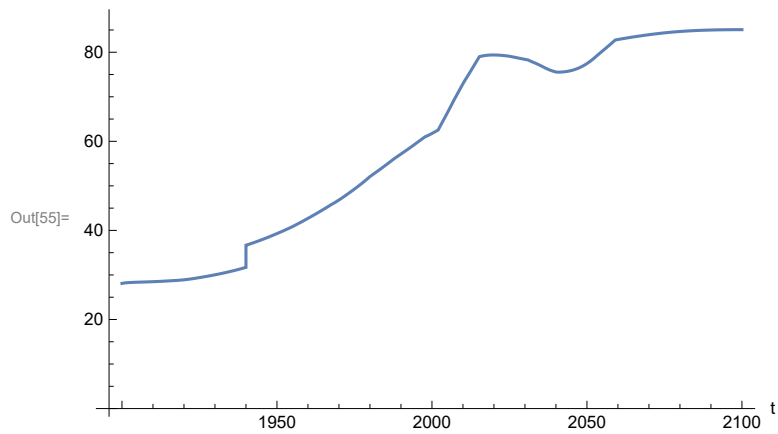
Plot land yield.

```
In[54]:= SystemModelPlot[testsim1970, {"Food_Production1.Land_Yield.y"}]
```



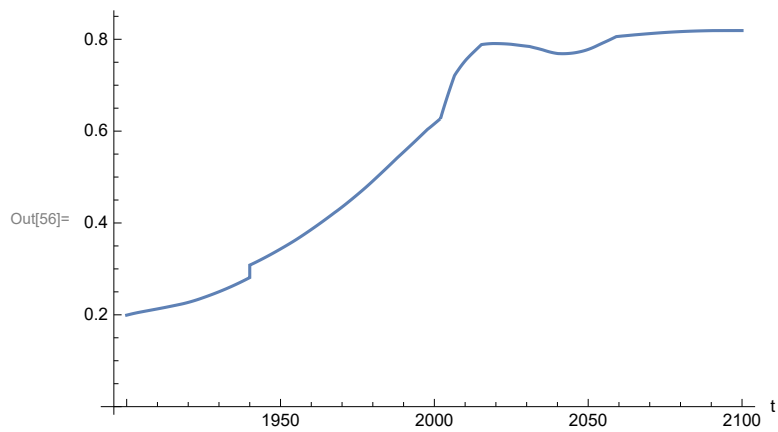
Plot life expectancy, in years.


```
In[55]:= SystemModelPlot[testsim1970, {"Life_Expectancy1.Life_Expectancy.y"}]
```



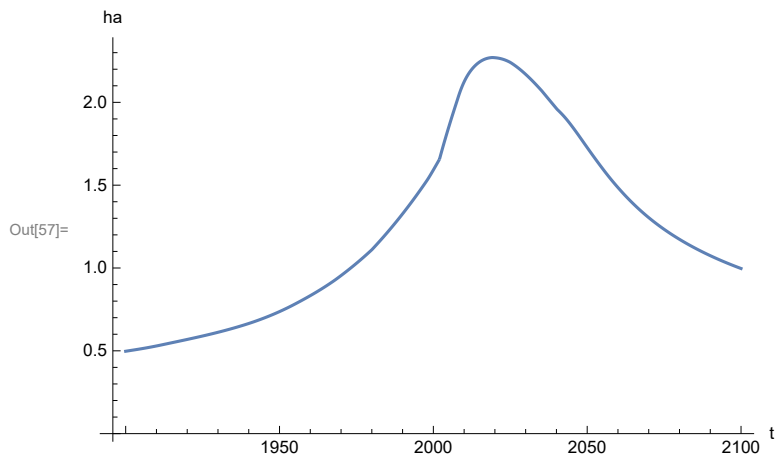
Plot the human welfare index.

```
In[56]:= SystemModelPlot[testsim1970, {"Human_Welfare_Index1.HWI_Human_Welfare_Index.hwi_human_welfare_index"}]
```



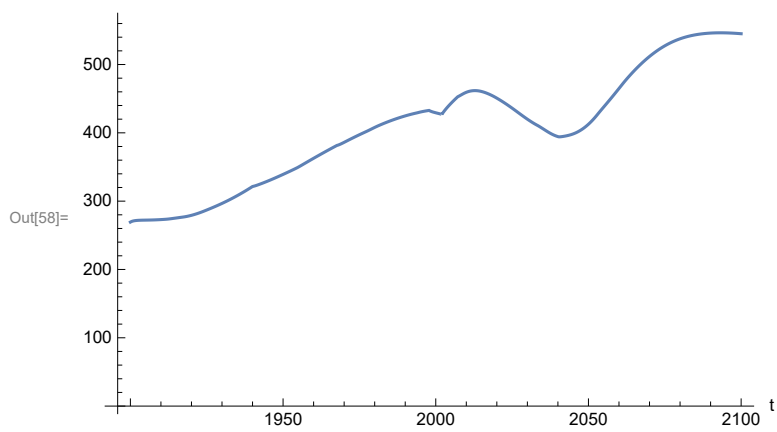
Plot the human ecological footprint, in hectares.

```
In[57]:= SystemModelPlot[testsim1970,
  {"Human_Ecological_Footprint1.HEF_Human_Ecological_Footprint.hef_human_ecological_
    _footprint"}]
```



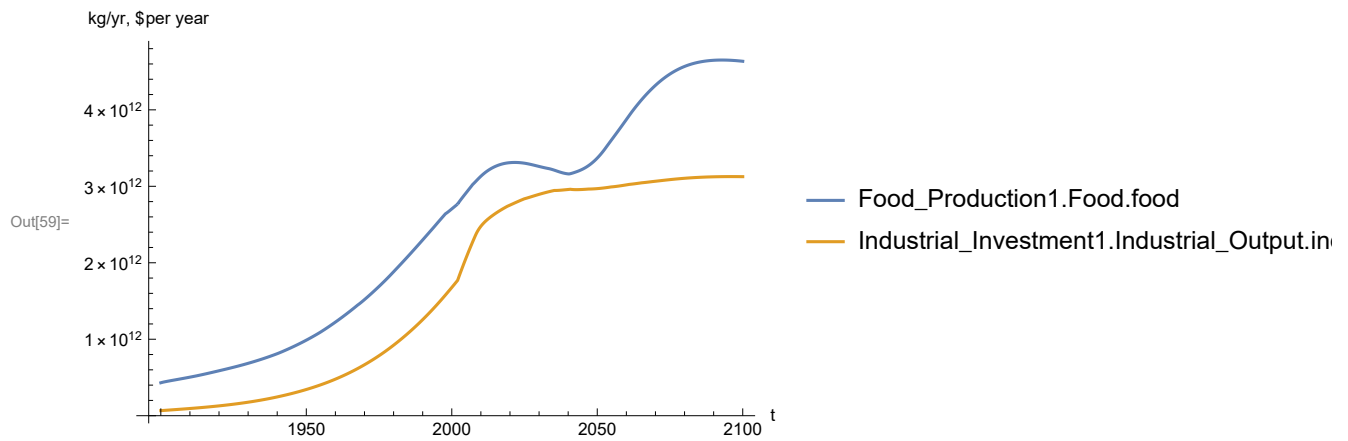
Plot per capita food production, kg/year.

```
In[58]:= SystemModelPlot[testsim1970, {"Food_Production1.Food_PC.y"}]
```



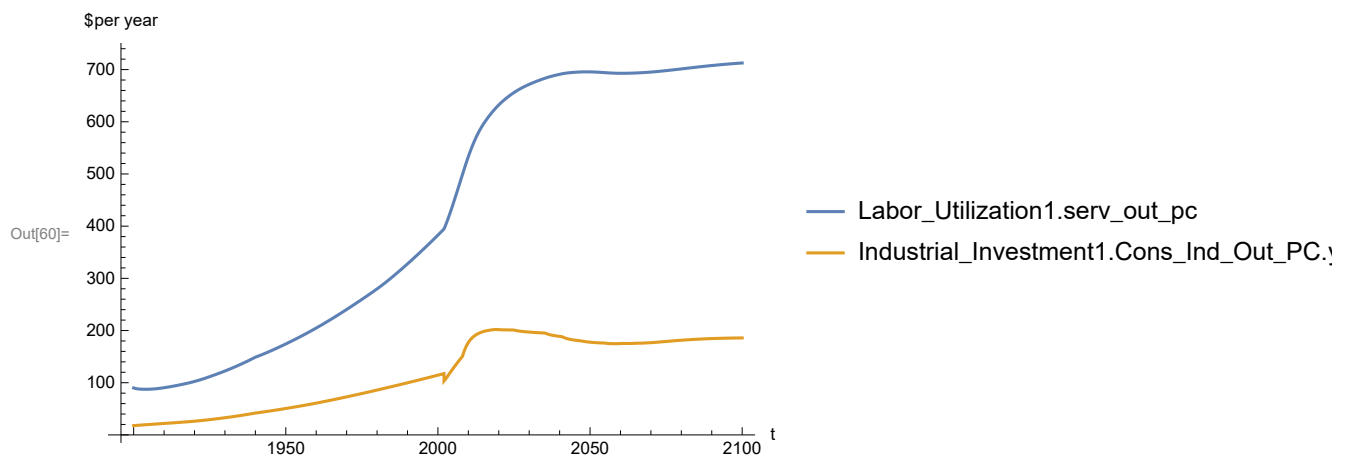
Plot total food production (kg/yr) and industrial output (in dollars).

```
In[59]:= SystemModelPlot[testsim1970, {"Food_Production1.Food.food",
  "Industrial_Investment1.Industrial_Output.industrial_output"}]
```



Plot labor utilization per capita and consolidated industrial output per capita (dollars/year).

```
In[60]:= SystemModelPlot[testsim1970,
  {"Labor_Utilization1.serv_out_pc", "Industrial_Investment1.Cons_Ind_Out_PC.y"}]
```



Find max and min of y values.

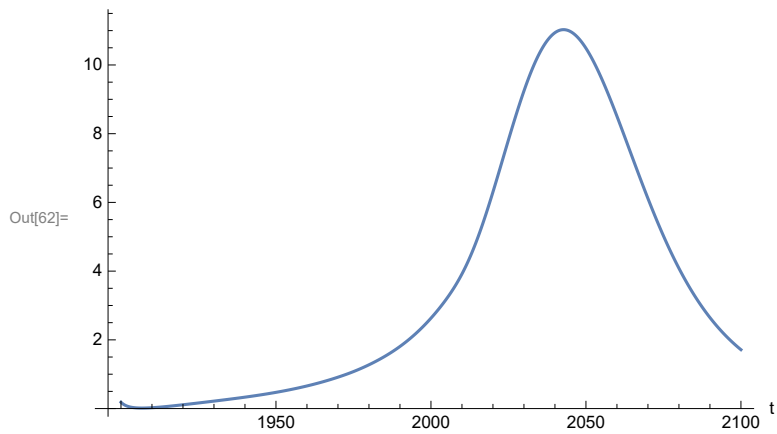
```
In[61]:= MinAndMax[testsim1970[{"Labor_Utilization1.serv_out_pc"}]]
```

Maximum is 712.65

Minimum is 87.4451

Plot persistent pollution index (normalized to 1970 value).

In[62]:= **SystemModelPlot**[testsim1970, {"Pollution_Dynamics1.PPoll_Index.y"}]



Find max and min of y values.

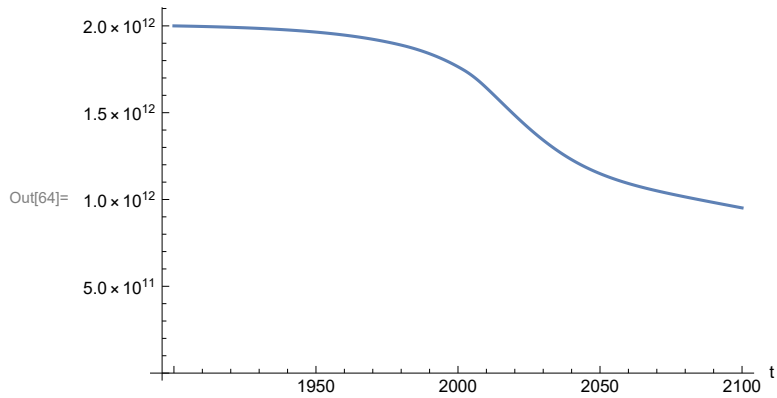
In[63]:= **MinAndMax**[testsim1970[{"Pollution_Dynamics1.PPoll_Index.y"}]]

Maximum is 11.028

Minimum is 0.0150765

Plot non-renewable resources remaining.

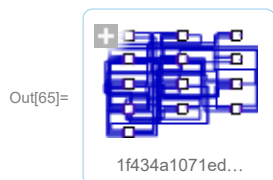
In[64]:= **SystemModelPlot**[testsim1970, {"NR_Resource_Utilization1.NR_Resources.y"}]



APPENDIX 44. "STRONG AIR POLLUTION" EFFECTS SCENARIO, Scenario 9, Experiment 4

Scenario 9 with air pollution effect on land yield changed as noted.

```
In[65]:= strsim = SystemModel[mysim, <|"ParameterValues" ->
      {"Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals" -> {0.7, 0.5, 0.3, 0.1}}|>]
```



```
In[66]:= basestrsim = SystemModelSimulate[strsim]
```

Out[66]= SystemModelSimulationData [ Model: W1f434a1071ed41d9b3b2f09d18b50c73
Time: 1.90×10^3 to 2.10×10^3]

Show Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals.

```
In[67]:= SystemModel[strsim] [
      {"ParameterValues", "Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[1]"}]
```

Out[67]= {Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[1] → 0.7}

```
In[68]:= SystemModel[strsim] [
      {"ParameterValues", "Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[2]"}]
```

Out[68]= {Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[2] → 0.5}

```
In[69]:= SystemModel[strsim] [
      {"ParameterValues", "Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[3]"}]
```

Out[69]= {Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[3] → 0.3}

```
In[70]:= SystemModel[strsim] [
      {"ParameterValues", "Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[4]"}]
```

Out[70]= {Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[4] → 0.1}

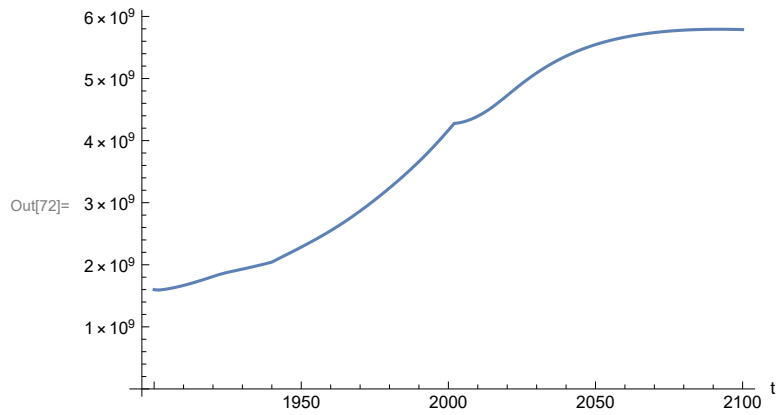
Show the value of t_air_poll_time (calendar year).

```
In[71]:= SystemModel[strsim] [{"ParameterValues", "t_air_poll_time"}]
```

Out[71]= {t_air_poll_time → 4000}

Plot the world population, people.

```
In[72]:= SystemModelPlot[basestransim, {"Population_Dynamics1.Birth_Rate.pop"}]
```



Find max and min of y values.

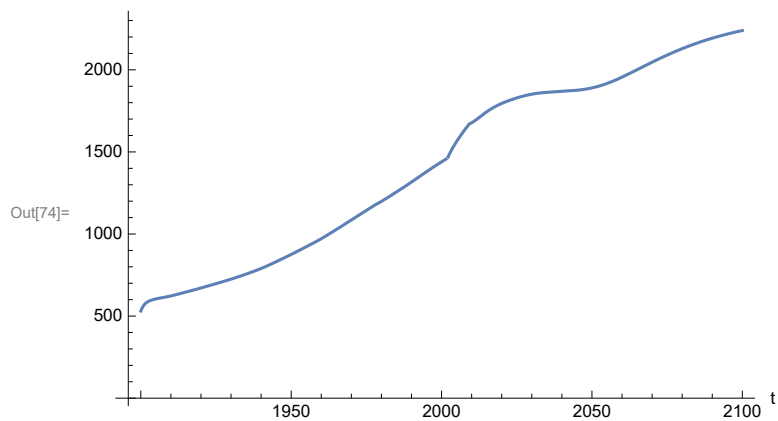
```
In[73]:= MinAndMax[basestransim[{"Population_Dynamics1.Birth_Rate.pop"}]]
```

Maximum is 5.7934×10^9

Minimum is 1.59431×10^9

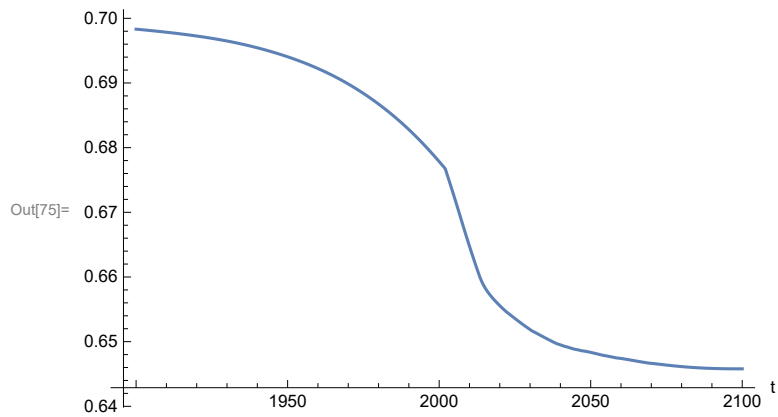
Plot land yield.

```
In[74]:= SystemModelPlot[basestransim, {"Food_Production1.Land_Yield.y"}]
```



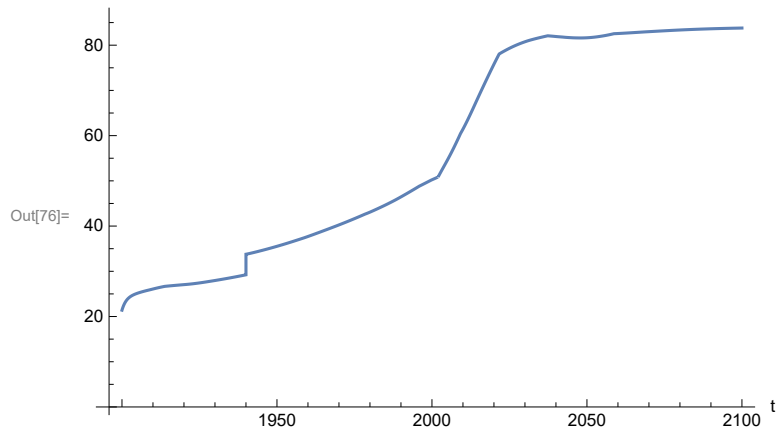
Plot multiplier of air pollution on land yield.

```
In[75]:= SystemModelPlot[basestransim, {"Food_Production1.s_yield_mlt_air_poll"}]
```



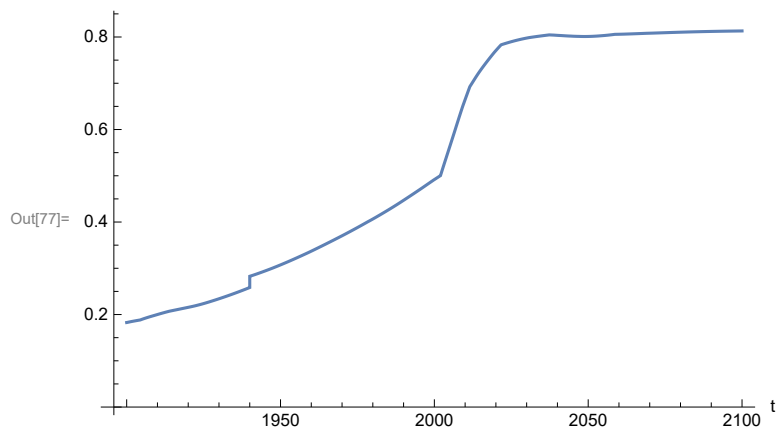
Plot life expectancy, in years.

```
In[76]:= SystemModelPlot[basestransim, {"Life_Expectancy1.Life_Expectancy.y"}]
```



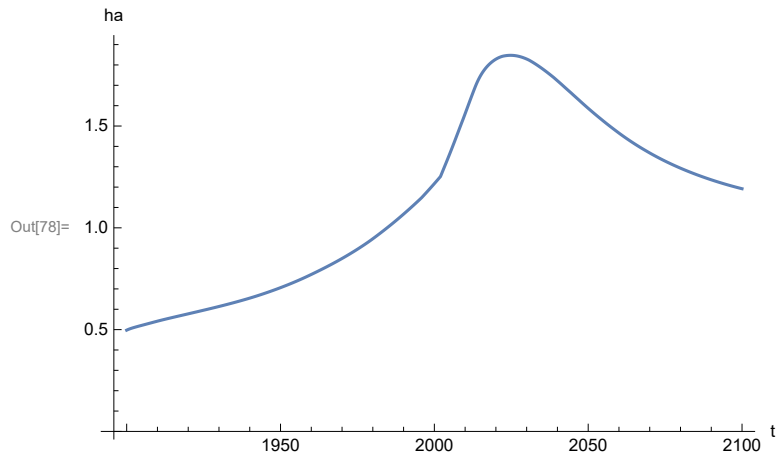
Plot the human welfare index.

```
In[77]:= SystemModelPlot[basestransim, {"Human_Welfare_Index1.HWI_Human_Welfare_Index.hwi_human_welfare_index"}]
```



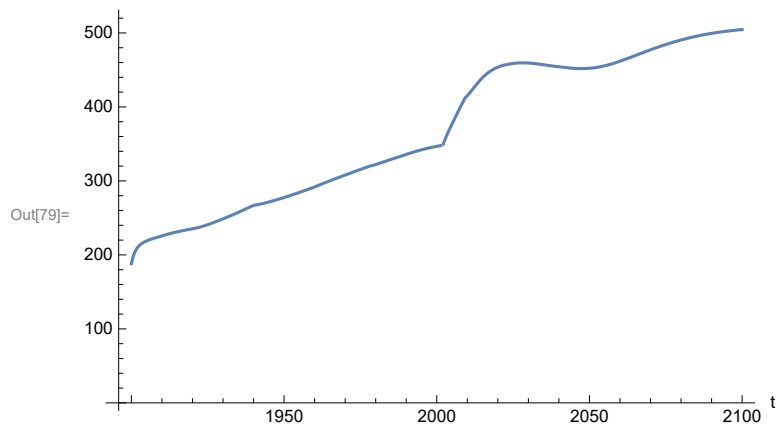
Plot the human ecological footprint, in hectares.

```
In[78]:= SystemModelPlot[basestrsim,
  {"Human_Ecological_Footprint1.HEF_Human_Ecological_Footprint.hef_human_ecological_
    _footprint"}]
```



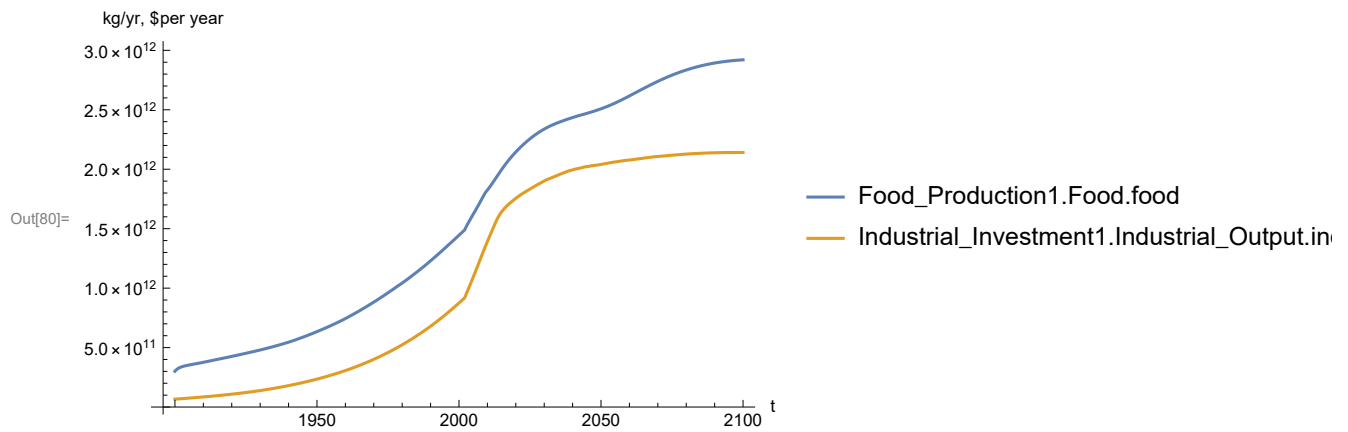
Plot per capita food production, kg/year.

```
In[79]:= SystemModelPlot[basestrsim, {"Food_Production1.Food_PC.y"}]
```



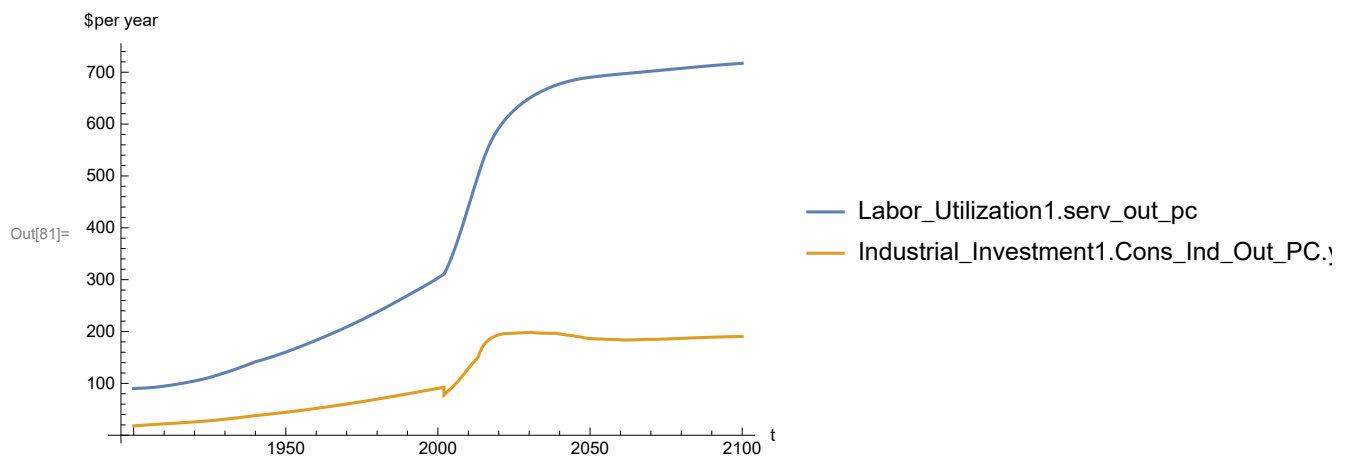
Plot total food production (kg/yr) and industrial output (in dollars).


```
In[80]:= SystemModelPlot[basestrnsim, {"Food_Production1.Food.food",
  "Industrial_Investment1.Industrial_Output.industrial_output"}]
```



Plot consolidated industrial output per capita (dollars/year).

```
In[81]:= SystemModelPlot[basestrnsim,
  {"Labor_Utilization1.serv_out_pc", "Industrial_Investment1.Cons_Ind_Out_PC.y"}]
```



Find max and min of y values.

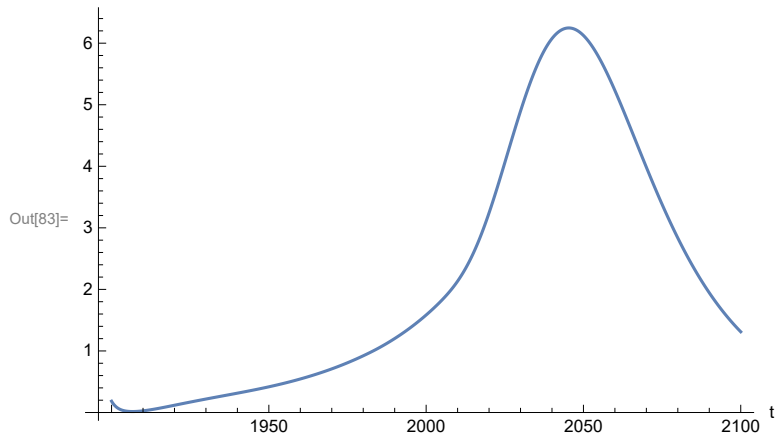
```
In[82]:= MinAndMax[basestrnsim[{"Labor_Utilization1.serv_out_pc"}]]
```

Maximum is 717.187

Minimum is 89.9974

Plot persistent pollution index (normalized to 1970 value).

```
In[83]:= SystemModelPlot[basestransim, {"Pollution_Dynamics1.PPoll_Index.y"}]
```



Find max and min of y values.

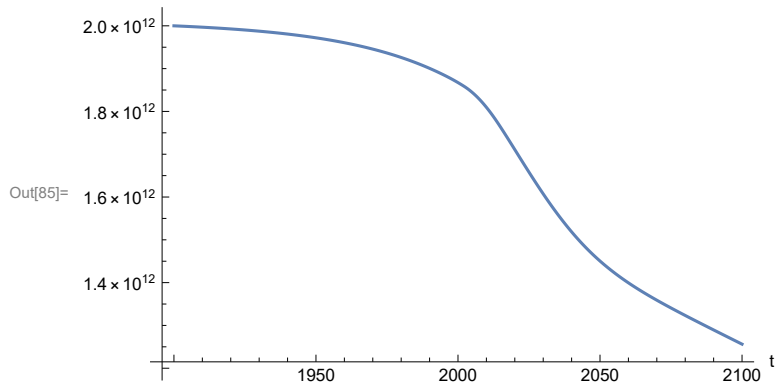
```
In[84]:= MinAndMax[basestransim[{"Pollution_Dynamics1.PPoll_Index.y"}]]
```

Maximum is 6.24739

Minimum is 0.0157768

Plot non-renewable resources remaining.

```
In[85]:= SystemModelPlot[basestransim, {"NR_Resource_Utilization1.NR_Resources.y"}]
```



APPENDIX 45. SEVERE LAND LOSS DUE TO AIR POLLUTION, Scenario 9, Experiment 5

Scenario 9 with air pollution effect on land yield changed as noted.

```
In[86]:= sevsim = SystemModel[mysim, <|"ParameterValues" ->
  {"Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals" -> {0.7, 0.1, 0.1, 0.1}}|>]
```



```
In[87]:= basesevsim = SystemModelSimulate[sevsim]
```

Out[87]= SystemModelSimulationData [ Model: Wabebea86a6b142adaed18a9b49d9362a
Time: 1.90×10^3 to 2.10×10^3]

Show Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals.

```
In[88]:= SystemModel[sevsim] [
  {"ParameterValues", "Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[1]"}]
```

Out[88]= {Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[1] → 0.7}

```
In[89]:= SystemModel[sevsim] [
  {"ParameterValues", "Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[2]"}]
```

Out[89]= {Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[2] → 0.1}

```
In[90]:= SystemModel[sevsim] [
  {"ParameterValues", "Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[3]"}]
```

Out[90]= {Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[3] → 0.1}

```
In[91]:= SystemModel[sevsim] [
  {"ParameterValues", "Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[4]"}]
```

Out[91]= {Pollution_Dynamics1.P_Yield_Mlt_Air_Poll_1.y_vals[4] → 0.1}

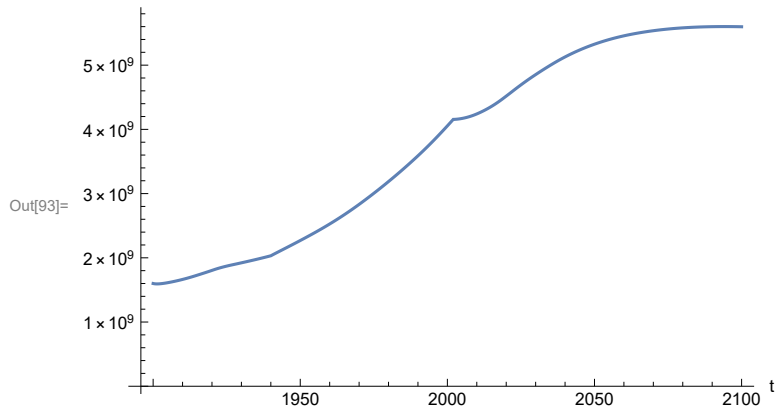
Show the value of t_air_poll_time (calendar year).

```
In[92]:= SystemModel[sevsim][{"ParameterValues", "t_air_poll_time"}]
```

```
Out[92]:= {t_air_poll_time → 4000}
```

Plot the world population, people.

```
In[93]:= SystemModelPlot[basesevsim, {"Population_Dynamics1.Birth_Rate.pop"}]
```



Find max and min of y values.

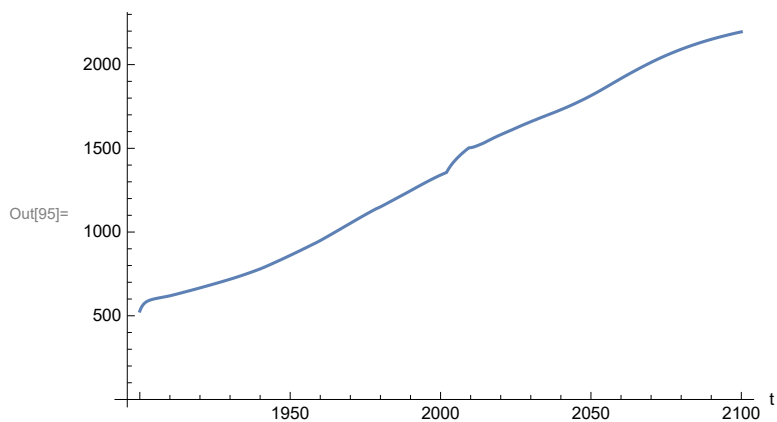
```
In[94]:= MinAndMax[basesevsim[{"Population_Dynamics1.Birth_Rate.pop"}]]
```

```
Maximum is 5.60077 × 109
```

```
Minimum is 1.59367 × 109
```

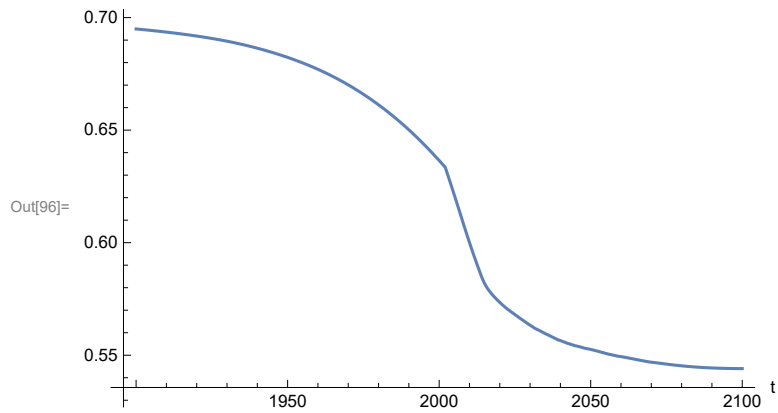
Plot land yield.

```
In[95]:= SystemModelPlot[basesevsim, {"Food_Production1.Land_Yield.y"}]
```



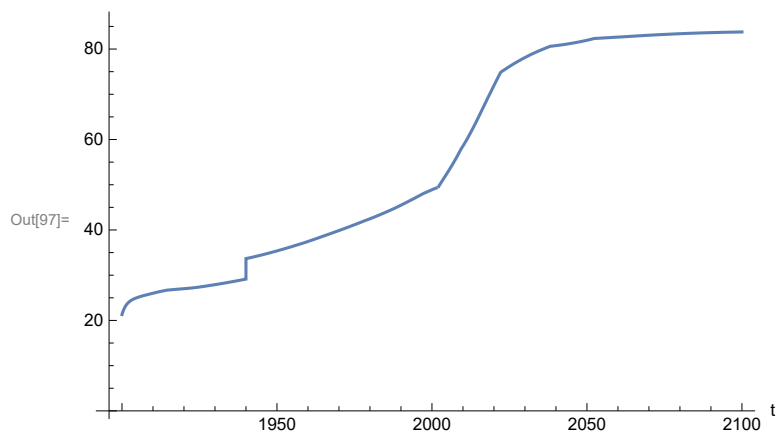
Plot multiplier of air pollution on land yield.

```
In[96]:= SystemModelPlot[basesevsim, {"Food_Production1.s_yield_mlt_air_poll"}]
```



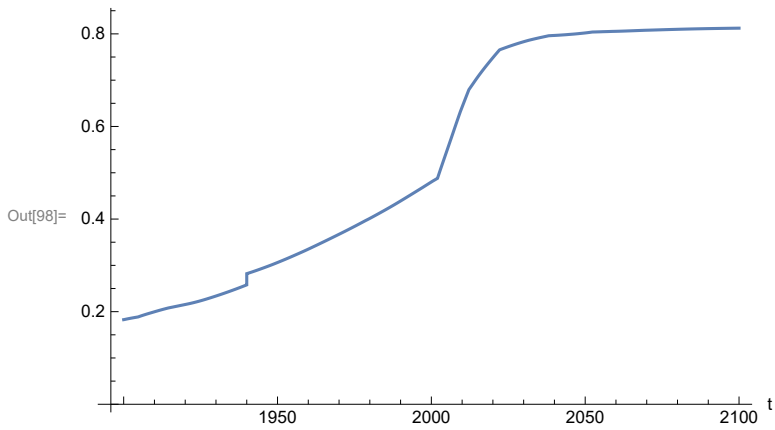
Plot life expectancy, in years.

```
In[97]:= SystemModelPlot[basesevsim, {"Life_Expectancy1.Life_Expectancy.y"}]
```



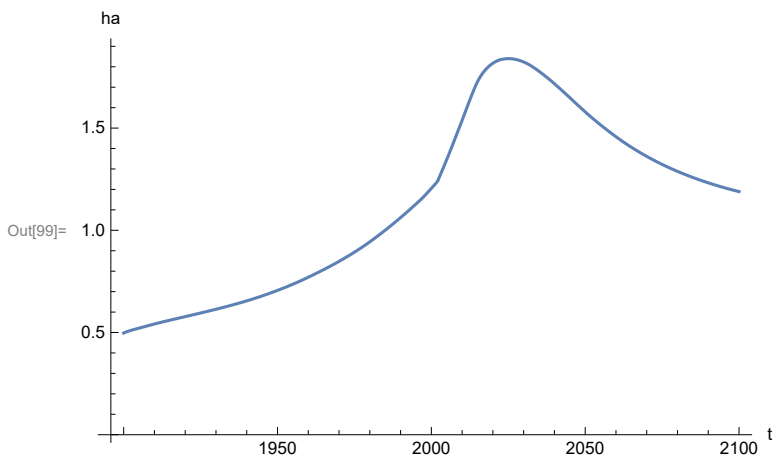
Plot the human welfare index.

```
In[98]:= SystemModelPlot[basesevsim,
  {"Human_Welfare_Index1.HWI_Human_Welfare_Index.hwi_human_welfare_index"}]
```



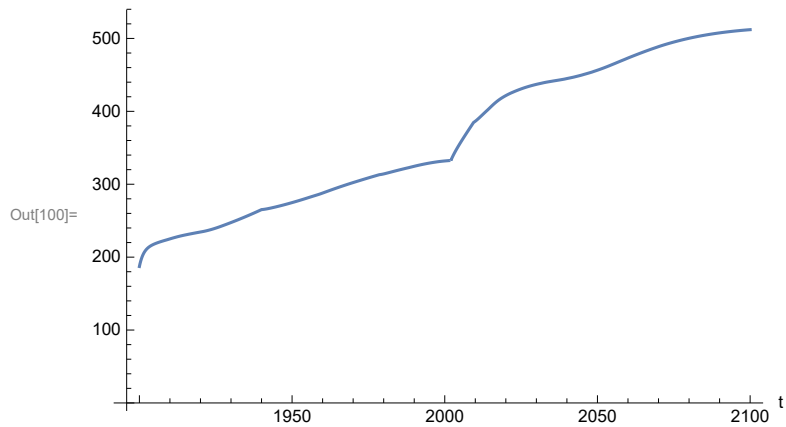
Plot the human ecological footprint, in hectares.

```
In[99]:= SystemModelPlot[basesevsim,
  {"Human_Ecological_Footprint1.HEF_Human_Ecological_Footprint.hef_human_ecological_footprint"}]
```



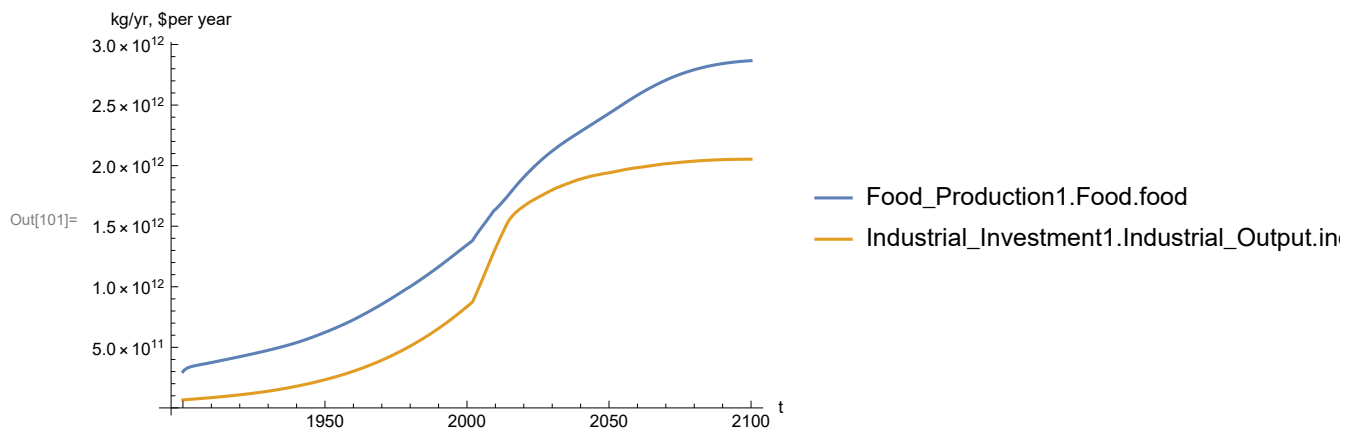
Plot per capita food production, kg/year.

```
In[100]:= SystemModelPlot[basesevsim, {"Food_Production1.Food_PC.y"}]
```



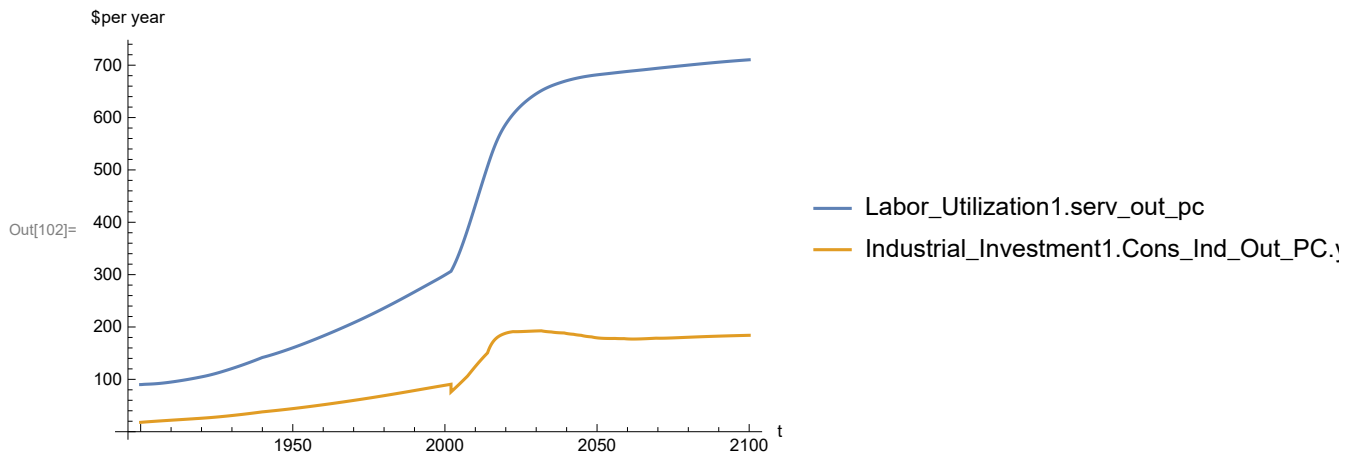
Plot total food production (kg/yr) and industrial output (in dollars).

```
In[101]:= SystemModelPlot[basesevsim, {"Food_Production1.Food.food",
  "Industrial_Investment1.Industrial_Output.industrial_output"}]
```



Plot consolidated industrial output per capita (dollars/year).

```
In[102]:= SystemModelPlot[basesevsim,
  {"Labor_Utilization1.serv_out_pc", "Industrial_Investment1.Cons_Ind_Out_PC.y"}]
```



Find max and min of y values.

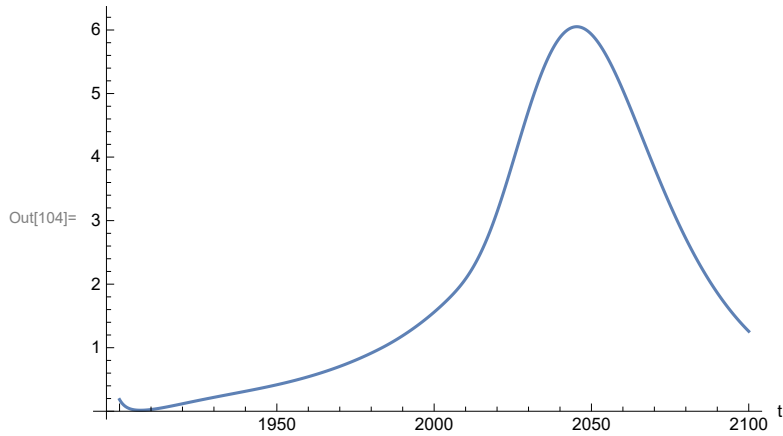
```
In[103]:= MinAndMax[basesevsim[{"Labor_Utilization1.serv_out_pc"}]]
```

Maximum is 710.349

Minimum is 90.

Plot persistent pollution index (normalized to 1970 value).

```
In[104]:= SystemModelPlot[basesevsim, {"Pollution_Dynamics1.PPoll_Index.y"}]
```



Find max and min of y values.

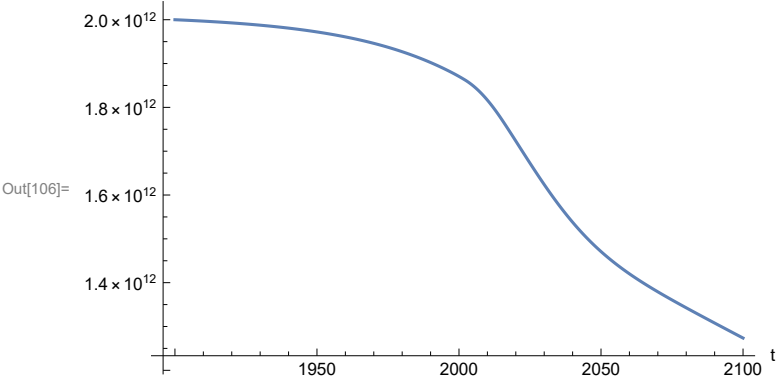
```
In[105]:= MinAndMax[basesevsim[{"Pollution_Dynamics1.PPoll_Index.y"}]]
```

Maximum is 6.05189

Minimum is 0.0157849

Plot non-renewable resources remaining.

```
In[106]:= SystemModelPlot[basesevsim, {"NR_Resource_Utilization1.NR_Resources.y"}]
```



APPENDIX 46. BENCHMARK SCENARIO 1, Accelerated Land Fertility Degradation Rate

Define a function that extracts range data from scenario data. (The right-hand-side of this definition is specific to a *World3* data structure and assumes that the function whose range is being extracted is globally (i.e., not piecewise) defined.)

```
In[34]:= RangeData[data_] := data[[1]][[4]][[3]];
```

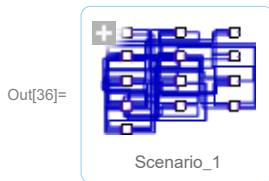
Define a procedure to determine and print minimum and maximum of “y” values.

```
In[35]:= MinAndMax[data_] := (myscenseries = RangeData[data];
    Print["Maximum is ", Max[myscenseries]]; Print["Minimum is ", Min[myscenseries]])
```

Here are some high-level properties of Benchmark Scenario 1.

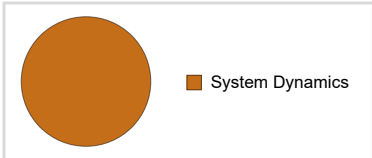
```
In[36]:=
```

```
mysim = SystemModel["SystemDynamics.WorldDynamics.World3.Scenario_1"]
```



```
In[37]:= mysummary = mysim["Summary"]
```

Out[37]=

ModelName	SystemDynamics.WorldDynamics.World3.Scenario_1
Description	Original WORLD3 model
SimulationModel	True
Plots	0
Components	106
Balanced	True
SystemEquations	1583
SystemVariables	1583
Domain	

Show Land_Fertility1.Land_Fert_Degr_Rt.y_vals in original scenario.

```
In[38]= SystemModel[mysim][{"ParameterValues", "Land_Fertility1.Land_Fert_Degr_Rt.y_vals[1]"}]
Out[38]= {Land_Fertility1.Land_Fert_Degr_Rt.y_vals[1] → 0}

In[39]= SystemModel[mysim][{"ParameterValues", "Land_Fertility1.Land_Fert_Degr_Rt.y_vals[2]"}]
Out[39]= {Land_Fertility1.Land_Fert_Degr_Rt.y_vals[2] → 0.1}

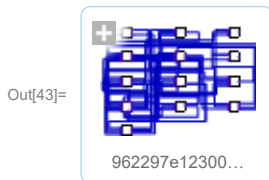
In[40]= SystemModel[mysim][{"ParameterValues", "Land_Fertility1.Land_Fert_Degr_Rt.y_vals[3]"}]
Out[40]= {Land_Fertility1.Land_Fert_Degr_Rt.y_vals[3] → 0.3}

In[41]= SystemModel[mysim][{"ParameterValues", "Land_Fertility1.Land_Fert_Degr_Rt.y_vals[4]"}]
Out[41]= {Land_Fertility1.Land_Fert_Degr_Rt.y_vals[4] → 0.5}

In[42]= SystemModel[mysim][{"ParameterValues", "Land_Fertility1.Land_Fert_Degr_Rt.y_vals[5]"}]
Out[42]= {Land_Fertility1.Land_Fert_Degr_Rt.y_vals[5] → 0.5}
```

Change scenario land fertility rates.

```
In[43]= strsim = SystemModel[mysim, <|"ParameterValues" ->
      {"Land_Fertility1.Land_Fert_Degr_Rt.y_vals" -> {0.0, 0.3, 0.5, 0.7, 0.7}}|>]
```



```
In[44]= basestrsim = SystemModelSimulate[strsim]
```

```
Out[44]= SystemModelSimulationData[   Model: W962297e1230048e8aa5c234cc333e180
      Time: 1.90 × 103 to 2.10 × 103 ]
```

Show changed Land_Fertility1.Land_Fert_Degr_Rt.y_vals.

```
In[45]= SystemModel[basestrsim][{"ParameterValues", "Land_Fertility1.Land_Fert_Degr_Rt.y_vals[1]"}]
Out[45]= {Land_Fertility1.Land_Fert_Degr_Rt.y_vals[1] → 0}

In[46]= SystemModel[basestrsim][{"ParameterValues", "Land_Fertility1.Land_Fert_Degr_Rt.y_vals[2]"}]
Out[46]= {Land_Fertility1.Land_Fert_Degr_Rt.y_vals[2] → 0.3}

In[47]= SystemModel[basestrsim][{"ParameterValues", "Land_Fertility1.Land_Fert_Degr_Rt.y_vals[3]"}]
Out[47]= {Land_Fertility1.Land_Fert_Degr_Rt.y_vals[3] → 0.5}
```

```
In[48]= SystemModel[strsim][{"ParameterValues", "Land_Fertility1.Land_Fert_Degr_Rt.y_vals[4]"}]
```

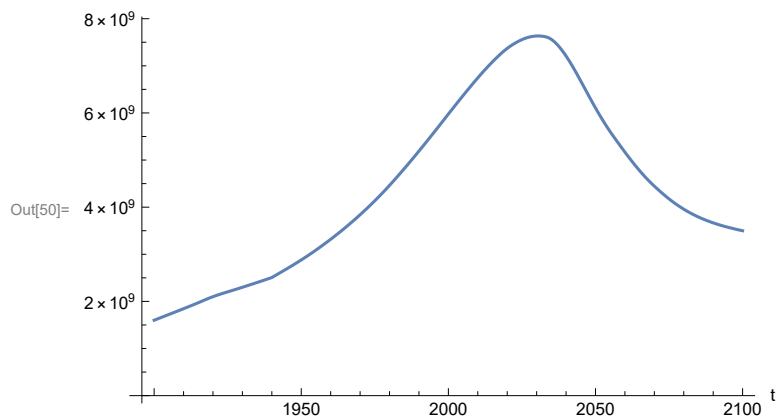
```
Out[48]= {Land_Fertility1.Land_Fert_Degr_Rt.y_vals[4] → 0.7}
```

```
In[49]= SystemModel[strsim][{"ParameterValues", "Land_Fertility1.Land_Fert_Degr_Rt.y_vals[5]"}]
```

```
Out[49]= {Land_Fertility1.Land_Fert_Degr_Rt.y_vals[5] → 0.7}
```

Plot the world population, people.

```
In[50]= SystemModelPlot[basestrsm, {"Population_Dynamics1.Birth_Rate.pop"}]
```



Find max and min of y values.

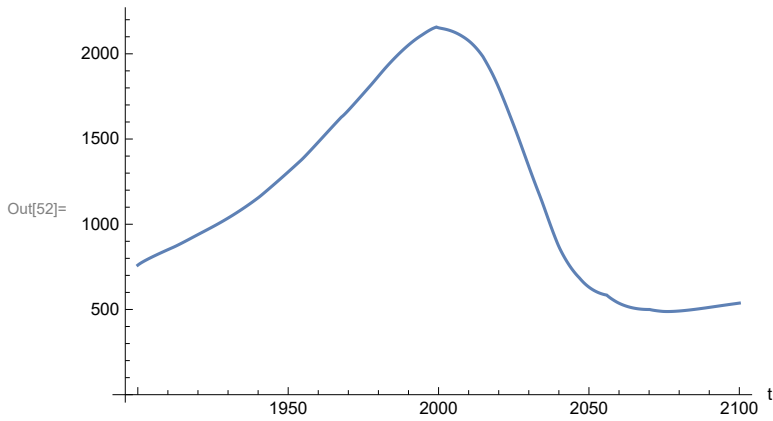
```
In[51]= MinAndMax[basestrsm[{"Population_Dynamics1.Birth_Rate.pop"}]]
```

```
Maximum is 7.63355 × 109
```

```
Minimum is 1.6 × 109
```

Plot land yield.

```
In[52]:= SystemModelPlot[basestransim, {"Food_Production1.Land_Yield.y"}]
```



Find max and min of y values.

```
In[53]:= MinAndMax[basestransim[{"Food_Production1.Land_Yield.y"}]]
```

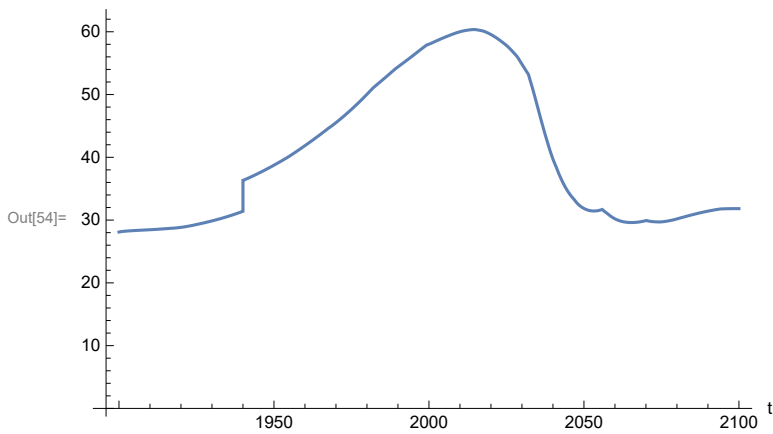
Maximum is 2157.07

Minimum is 487.907

Plot multiplier of air pollution on land yield.

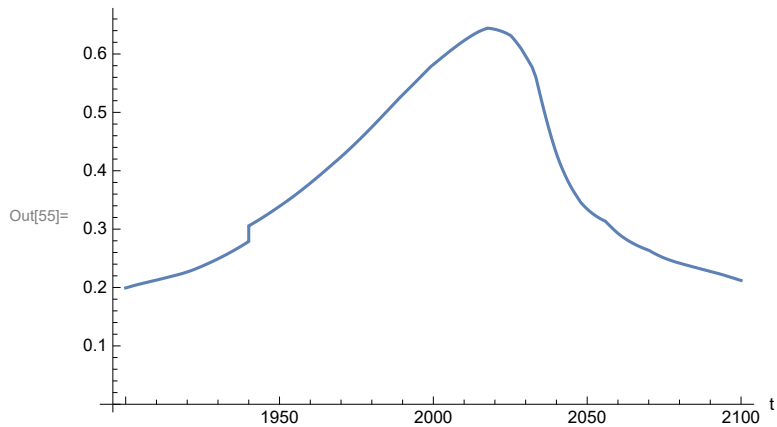
Plot life expectancy, in years.

```
In[54]:= SystemModelPlot[basestransim, {"Life_Expectancy1.Life_Expectancy.y"}]
```



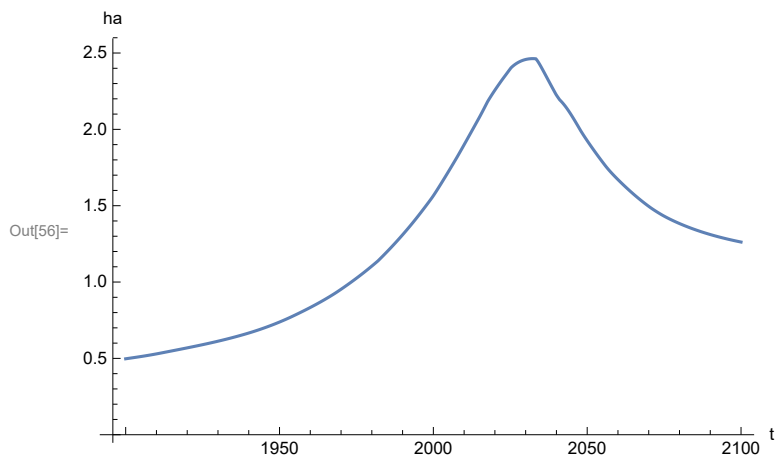
Plot the human welfare index.

```
In[55]:= SystemModelPlot[basestransim,
  {"Human_Welfare_Index1.HWI_Human_Welfare_Index.hwi_human_welfare_index"}]
```



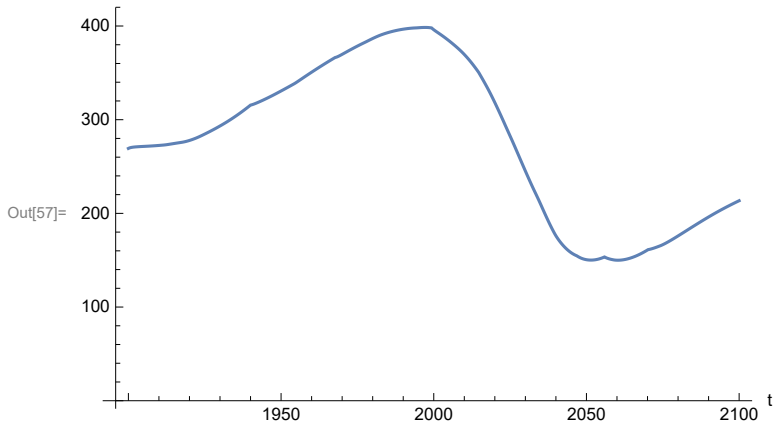
Plot the human ecological footprint, in hectares.

```
In[56]:= SystemModelPlot[basestransim,
  {"Human_Ecological_Footprint1.HEF_Human_Ecological_Footprint.hef_human_ecological_footprint"}]
```



Plot per capita food production, kg/year.

```
In[57]:= SystemModelPlot[basestransim, {"Food_Production1.Food_PC.y"}]
```



Find max and min of y values.

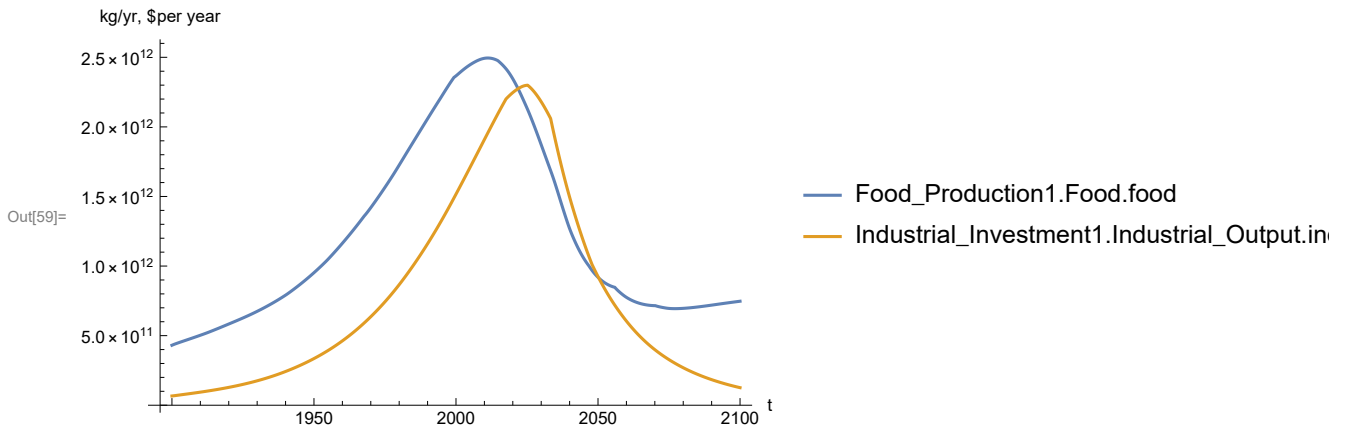
```
In[58]:= MinAndMax[basestransim[{"Food_Production1.Food_PC.y"}]]
```

Maximum is 398.474

Minimum is 149.993

Plot total food production (kg/yr) and industrial output (in dollars).

```
In[59]:= SystemModelPlot[basestransim, {"Food_Production1.Food.food",
    "Industrial_Investment1.Industrial_Output.industrial_output"}]
```



Find max and min of y values.

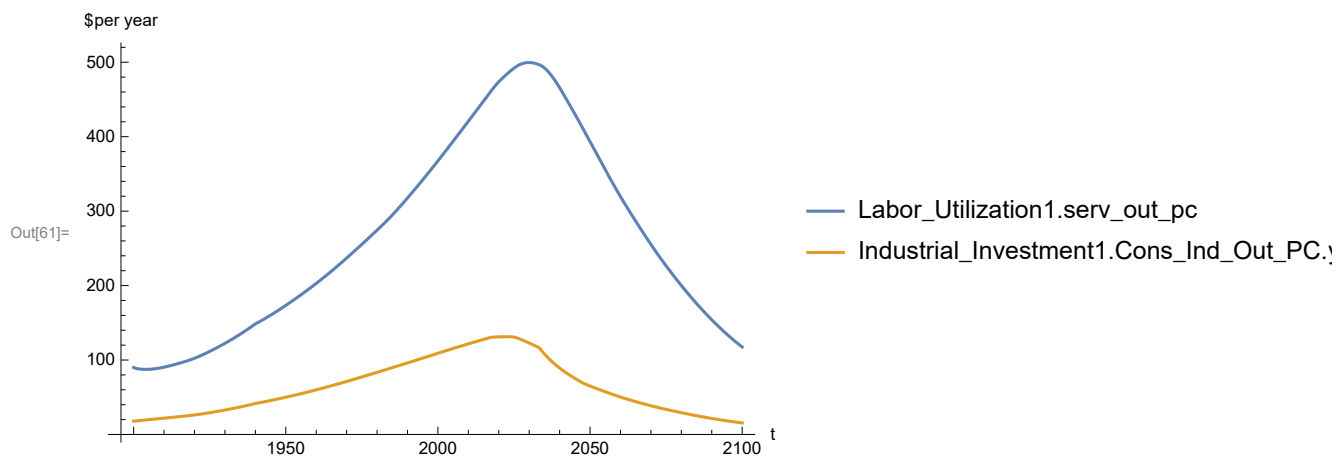
```
In[60]:= MinAndMax[basestransim[{"Industrial_Investment1.Industrial_Output.industrial_output"}]]
```

Maximum is 2.29927×10^{12}

Minimum is 6.65×10^{10}

Plot consolidated industrial output per capita (dollars/year).

```
In[61]:= SystemModelPlot[basestransim,
  {"Labor_Utilization1.serv_out_pc", "Industrial_Investment1.Cons_Ind_Out_PC.y"}]
```



Find max and min of y values.

```
In[62]:= MinAndMax[basestransim[{"Labor_Utilization1.serv_out_pc"}]]
```

Maximum is 499.568

Minimum is 87.4733

Find max and min of y values.

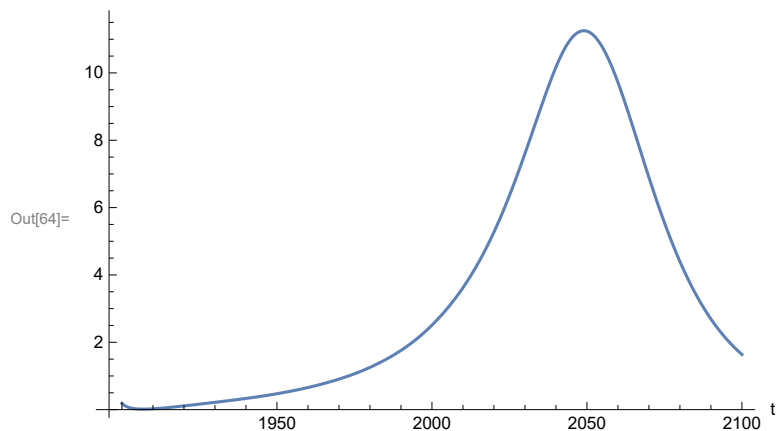
```
In[63]:= MinAndMax[basestransim[{"Industrial_Investment1.Cons_Ind_Out_PC.y"}]]
```

Maximum is 131.282

Minimum is 15.5085

Plot persistent pollution index (normalized to 1970 value).

```
In[64]:= SystemModelPlot[basestransim, {"Pollution_Dynamics1.PPoll_Index.y"}]
```



Find max and min of y values.

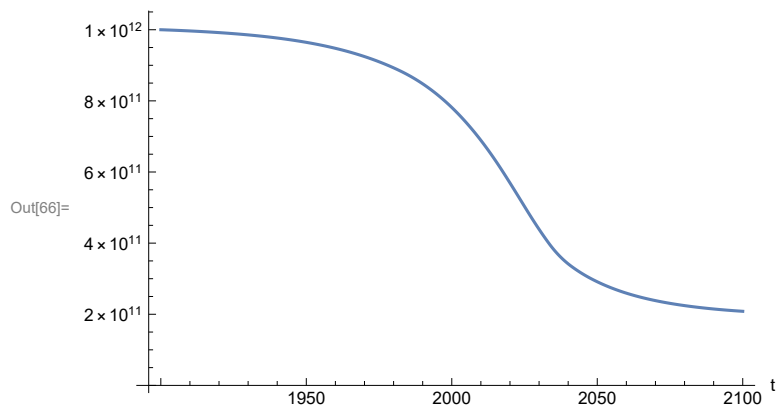
```
In[65]:= MinAndMax[basestransim[{"Pollution_Dynamics1.PPoll_Index.y"}]]
```

Maximum is 11.2531

Minimum is 0.0150836

Plot non-renewable resources remaining.

```
In[66]:= SystemModelPlot[basestransim, {"NR_Resource_Utilization1.NR_Resources.y"}]
```



APPENDIX 47. BENCHMARK SCENARIO 2, Accelerated Land Fertility Degradation Rate

Define a function that extracts range data from scenario data. (The right-hand-side of this definition is specific to a *World3* data structure and assumes that the function whose range is being extracted is globally (i.e., not piecewise) defined.)

```
In[1]:= RangeData[data_] := data[[1]][[4]][[3]];
```

Define a procedure to determine and print minimum and maximum of “y” values.

```
In[2]:= MinAndMax[data_] := (myscenseries = RangeData[data];
  Print["Maximum is ", Max[myscenseries]]; Print["Minimum is ", Min[myscenseries]])
```

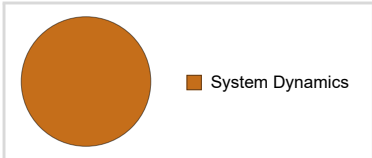
Here are some high-level properties of Benchmark Scenario 2.

```
In[3]:= mysim = SystemModel["SystemDynamics.WorldDynamics.World3.Scenario_2"]
```



```
In[4]:= mysummary = mysim["Summary"]
```

Out[4]=

ModelName	SystemDynamics.WorldDynamics.World3.Scenario_2
Description	More abundant non-recoverable natural resources
SimulationModel	True
Plots	0
Components	106
Balanced	True
SystemEquations	1583
SystemVariables	1583
Domain	

Show Land_Fertility1.Land_Fert_Degr_Rt.y_vals in original scenario.

```
In[5]:= SystemModel[mysim][{"ParameterValues", "Land_Fertility1.Land_Fert_Degr_Rt.y_vals[1]"}]
```

```
Out[5]= {Land_Fertility1.Land_Fert_Degr_Rt.y_vals[1] → 0}
```

```
In[6]:= SystemModel[mysim][{"ParameterValues", "Land_Fertility1.Land_Fert_Degr_Rt.y_vals[2]"}]
```

```
Out[6]= {Land_Fertility1.Land_Fert_Degr_Rt.y_vals[2] → 0.1}
```

```
In[7]:= SystemModel[mysim][{"ParameterValues", "Land_Fertility1.Land_Fert_Degr_Rt.y_vals[3]"}]
```

```
Out[7]= {Land_Fertility1.Land_Fert_Degr_Rt.y_vals[3] → 0.3}
```

```
In[8]:= SystemModel[mysim][{"ParameterValues", "Land_Fertility1.Land_Fert_Degr_Rt.y_vals[4]"}]
```

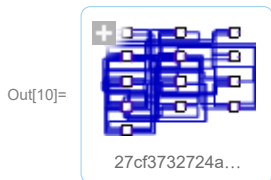
```
Out[8]= {Land_Fertility1.Land_Fert_Degr_Rt.y_vals[4] → 0.5}
```

```
In[9]:= SystemModel[mysim][{"ParameterValues", "Land_Fertility1.Land_Fert_Degr_Rt.y_vals[5]"}]
```

```
Out[9]= {Land_Fertility1.Land_Fert_Degr_Rt.y_vals[5] → 0.5}
```

Change scenario land fertility rates.

```
In[10]:= strsim = SystemModel[mysim, <|"ParameterValues" ->
      {"Land_Fertility1.Land_Fert_Degr_Rt.y_vals" -> {0.0, 0.3, 0.5, 0.7, 0.7}}|>]
```



```
In[11]:= basestrsim = SystemModelSimulate[strsim]
```

```
Out[11]= SystemModelSimulationData[  Model: W27cf3732724a4635858b3d7c30d6f5c0
      Time: 1.90 × 103 to 2.10 × 103 ]
```

Show changed Land_Fertility1.Land_Fert_Degr_Rt.y_vals.

```
In[12]:= SystemModel[strsim][{"ParameterValues", "Land_Fertility1.Land_Fert_Degr_Rt.y_vals[1]"}]
```

```
Out[12]= {Land_Fertility1.Land_Fert_Degr_Rt.y_vals[1] → 0}
```

```
In[13]:= SystemModel[strsim][{"ParameterValues", "Land_Fertility1.Land_Fert_Degr_Rt.y_vals[2]"}]
```

```
Out[13]= {Land_Fertility1.Land_Fert_Degr_Rt.y_vals[2] → 0.3}
```

```
In[14]:= SystemModel[strsim][{"ParameterValues", "Land_Fertility1.Land_Fert_Degr_Rt.y_vals[3]"}]
```

```
Out[14]= {Land_Fertility1.Land_Fert_Degr_Rt.y_vals[3] → 0.5}
```

```
In[15]= SystemModel[strsim][{"ParameterValues", "Land_Fertility1.Land_Fert_Degr_Rt.y_vals[4]"}]
```

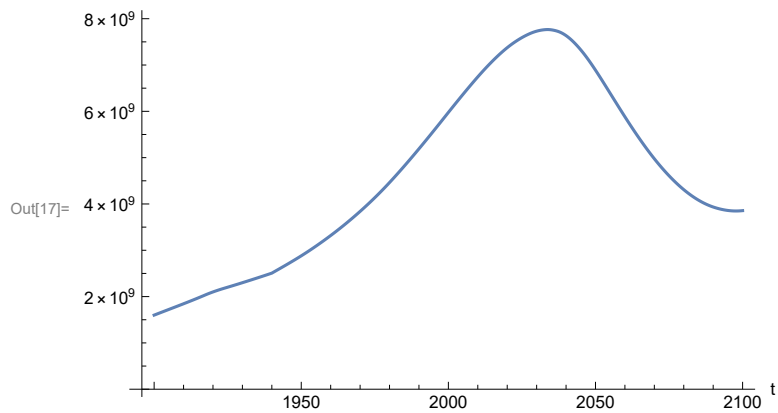
```
Out[15]= {Land_Fertility1.Land_Fert_Degr_Rt.y_vals[4] → 0.7}
```

```
In[16]= SystemModel[strsim][{"ParameterValues", "Land_Fertility1.Land_Fert_Degr_Rt.y_vals[5]"}]
```

```
Out[16]= {Land_Fertility1.Land_Fert_Degr_Rt.y_vals[5] → 0.7}
```

Plot the world population, people.

```
In[17]= SystemModelPlot[basestrsim, {"Population_Dynamics1.Birth_Rate.pop"}]
```



Find max and min of y values.

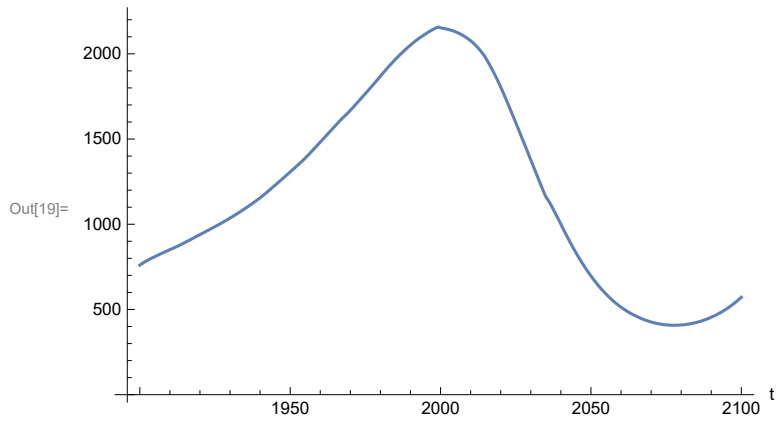
```
In[18]= MinAndMax[basestrsim[{"Population_Dynamics1.Birth_Rate.pop"}]]
```

```
Maximum is  $7.76579 \times 10^9$ 
```

```
Minimum is  $1.6 \times 10^9$ 
```

Plot land yield.

In[19]:= **SystemModelPlot**[basestrsim, {"Food_Production1.Land_Yield.y"}]



Find max and min of y values.

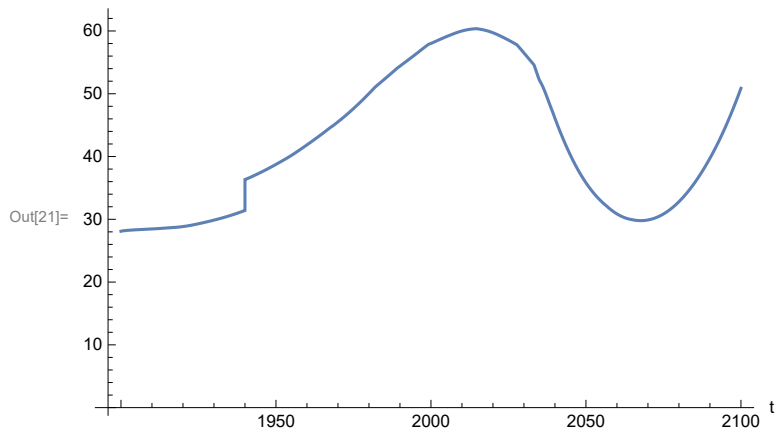
In[20]:= **MinAndMax**[basestrsim[{"Food_Production1.Land_Yield.y"}]]

Maximum is 2157.07

Minimum is 407.45

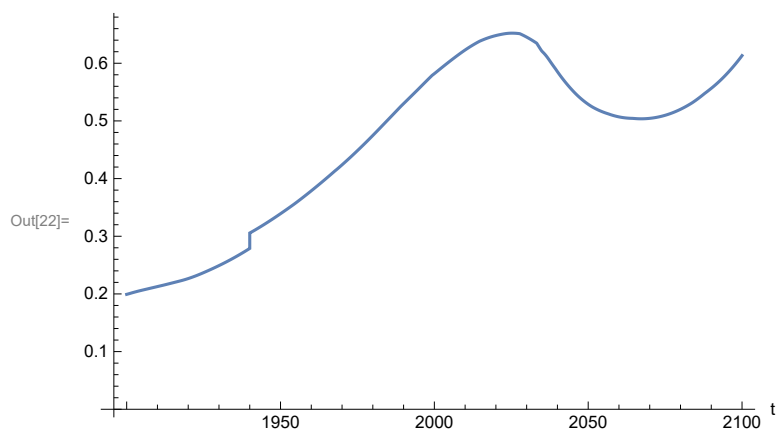
Plot life expectancy, in years.

In[21]:= **SystemModelPlot**[basestrsim, {"Life_Expectancy1.Life_Expectancy.y"}]



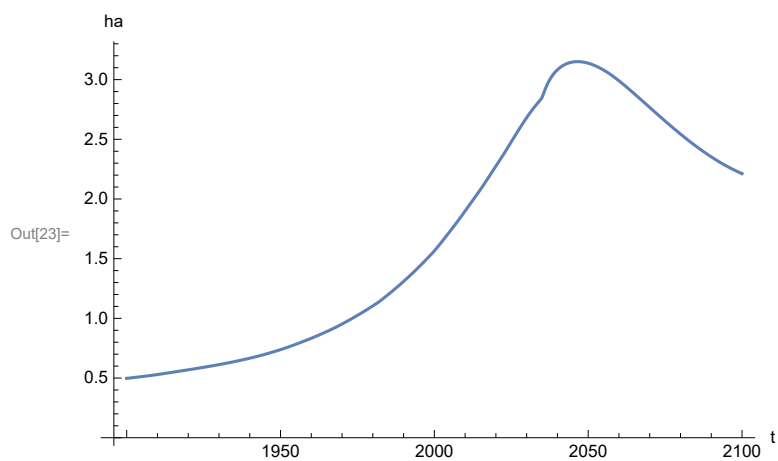
Plot the human welfare index.

```
In[22]:= SystemModelPlot[basestransim,
  {"Human_Welfare_Index1.HWI_Human_Welfare_Index.hwi_human_welfare_index"}]
```



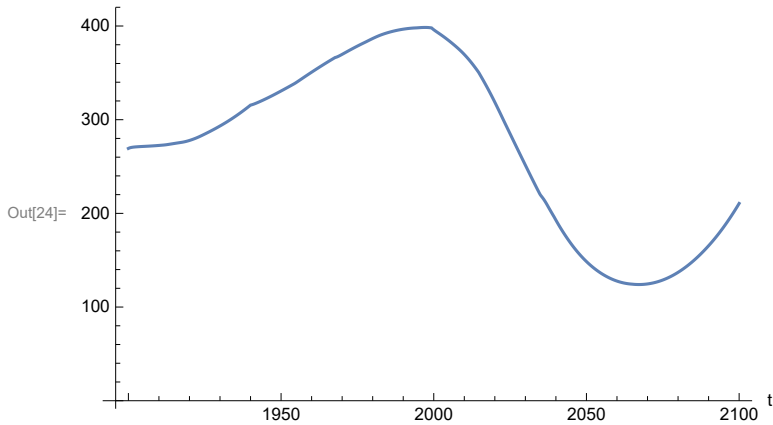
Plot the human ecological footprint, in hectares.

```
In[23]:= SystemModelPlot[basestransim,
  {"Human_Ecological_Footprint1.HEF_Human_Ecological_Footprint.hef_human_ecological_
    _footprint"}]
```



Plot per capita food production, kg/year.

```
In[24]:= SystemModelPlot[basestransim, {"Food_Production1.Food_PC.y"}]
```



Find max and min of y values.

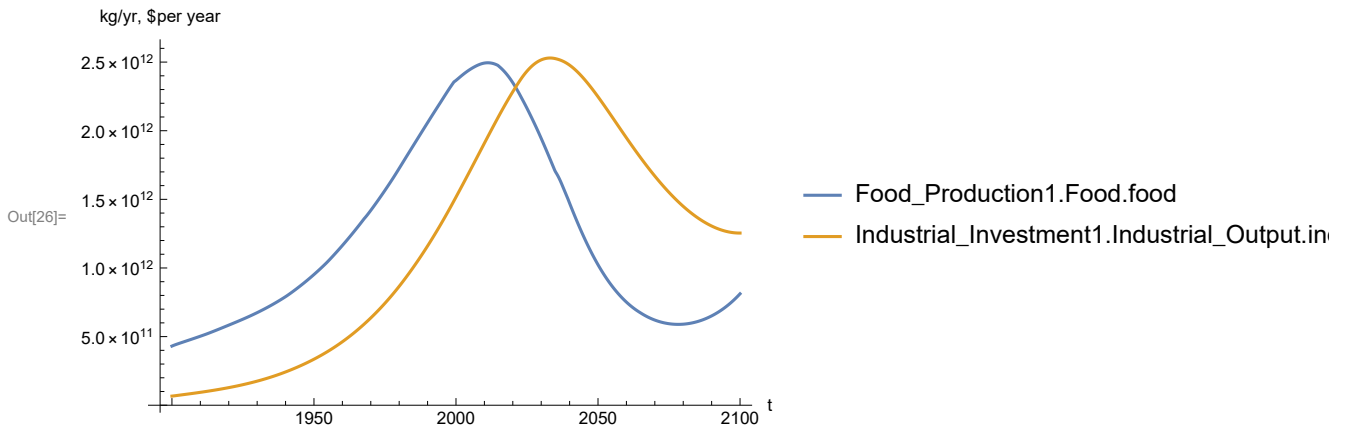
```
In[25]:= MinAndMax[basestransim[{"Food_Production1.Food_PC.y"}]]
```

Maximum is 398.474

Minimum is 124.041

Plot total food production (kg/yr) and industrial output (in dollars).

```
In[26]:= SystemModelPlot[basestransim, {"Food_Production1.Food.food",
    "Industrial_Investment1.Industrial_Output.industrial_output"}]
```



Find max and min of y values.

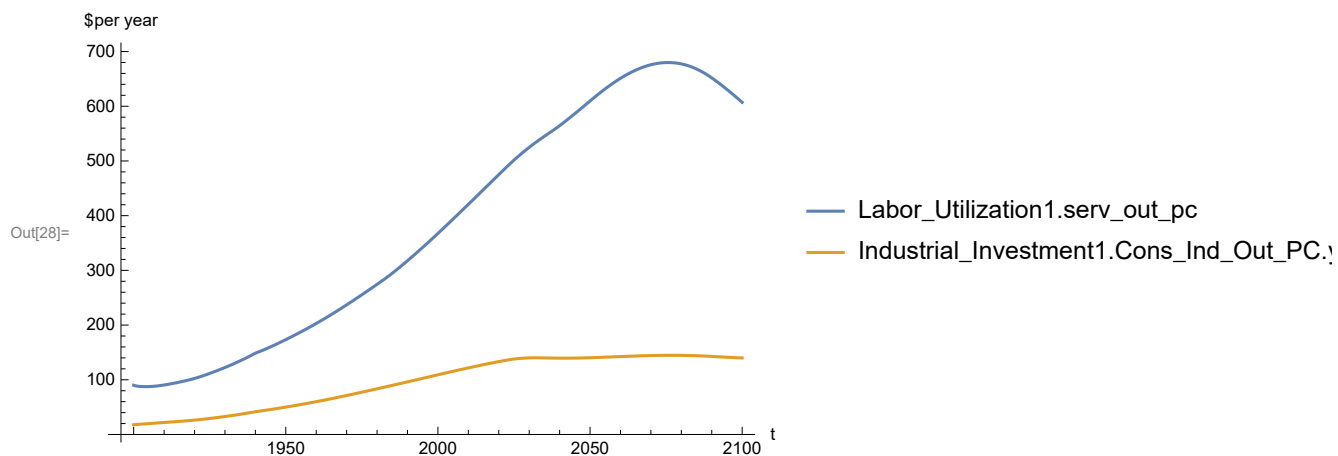
```
In[27]:= MinAndMax[basestransim[{"Industrial_Investment1.Industrial_Output.industrial_output"}]]
```

Maximum is 2.52969×10^{12}

Minimum is 6.65×10^{10}

Plot consolidated industrial output per capita (dollars/year).

```
In[28]:= SystemModelPlot[basestransim,
  {"Labor_Utilization1.serv_out_pc", "Industrial_Investment1.Cons_Ind_Out_PC.y"}]
```



Find max and min of y values.

```
In[29]:= MinAndMax[basestransim[{"Labor_Utilization1.serv_out_pc"}]]
```

Maximum is 679.865

Minimum is 87.4733

Find max and min of y values.

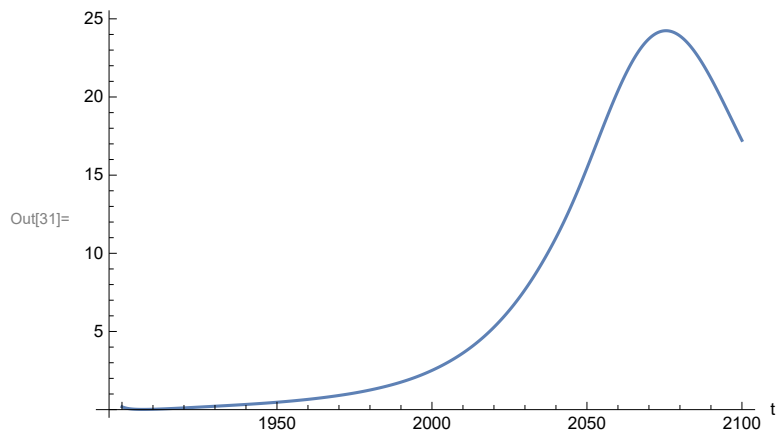
```
In[30]:= MinAndMax[basestransim[{"Industrial_Investment1.Cons_Ind_Out_PC.y"}]]
```

Maximum is 144.699

Minimum is 17.8719

Plot persistent pollution index (normalized to 1970 value).

```
In[31]:= SystemModelPlot[basestransim, {"Pollution_Dynamics1.PPoll_Index.y"}]
```



Find max and min of y values.

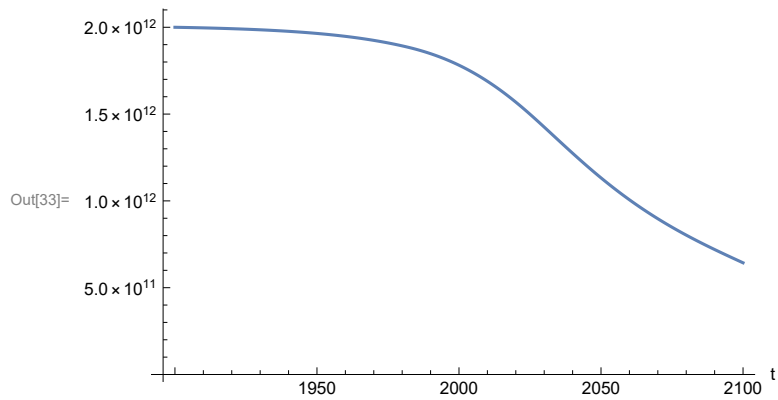
```
In[32]:= MinAndMax[basestransim[{"Pollution_Dynamics1.PPoll_Index.y"}]]
```

Maximum is 24.2396

Minimum is 0.0150836

Plot non-renewable resources remaining.

```
In[33]:= SystemModelPlot[basestransim, {"NR_Resource_Utilization1.NR_Resources.y"}]
```



APPENDIX 48. BENCHMARK SCENARIO 3, Accelerated Land Fertility Degradation Rate

Define a function that extracts range data from scenario data. (The right-hand-side of this definition is specific to a *World3* data structure and assumes that the function whose range is being extracted is globally (i.e., not piecewise) defined.)

```
In[1]:= RangeData[data_] := data[[1]][[4]][[3]];
```

Define a procedure to determine and print minimum and maximum of “y” values.

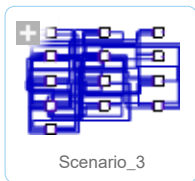
```
In[2]:= MinAndMax[data_] := (myscenseries = RangeData[data];
  Print["Maximum is ", Max[myscenseries]]; Print["Minimum is ", Min[myscenseries]])
```

Here are some high-level properties of Benchmark Scenario 3.

```
In[3]:=
```

```
mysim = SystemModel["SystemDynamics.WorldDynamics.World3.Scenario_3"]
```

```
Out[3]=
```



```
In[4]:=
```

```
mysummary = mysim["Summary"]
```

```
Out[4]=
```

ModelName	SystemDynamics.WorldDynamics.World3.Scenario_3
Description	More accessible non-recoverable natural resources and pollution control
SimulationModel	True
Plots	0
Components	106
Balanced	True
SystemEquations	1583
SystemVariables	1583
Domain	

Show Land_Fertility1.Land_Fert_Degr_Rt.y_vals in original scenario.

```
In[5]:= SystemModel[mysim][{"ParameterValues", "Land_Fertility1.Land_Fert_Degr_Rt.y_vals[1]"}]
```

```
Out[5]= {Land_Fertility1.Land_Fert_Degr_Rt.y_vals[1] → 0}
```

```
In[6]:= SystemModel[mysim][{"ParameterValues", "Land_Fertility1.Land_Fert_Degr_Rt.y_vals[2]"}]
```

```
Out[6]= {Land_Fertility1.Land_Fert_Degr_Rt.y_vals[2] → 0.1}
```

```
In[7]:= SystemModel[mysim][{"ParameterValues", "Land_Fertility1.Land_Fert_Degr_Rt.y_vals[3]"}]
```

```
Out[7]= {Land_Fertility1.Land_Fert_Degr_Rt.y_vals[3] → 0.3}
```

```
In[8]:= SystemModel[mysim][{"ParameterValues", "Land_Fertility1.Land_Fert_Degr_Rt.y_vals[4]"}]
```

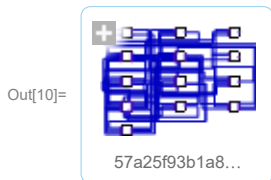
```
Out[8]= {Land_Fertility1.Land_Fert_Degr_Rt.y_vals[4] → 0.5}
```

```
In[9]:= SystemModel[mysim][{"ParameterValues", "Land_Fertility1.Land_Fert_Degr_Rt.y_vals[5]"}]
```

```
Out[9]= {Land_Fertility1.Land_Fert_Degr_Rt.y_vals[5] → 0.5}
```

Change scenario land fertility rates.

```
In[10]:= strsim = SystemModel[mysim, <|"ParameterValues" ->
      {"Land_Fertility1.Land_Fert_Degr_Rt.y_vals" -> {0.0, 0.3, 0.5, 0.7, 0.7}}|>]
```



```
In[11]:= basestrsim = SystemModelSimulate[strsim]
```

```
Out[11]= SystemModelSimulationData[  Model: W57a25f93b1a84f229f9a2deebd81ae25  
Time:  $1.90 \times 10^3$  to  $2.10 \times 10^3$  ]
```

Show changed Land_Fertility1.Land_Fert_Degr_Rt.y_vals.

```
In[12]:= SystemModel[strsim][{"ParameterValues", "Land_Fertility1.Land_Fert_Degr_Rt.y_vals[1]"}]
```

```
Out[12]= {Land_Fertility1.Land_Fert_Degr_Rt.y_vals[1] → 0}
```

```
In[13]:= SystemModel[strsim][{"ParameterValues", "Land_Fertility1.Land_Fert_Degr_Rt.y_vals[2]"}]
```

```
Out[13]= {Land_Fertility1.Land_Fert_Degr_Rt.y_vals[2] → 0.3}
```

```
In[14]:= SystemModel[strsim][{"ParameterValues", "Land_Fertility1.Land_Fert_Degr_Rt.y_vals[3]"}]
```

```
Out[14]= {Land_Fertility1.Land_Fert_Degr_Rt.y_vals[3] → 0.5}
```

```
In[15]= SystemModel[strsim][{"ParameterValues", "Land_Fertility1.Land_Fert_Degr_Rt.y_vals[4]"}]
```

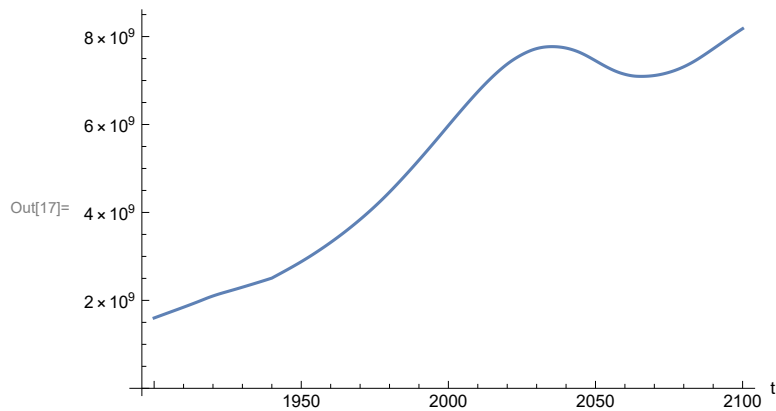
```
Out[15]= {Land_Fertility1.Land_Fert_Degr_Rt.y_vals[4] → 0.7}
```

```
In[16]= SystemModel[strsim][{"ParameterValues", "Land_Fertility1.Land_Fert_Degr_Rt.y_vals[5]"}]
```

```
Out[16]= {Land_Fertility1.Land_Fert_Degr_Rt.y_vals[5] → 0.7}
```

Plot the world population, people.

```
In[17]= SystemModelPlot[basestransim, {"Population_Dynamics1.Birth_Rate.pop"}]
```



Find max and min of y values.

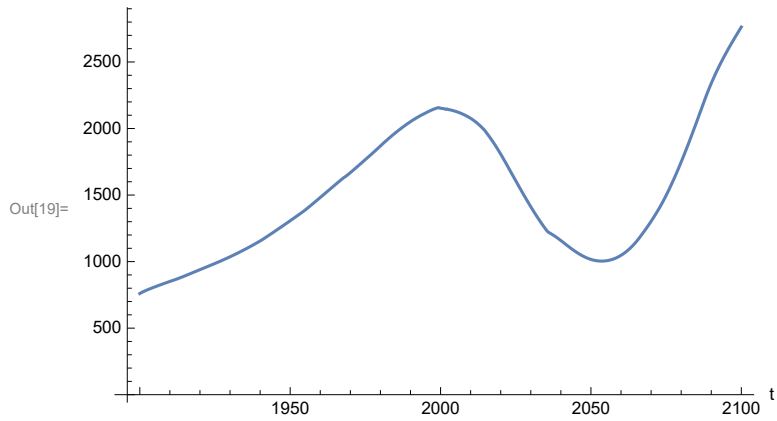
```
In[18]= MinAndMax[basestransim[{"Population_Dynamics1.Birth_Rate.pop"}]]
```

```
Maximum is  $8.17983 \times 10^9$ 
```

```
Minimum is  $1.6 \times 10^9$ 
```

Plot land yield.

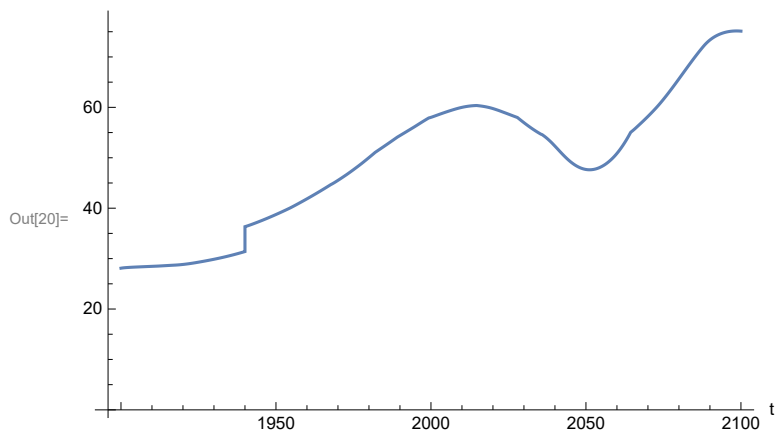
```
In[19]:= SystemModelPlot[basestrsim, {"Food_Production1.Land_Yield.y"}]
```



Plot multiplier of air pollution on land yield.

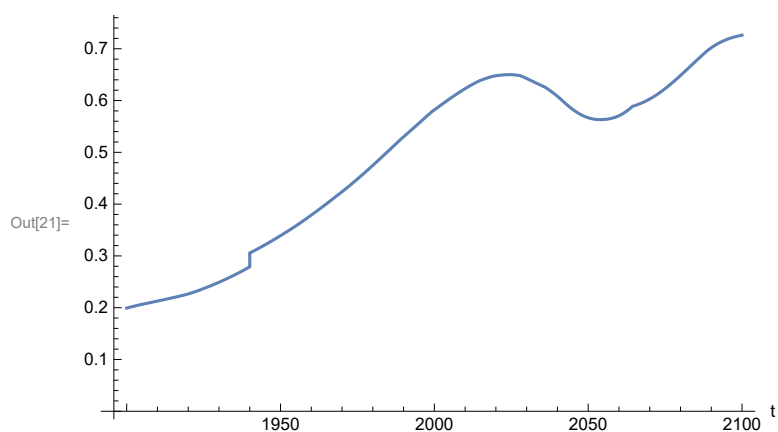
Plot life expectancy, in years.

```
In[20]:= SystemModelPlot[basestrsim, {"Life_Expectancy1.Life_Expectancy.y"}]
```



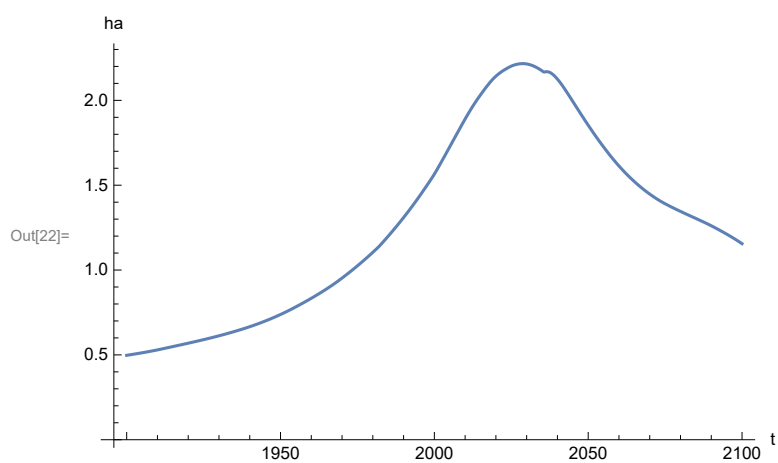
Plot the human welfare index.

```
In[21]:= SystemModelPlot[basestrsim,
  {"Human_Welfare_Index1.HWI_Human_Welfare_Index.hwi_human_welfare_index"}]
```



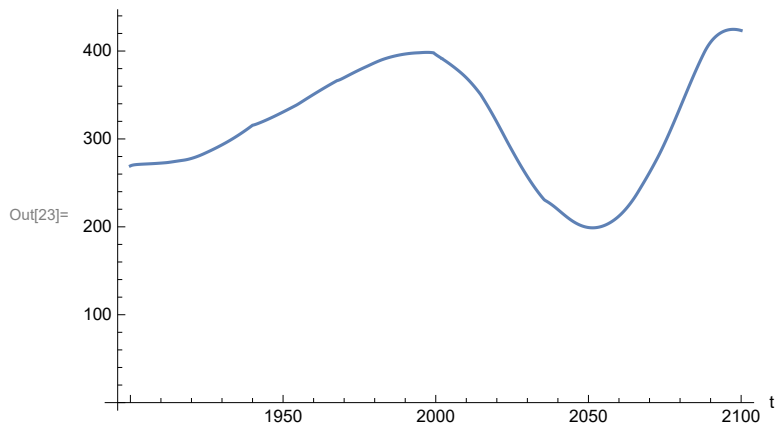
Plot the human ecological footprint, in hectares.

```
In[22]:= SystemModelPlot[basestrsim,
  {"Human_Ecological_Footprint1.HEF_Human_Ecological_Footprint.hef_human_ecological_
    _footprint"}]
```



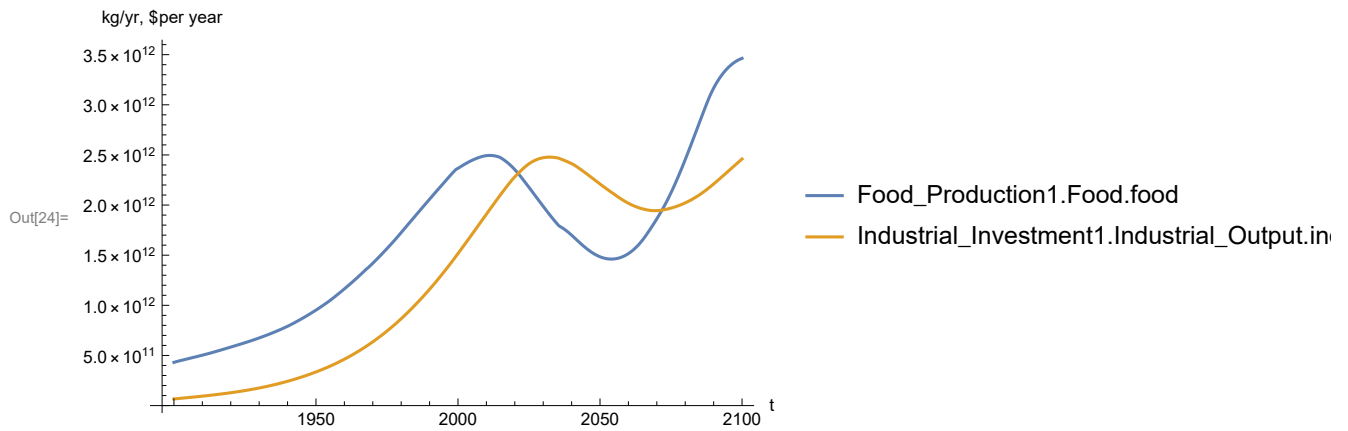
Plot per capita food production, kg/year.

In[23]:= `SystemModelPlot[basestransim, {"Food_Production1.Food_PC.y"}]`



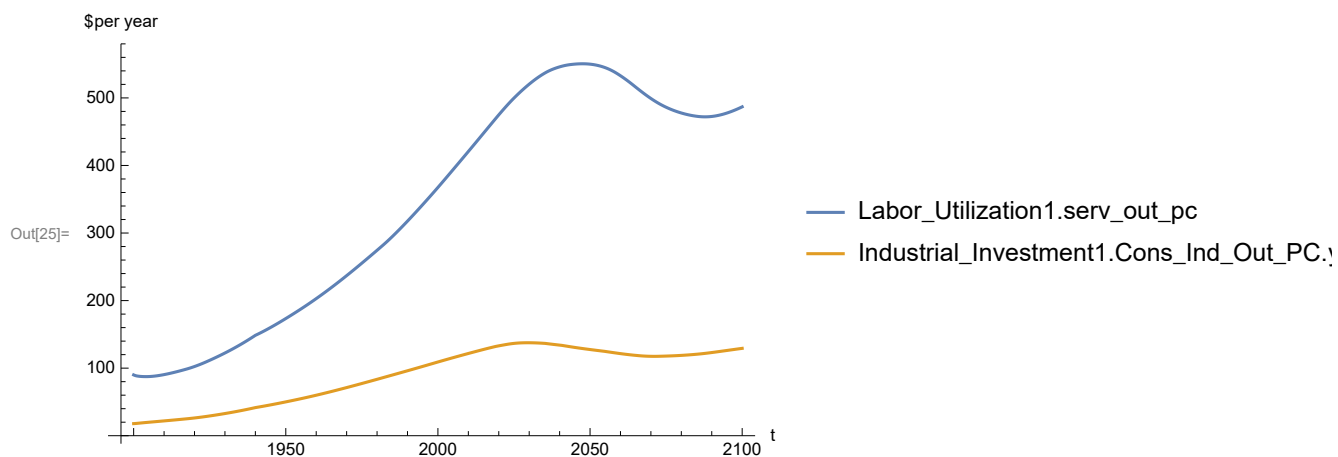
Plot total food production (kg/yr) and industrial output (in dollars).

In[24]:= `SystemModelPlot[basestransim, {"Food_Production1.Food.food", "Industrial_Investment1.Industrial_Output.industrial_output"}]`



Plot consolidated industrial output per capita (dollars/year).

```
In[25]:= SystemModelPlot[basestrsim,
  {"Labor_Utilization1.serv_out_pc", "Industrial_Investment1.Cons_Ind_Out_PC.y"}]
```



Find max and min of y values.

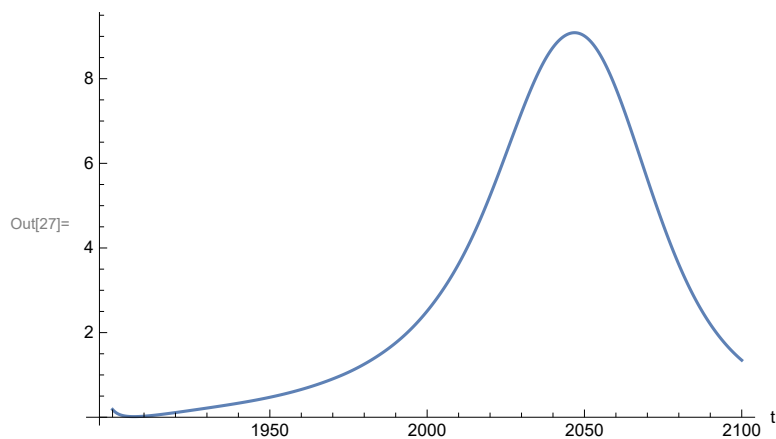
```
In[26]:= MinAndMax[basestrsim[{"Labor_Utilization1.serv_out_pc"}]]
```

Maximum is 550.516

Minimum is 87.4733

Plot persistent pollution index (normalized to 1970 value).

```
In[27]:= SystemModelPlot[basestrsim, {"Pollution_Dynamics1.PPoll_Index.y"}]
```



Find max and min of y values.

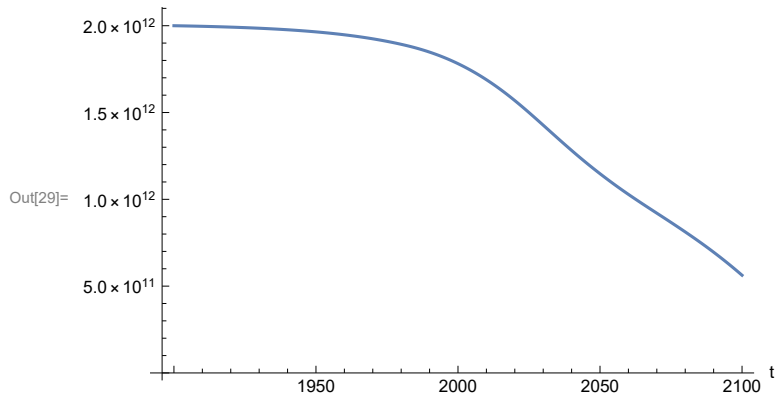
```
In[28]:= MinAndMax[basestrsim[{"Pollution_Dynamics1.PPoll_Index.y"}]]
```

Maximum is 9.08724

Minimum is 0.0150836

Plot non-renewable resources remaining.

```
In[29]:= SystemModelPlot[basestransim, {"NR_Resource_Utilization1.NR_Resources.y"}]
```



APPENDIX 49. BENCHMARK SCENARIO 4, Accelerated Land Fertility Degradation Rate

Define a function that extracts range data from scenario data. (The right-hand-side of this definition is specific to a *World3* data structure and assumes that the function whose range is being extracted is globally (i.e., not piecewise) defined.)

```
In[1]:= RangeData[data_] := data[[1]][[4]][[3]];
```

Define a procedure to determine and print minimum and maximum of “y” values.

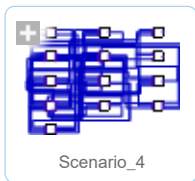
```
In[2]:= MinAndMax[data_] := (myscenseries = RangeData[data];
    Print["Maximum is ", Max[myscenseries]]; Print["Minimum is ", Min[myscenseries]])
```

Here are some high-level properties of Benchmark Scenario 4.

```
In[3]:=
```

```
mysim = SystemModel["SystemDynamics.WorldDynamics.World3.Scenario_4"]
```

```
Out[3]=
```



```
In[4]:= mysummary = mysim["Summary"]
```

```
Out[4]=
```

ModelName	SystemDynamics.WorldDynamics.World3.Scenario_4
Description	More accessible non-recoverable natural resources, pollution control, and land yield ent
SimulationModel	True
Plots	0
Components	106
Balanced	True
SystemEquations	1583
SystemVariables	1583
Domain	

Show Land_Fertility1.Land_Fert_Degr_Rt.y_vals in original scenario.

```
In[5]:= SystemModel[mysim][{"ParameterValues", "Land_Fertility1.Land_Fert_Degr_Rt.y_vals[1]"}]
```

```
Out[5]= {Land_Fertility1.Land_Fert_Degr_Rt.y_vals[1] → 0}
```

```
In[6]:= SystemModel[mysim][{"ParameterValues", "Land_Fertility1.Land_Fert_Degr_Rt.y_vals[2]"}]
```

```
Out[6]= {Land_Fertility1.Land_Fert_Degr_Rt.y_vals[2] → 0.1}
```

```
In[7]:= SystemModel[mysim][{"ParameterValues", "Land_Fertility1.Land_Fert_Degr_Rt.y_vals[3]"}]
```

```
Out[7]= {Land_Fertility1.Land_Fert_Degr_Rt.y_vals[3] → 0.3}
```

```
In[8]:= SystemModel[mysim][{"ParameterValues", "Land_Fertility1.Land_Fert_Degr_Rt.y_vals[4]"}]
```

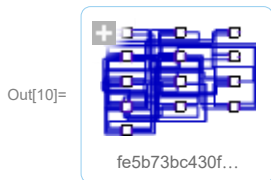
```
Out[8]= {Land_Fertility1.Land_Fert_Degr_Rt.y_vals[4] → 0.5}
```

```
In[9]:= SystemModel[mysim][{"ParameterValues", "Land_Fertility1.Land_Fert_Degr_Rt.y_vals[5]"}]
```


```
Out[9]= {Land_Fertility1.Land_Fert_Degr_Rt.y_vals[5] → 0.5}
```

Change scenario land fertility rates.

```
In[10]:= strsim = SystemModel[mysim, <|"ParameterValues" ->
      {"Land_Fertility1.Land_Fert_Degr_Rt.y_vals" -> {0.0, 0.3, 0.5, 0.7, 0.7}}|>]
```



```
In[11]:= basestrsim = SystemModelSimulate[strsim]
```

```
Out[11]= SystemModelSimulationData [   Model: Wfe5b73bc430f48a58b4f1cd49a7b7253
      Time: 1.90 × 103 to 2.10 × 103 ]
```

Show changed Land_Fertility1.Land_Fert_Degr_Rt.y_vals.

```
In[12]:= SystemModel[strsim][{"ParameterValues", "Land_Fertility1.Land_Fert_Degr_Rt.y_vals[1]"}]
```

```
Out[12]= {Land_Fertility1.Land_Fert_Degr_Rt.y_vals[1] → 0}
```

```
In[13]:= SystemModel[strsim][{"ParameterValues", "Land_Fertility1.Land_Fert_Degr_Rt.y_vals[2]"}]
```

```
Out[13]= {Land_Fertility1.Land_Fert_Degr_Rt.y_vals[2] → 0.3}
```

```
In[14]:= SystemModel[strsim][{"ParameterValues", "Land_Fertility1.Land_Fert_Degr_Rt.y_vals[3]"}]
```

```
Out[14]= {Land_Fertility1.Land_Fert_Degr_Rt.y_vals[3] → 0.5}
```

```
In[15]= SystemModel[strsim][{"ParameterValues", "Land_Fertility1.Land_Fert_Degr_Rt.y_vals[4]"}]
```

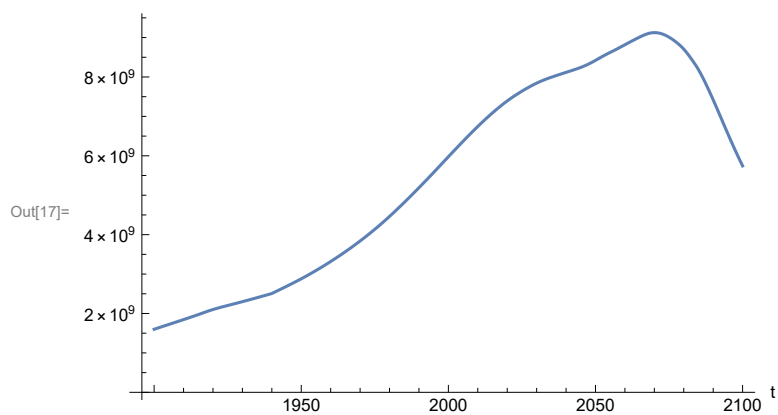
```
Out[15]= {Land_Fertility1.Land_Fert_Degr_Rt.y_vals[4] → 0.7}
```

```
In[16]= SystemModel[strsim][{"ParameterValues", "Land_Fertility1.Land_Fert_Degr_Rt.y_vals[5]"}]
```

```
Out[16]= {Land_Fertility1.Land_Fert_Degr_Rt.y_vals[5] → 0.7}
```

Plot the world population, people.

```
In[17]= SystemModelPlot[basestransim, {"Population_Dynamics1.Birth_Rate.pop"}]
```



Find max and min of y values.

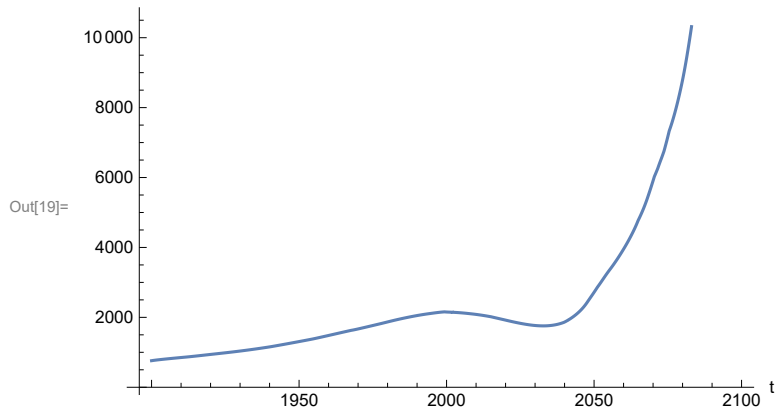
```
In[18]= MinAndMax[basestransim[{"Population_Dynamics1.Birth_Rate.pop"}]]
```

```
Maximum is 9.12435 × 109
```

```
Minimum is 1.6 × 109
```

Plot land yield.

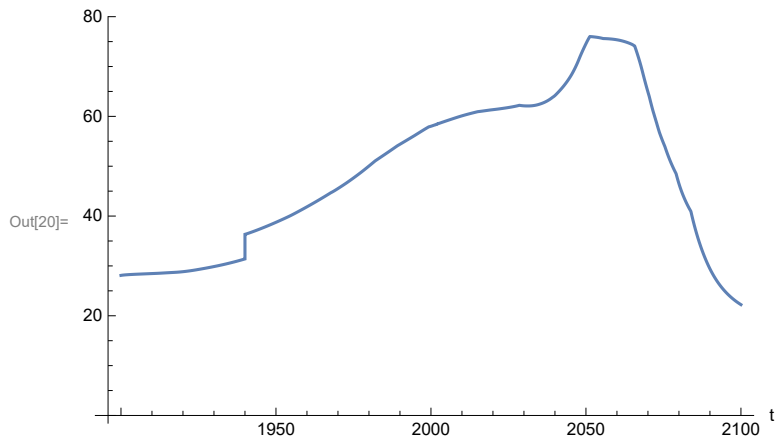
```
In[19]:= SystemModelPlot[basestrsim, {"Food_Production1.Land_Yield.y"}]
```



Plot multiplier of air pollution on land yield.

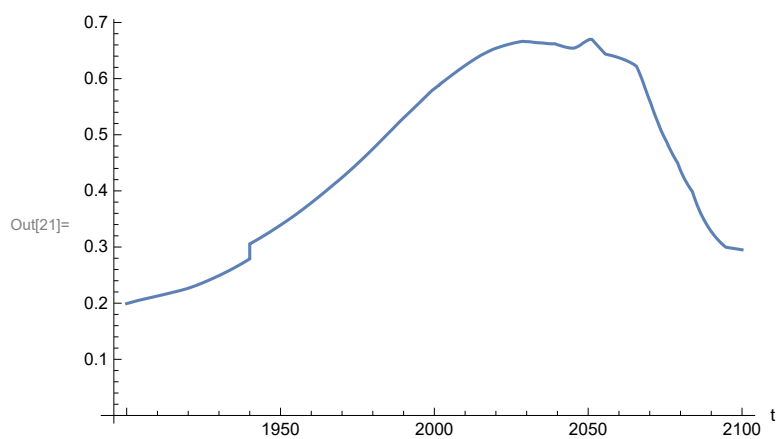
Plot life expectancy, in years.

```
In[20]:= SystemModelPlot[basestrsim, {"Life_Expectancy1.Life_Expectancy.y"}]
```



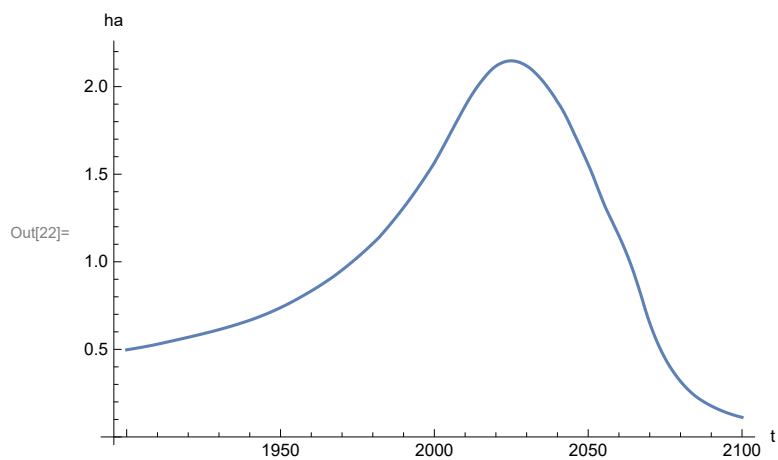
Plot the human welfare index.

```
In[21]:= SystemModelPlot[basestrsim,
  {"Human_Welfare_Index1.HWI_Human_Welfare_Index.hwi_human_welfare_index"}]
```



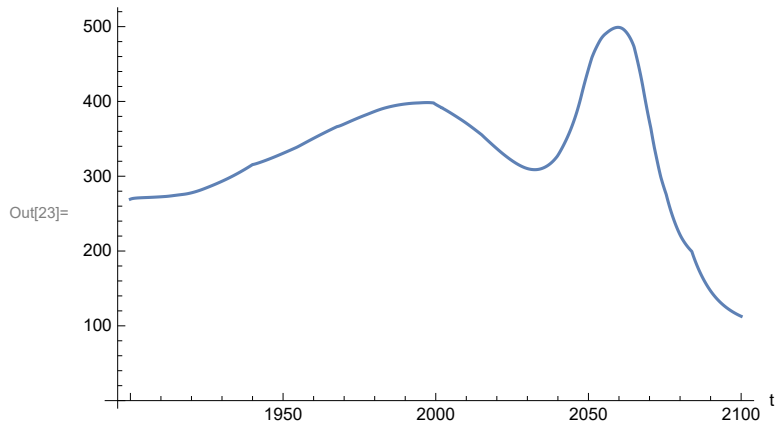
Plot the human ecological footprint, in hectares.

```
In[22]:= SystemModelPlot[basestrsim,
  {"Human_Ecological_Footprint1.HEF_Human_Ecological_Footprint.hef_human_ecological_
    _footprint"}]
```



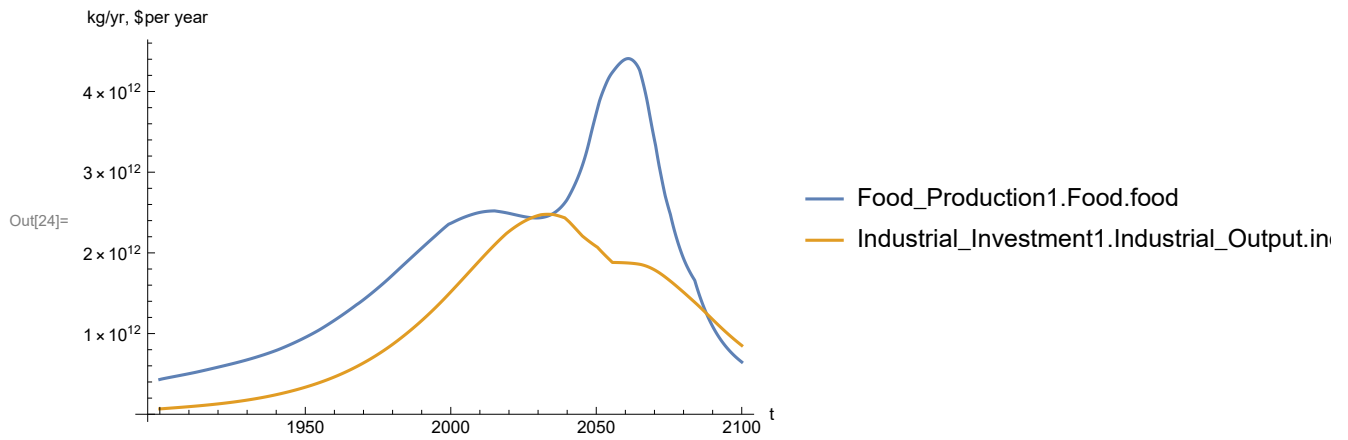
Plot per capita food production, kg/year.

In[23]:= `SystemModelPlot[basestransim, {"Food_Production1.Food_PC.y"}]`



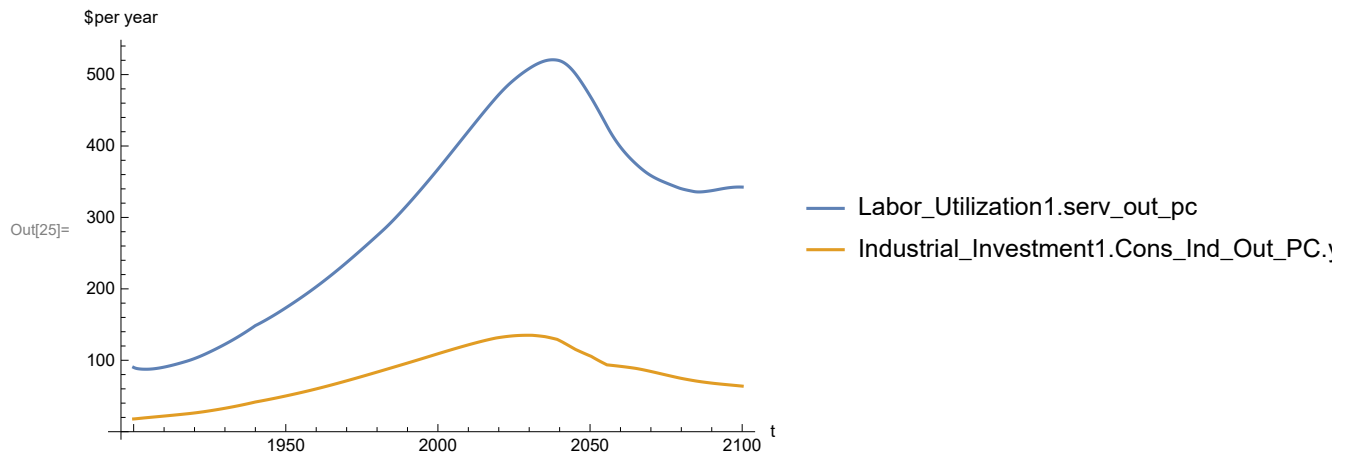
Plot total food production (kg/yr) and industrial output (in dollars).

In[24]:= `SystemModelPlot[basestransim, {"Food_Production1.Food.food", "Industrial_Investment1.Industrial_Output.industrial_output"}]`



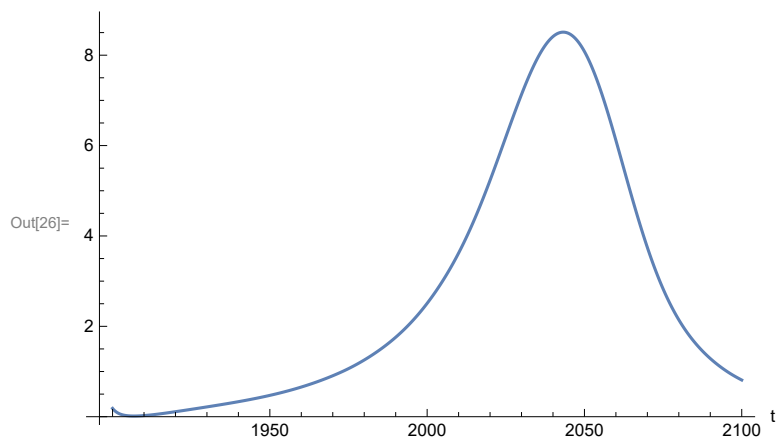
Plot consolidated industrial output per capita (dollars/year).

```
In[25]:= SystemModelPlot[basestransim,
  {"Labor_Utilization1.serv_out_pc", "Industrial_Investment1.Cons_Ind_Out_PC.y"}]
```



Plot persistent pollution index (normalized to 1970 value).

```
In[26]:= SystemModelPlot[basestransim, {"Pollution_Dynamics1.PPoll_Index.y"}]
```



Find max and min of y values.

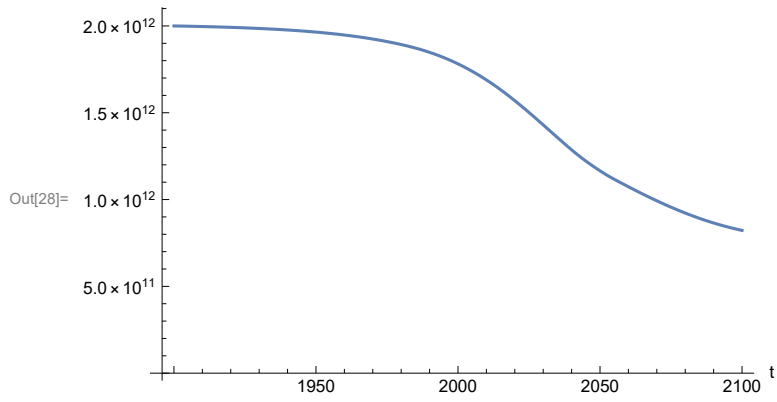
```
In[27]:= MinAndMax[basestransim[{"Pollution_Dynamics1.PPoll_Index.y"}]]
```

Maximum is 8.50998

Minimum is 0.0150836

Plot non-renewable resources remaining.


```
In[28]:= SystemModelPlot[basestransim, {"NR_Resource_Utilization1.NR_Resources.y"}]
```



APPENDIX 50. BENCHMARK SCENARIO 5, Accelerated Land Fertility Degradation Rate

Define a function that extracts range data from scenario data. (The right-hand-side of this definition is specific to a *World3* data structure and assumes that the function whose range is being extracted is globally (i.e., not piecewise) defined.)

```
In[1]:= RangeData[data_] := data[[1]][[4]][[3]];
```

Define a procedure to determine and print minimum and maximum of “y” values.

```
In[2]:= MinAndMax[data_] := (myscenseries = RangeData[data];
  Print["Maximum is ", Max[myscenseries]]; Print["Minimum is ", Min[myscenseries]])
```

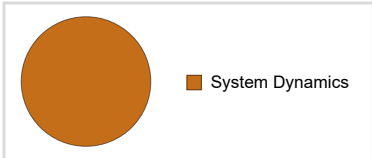
Here are some high-level properties of Benchmark Scenario 5.

```
In[3]:= mysim = SystemModel["SystemDynamics.WorldDynamics.World3.Scenario_5"]
```



```
In[4]:= mysummary = mysim["Summary"]
```

Out[4]=

ModelName	SystemDynamics.WorldDynamics.World3.Scenario_5
Description	More accessible non-recoverable natural resources, pollution control, land yield
SimulationModel	True
Plots	0
Components	106
Balanced	True
SystemEquations	1583
SystemVariables	1583
Domain	

Show Land_Fertility1.Land_Fert_Degr_Rt.y_vals in original scenario.

```
In[5]:= SystemModel[mysim][{"ParameterValues", "Land_Fertility1.Land_Fert_Degr_Rt.y_vals[1]"}]
```

```
Out[5]= {Land_Fertility1.Land_Fert_Degr_Rt.y_vals[1] → 0}
```

```
In[6]:= SystemModel[mysim][{"ParameterValues", "Land_Fertility1.Land_Fert_Degr_Rt.y_vals[2]"}]
```

```
Out[6]= {Land_Fertility1.Land_Fert_Degr_Rt.y_vals[2] → 0.1}
```

```
In[7]:= SystemModel[mysim][{"ParameterValues", "Land_Fertility1.Land_Fert_Degr_Rt.y_vals[3]"}]
```

```
Out[7]= {Land_Fertility1.Land_Fert_Degr_Rt.y_vals[3] → 0.3}
```

```
In[8]:= SystemModel[mysim][{"ParameterValues", "Land_Fertility1.Land_Fert_Degr_Rt.y_vals[4]"}]
```

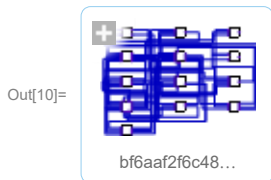
```
Out[8]= {Land_Fertility1.Land_Fert_Degr_Rt.y_vals[4] → 0.5}
```

```
In[9]:= SystemModel[mysim][{"ParameterValues", "Land_Fertility1.Land_Fert_Degr_Rt.y_vals[5]"}]
```

```
Out[9]= {Land_Fertility1.Land_Fert_Degr_Rt.y_vals[5] → 0.5}
```

Change scenario land fertility rates.

```
In[10]:= strsim = SystemModel[mysim, <|"ParameterValues" ->
      {"Land_Fertility1.Land_Fert_Degr_Rt.y_vals" -> {0.0, 0.3, 0.5, 0.7, 0.7}}|>]
```



```
In[11]:= basestrsim = SystemModelSimulate[strsim]
```

```
Out[11]= SystemModelSimulationData[  Model: Wbf6aaf2f6c4848fb8f5e8943d5f2f365
      Time: 1.90 × 103 to 2.10 × 103 ]
```

Show changed Land_Fertility1.Land_Fert_Degr_Rt.y_vals.

```
In[12]:= SystemModel[strsim][{"ParameterValues", "Land_Fertility1.Land_Fert_Degr_Rt.y_vals[1]"}]
```

```
Out[12]= {Land_Fertility1.Land_Fert_Degr_Rt.y_vals[1] → 0}
```

```
In[13]:= SystemModel[strsim][{"ParameterValues", "Land_Fertility1.Land_Fert_Degr_Rt.y_vals[2]"}]
```

```
Out[13]= {Land_Fertility1.Land_Fert_Degr_Rt.y_vals[2] → 0.3}
```

```
In[14]:= SystemModel[strsim][{"ParameterValues", "Land_Fertility1.Land_Fert_Degr_Rt.y_vals[3]"}]
```

```
Out[14]= {Land_Fertility1.Land_Fert_Degr_Rt.y_vals[3] → 0.5}
```

```
In[15]= SystemModel[strsim][{"ParameterValues", "Land_Fertility1.Land_Fert_Degr_Rt.y_vals[4]"}]
```

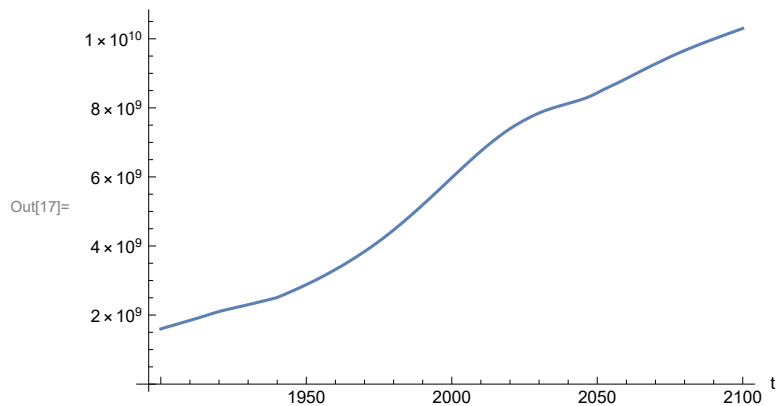
```
Out[15]= {Land_Fertility1.Land_Fert_Degr_Rt.y_vals[4] → 0.7}
```

```
In[16]= SystemModel[strsim][{"ParameterValues", "Land_Fertility1.Land_Fert_Degr_Rt.y_vals[5]"}]
```

```
Out[16]= {Land_Fertility1.Land_Fert_Degr_Rt.y_vals[5] → 0.7}
```

Plot the world population, people.

```
In[17]= SystemModelPlot[basestrsim, {"Population_Dynamics1.Birth_Rate.pop"}]
```



Find max and min of y values.

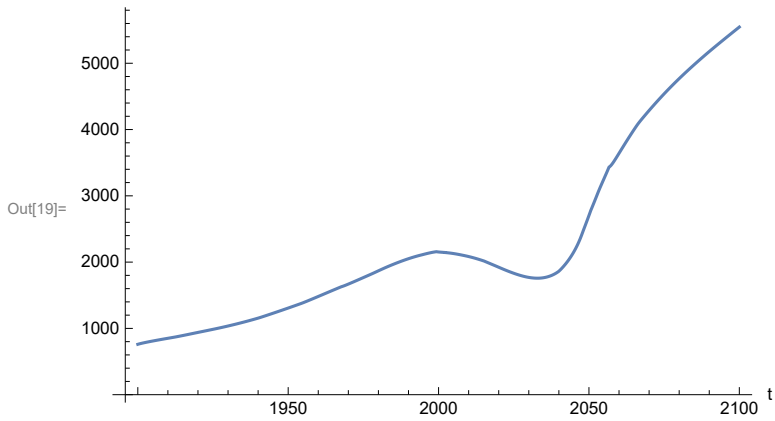
```
In[18]= MinAndMax[basestrsim[{"Population_Dynamics1.Birth_Rate.pop"}]]
```

```
Maximum is  $1.02999 \times 10^{10}$ 
```

```
Minimum is  $1.6 \times 10^9$ 
```

Plot land yield.

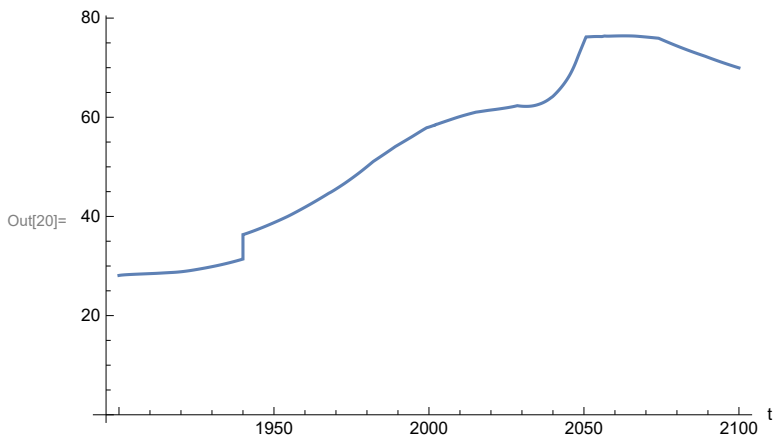
```
In[19]:= SystemModelPlot[basestransim, {"Food_Production1.Land_Yield.y"}]
```



Plot multiplier of air pollution on land yield.

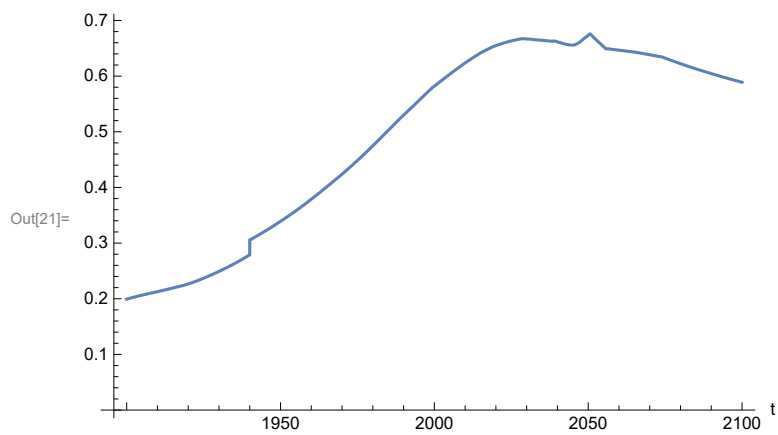
Plot life expectancy, in years.

```
In[20]:= SystemModelPlot[basestransim, {"Life_Expectancy1.Life_Expectancy.y"}]
```



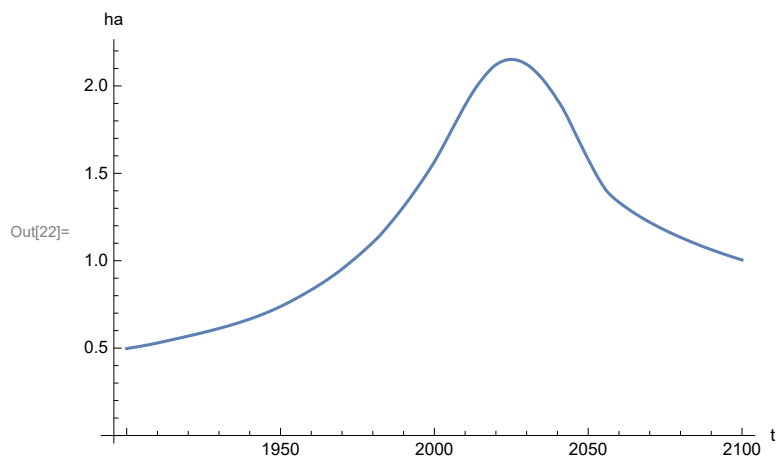
Plot the human welfare index.

```
In[21]:= SystemModelPlot[basestransim,
  {"Human_Welfare_Index1.HWI_Human_Welfare_Index.hwi_human_welfare_index"}]
```



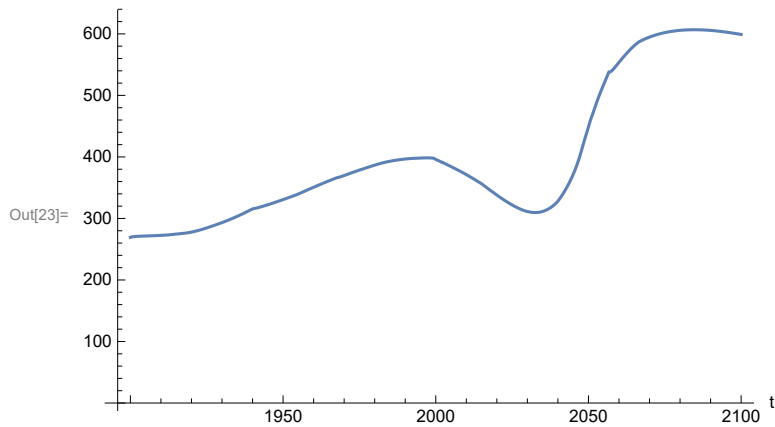
Plot the human ecological footprint, in hectares.

```
In[22]:= SystemModelPlot[basestransim,
  {"Human_Ecological_Footprint1.HEF_Human_Ecological_Footprint.hef_human_ecological_
    _footprint"}]
```



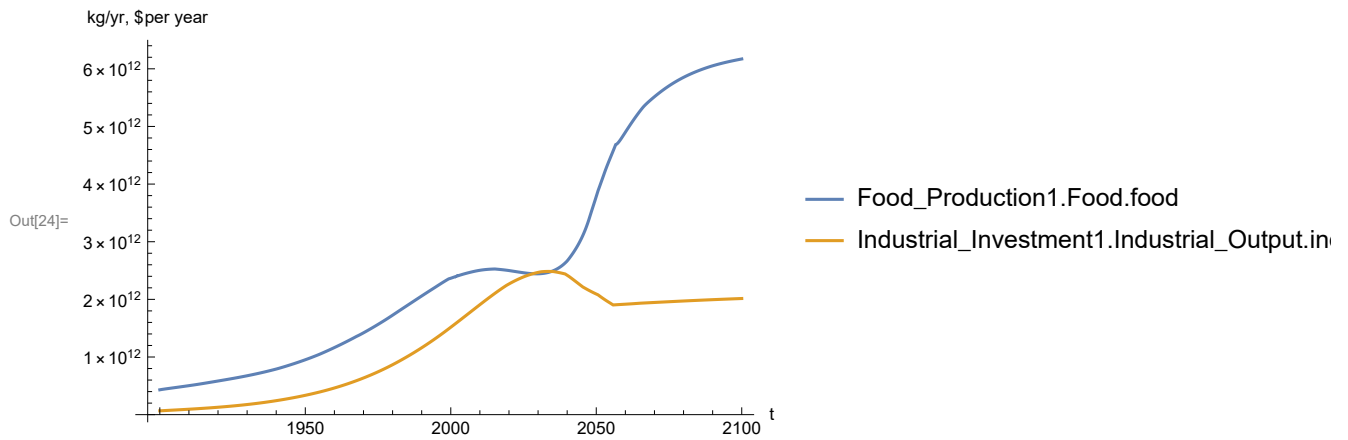
Plot per capita food production, kg/year.

In[23]:= SystemModelPlot[basestransim, {"Food_Production1.Food_PC.y"}]



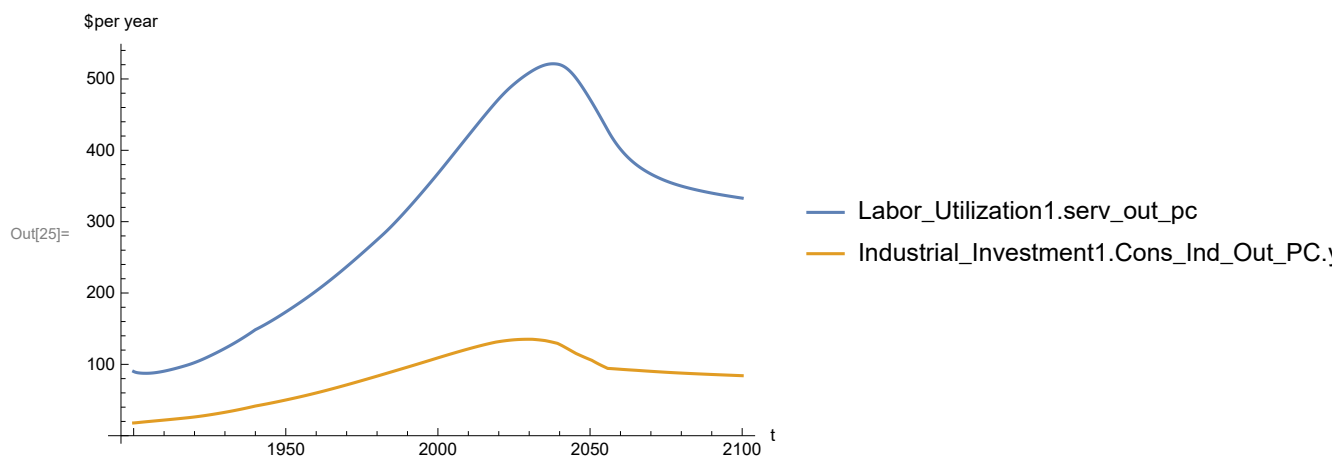
Plot total food production (kg/yr) and industrial output (in dollars).

In[24]:= SystemModelPlot[basestransim, {"Food_Production1.Food.food", "Industrial_Investment1.Industrial_Output.industrial_output"}]



Plot consolidated industrial output per capita (dollars/year).

```
In[25]:= SystemModelPlot[basestrsim,
  {"Labor_Utilization1.serv_out_pc", "Industrial_Investment1.Cons_Ind_Out_PC.y"}]
```



Find max and min of y values.

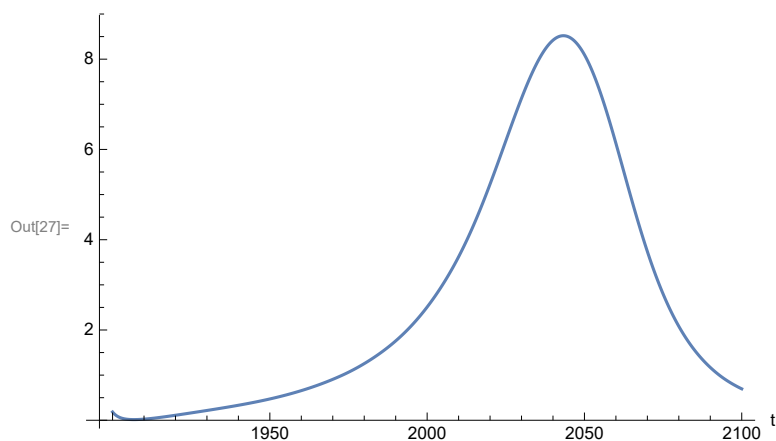
```
In[26]:= MinAndMax[basestrsim[{"Labor_Utilization1.serv_out_pc"}]]
```

Maximum is 521.275

Minimum is 87.4733

Plot persistent pollution index (normalized to 1970 value).

```
In[27]:= SystemModelPlot[basestrsim, {"Pollution_Dynamics1.PPoll_Index.y"}]
```



Find max and min of y values.

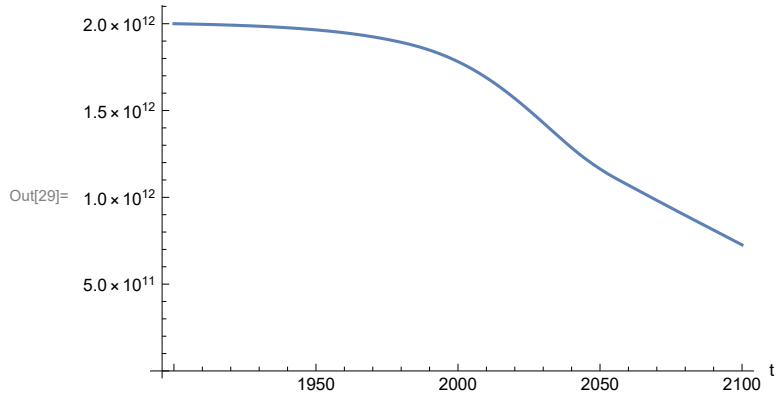
```
In[28]:= MinAndMax[basestrsim[{"Pollution_Dynamics1.PPoll_Index.y"}]]
```

Maximum is 8.51958

Minimum is 0.0150836

Plot non-renewable resources remaining.

```
In[29]:= SystemModelPlot[basestransim, {"NR_Resource_Utilization1.NR_Resources.y"}]
```



APPENDIX 51. BENCHMARK SCENARIO 6, Accelerated Land Fertility Degradation Rate

Define a function that extracts range data from scenario data. (The right-hand-side of this definition is specific to a *World3* data structure and assumes that the function whose range is being extracted is globally (i.e., not piecewise) defined.)

```
In[1]:= RangeData[data_] := data[[1]][[4]][[3]];
```

Define a procedure to determine and print minimum and maximum of “y” values.

```
In[2]:= MinAndMax[data_] := (myscenseries = RangeData[data];
    Print["Maximum is ", Max[myscenseries]]; Print["Minimum is ", Min[myscenseries]])
```

Here are some high-level properties of Benchmark Scenario 6.

```
In[3]:= mysim = SystemModel["SystemDynamics.WorldDynamics.World3.Scenario_6"]
```



```
In[4]:= mysummary = mysim["Summary"]
```

Out[4]=

ModelName	SystemDynamics.WorldDynamics.World3.Scenario_6
Description	More accessible non-recoverable natural resources, pollution control, land yield
SimulationModel	True
Plots	0
Components	106
Balanced	True
SystemEquations	1583
SystemVariables	1583
Domain	

Show Land_Fertility1.Land_Fert_Degr_Rt.y_vals in original scenario.

```
In[5]:= SystemModel[mysim][{"ParameterValues", "Land_Fertility1.Land_Fert_Degr_Rt.y_vals[1]"}]
```

```
Out[5]= {Land_Fertility1.Land_Fert_Degr_Rt.y_vals[1] → 0}
```

```
In[6]:= SystemModel[mysim][{"ParameterValues", "Land_Fertility1.Land_Fert_Degr_Rt.y_vals[2]"}]
```

```
Out[6]= {Land_Fertility1.Land_Fert_Degr_Rt.y_vals[2] → 0.1}
```

```
In[7]:= SystemModel[mysim][{"ParameterValues", "Land_Fertility1.Land_Fert_Degr_Rt.y_vals[3]"}]
```

```
Out[7]= {Land_Fertility1.Land_Fert_Degr_Rt.y_vals[3] → 0.3}
```

```
In[8]:= SystemModel[mysim][{"ParameterValues", "Land_Fertility1.Land_Fert_Degr_Rt.y_vals[4]"}]
```

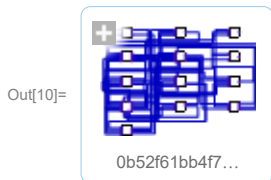
```
Out[8]= {Land_Fertility1.Land_Fert_Degr_Rt.y_vals[4] → 0.5}
```

```
In[9]:= SystemModel[mysim][{"ParameterValues", "Land_Fertility1.Land_Fert_Degr_Rt.y_vals[5]"}]
```

```
Out[9]= {Land_Fertility1.Land_Fert_Degr_Rt.y_vals[5] → 0.5}
```

Change scenario land fertility rates.

```
In[10]:= strsim = SystemModel[mysim, <|"ParameterValues" ->
      {"Land_Fertility1.Land_Fert_Degr_Rt.y_vals" -> {0.0, 0.3, 0.5, 0.7, 0.7}}|>]
```



```
In[11]:= basestrsim = SystemModelSimulate[strsim]
```

```
Out[11]= SystemModelSimulationData[  ]
```

Show changed Land_Fertility1.Land_Fert_Degr_Rt.y_vals.

```
In[12]:= SystemModel[strsim][{"ParameterValues", "Land_Fertility1.Land_Fert_Degr_Rt.y_vals[1]"}]
```

```
Out[12]= {Land_Fertility1.Land_Fert_Degr_Rt.y_vals[1] → 0}
```

```
In[13]:= SystemModel[strsim][{"ParameterValues", "Land_Fertility1.Land_Fert_Degr_Rt.y_vals[2]"}]
```

```
Out[13]= {Land_Fertility1.Land_Fert_Degr_Rt.y_vals[2] → 0.3}
```

```
In[14]:= SystemModel[strsim][{"ParameterValues", "Land_Fertility1.Land_Fert_Degr_Rt.y_vals[3]"}]
```

```
Out[14]= {Land_Fertility1.Land_Fert_Degr_Rt.y_vals[3] → 0.5}
```

```
In[15]= SystemModel[strsim][{"ParameterValues", "Land_Fertility1.Land_Fert_Degr_Rt.y_vals[4]"}]
```

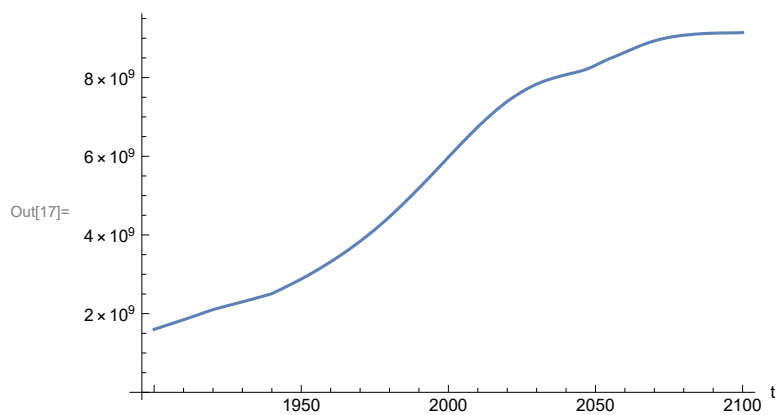
```
Out[15]= {Land_Fertility1.Land_Fert_Degr_Rt.y_vals[4] → 0.7}
```

```
In[16]= SystemModel[strsim][{"ParameterValues", "Land_Fertility1.Land_Fert_Degr_Rt.y_vals[5]"}]
```

```
Out[16]= {Land_Fertility1.Land_Fert_Degr_Rt.y_vals[5] → 0.7}
```

Plot the world population, people.

```
In[17]= SystemModelPlot[basestransim, {"Population_Dynamics1.Birth_Rate.pop"}]
```



Find max and min of y values.

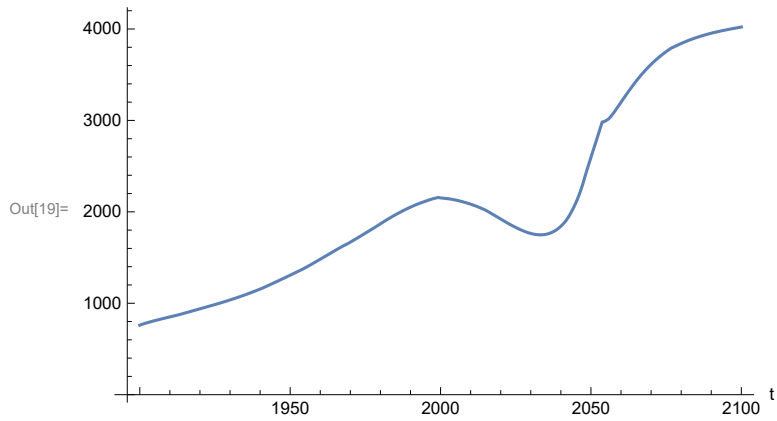
```
In[18]= MinAndMax[basestransim[{"Population_Dynamics1.Birth_Rate.pop"}]]
```

```
Maximum is  $9.1424 \times 10^9$ 
```

```
Minimum is  $1.6 \times 10^9$ 
```

Plot land yield.

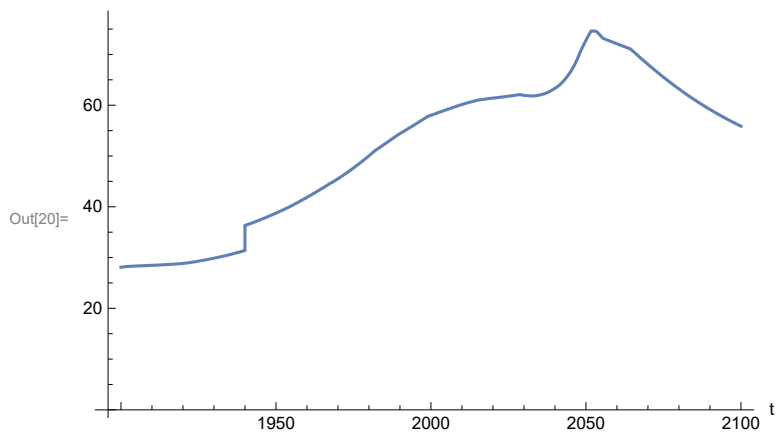
```
In[19]:= SystemModelPlot[basestransim, {"Food_Production1.Land_Yield.y"}]
```



Plot multiplier of air pollution on land yield.

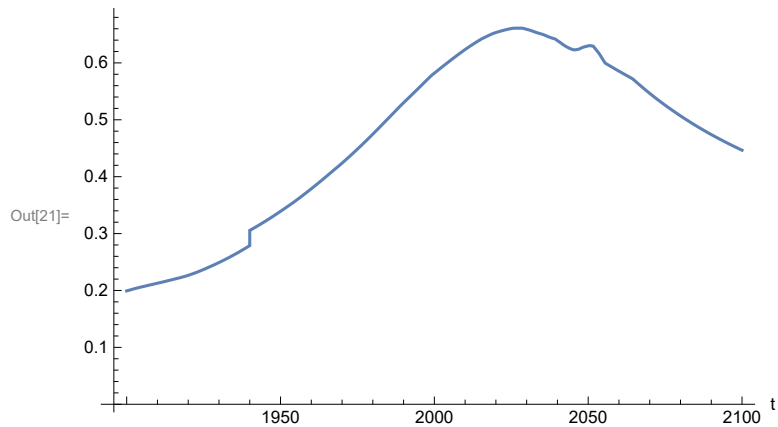
Plot life expectancy, in years.

```
In[20]:= SystemModelPlot[basestransim, {"Life_Expectancy1.Life_Expectancy.y"}]
```



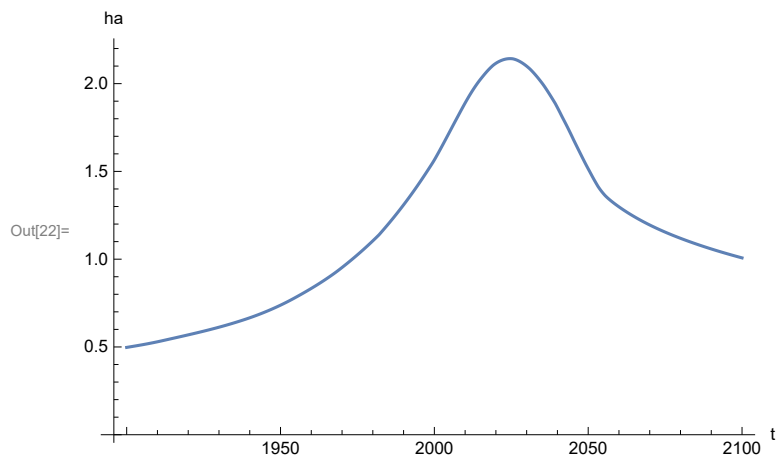
Plot the human welfare index.

```
In[21]:= SystemModelPlot[basestrsim,
  {"Human_Welfare_Index1.HWI_Human_Welfare_Index.hwi_human_welfare_index"}]
```



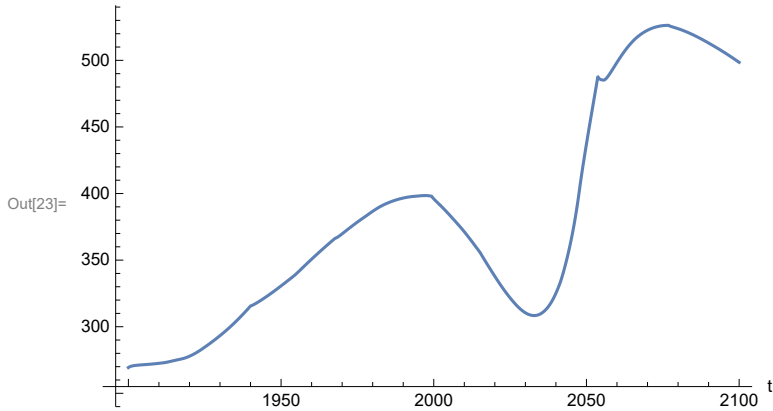
Plot the human ecological footprint, in hectares.

```
In[22]:= SystemModelPlot[basestrsim,
  {"Human_Ecological_Footprint1.HEF_Human_Ecological_Footprint.hef_human_ecological_
    _footprint"}]
```



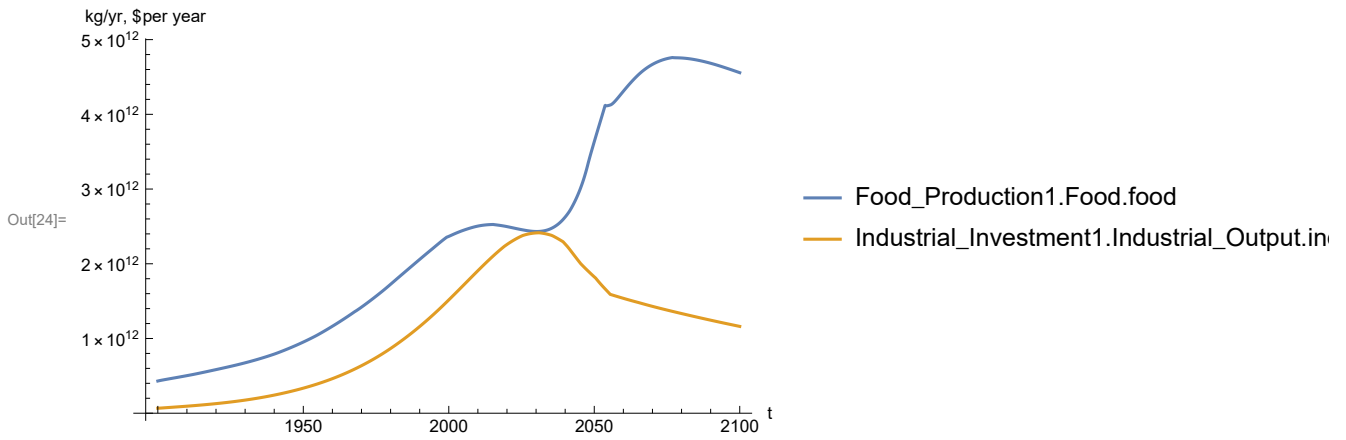
Plot per capita food production, kg/year.

In[23]:= `SystemModelPlot[basestransim, {"Food_Production1.Food_PC.y"}]`



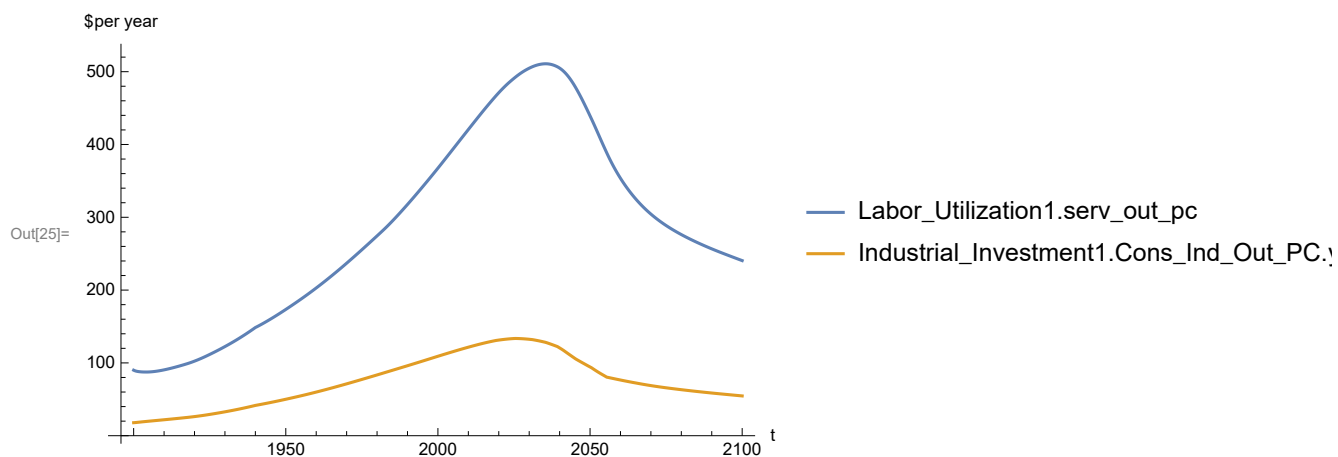
Plot total food production (kg/yr) and industrial output (in dollars).

In[24]:= `SystemModelPlot[basestransim, {"Food_Production1.Food.food", "Industrial_Investment1.Industrial_Output.industrial_output"}]`



Plot consolidated industrial output per capita (dollars/year).

```
In[25]:= SystemModelPlot[basestrsim,
  {"Labor_Utilization1.serv_out_pc", "Industrial_Investment1.Cons_Ind_Out_PC.y"}]
```



Find max and min of y values.

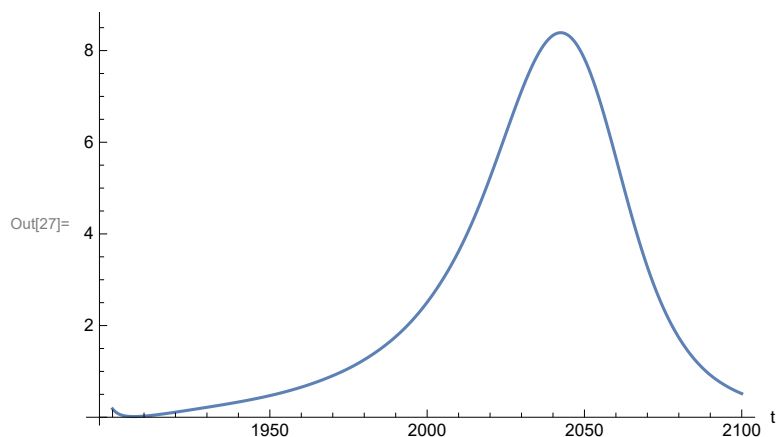
```
In[26]:= MinAndMax[basestrsim[{"Labor_Utilization1.serv_out_pc"}]]
```

Maximum is 510.85

Minimum is 87.4733

Plot persistent pollution index (normalized to 1970 value).

```
In[27]:= SystemModelPlot[basestrsim, {"Pollution_Dynamics1.PPoll_Index.y"}]
```



Find max and min of y values.

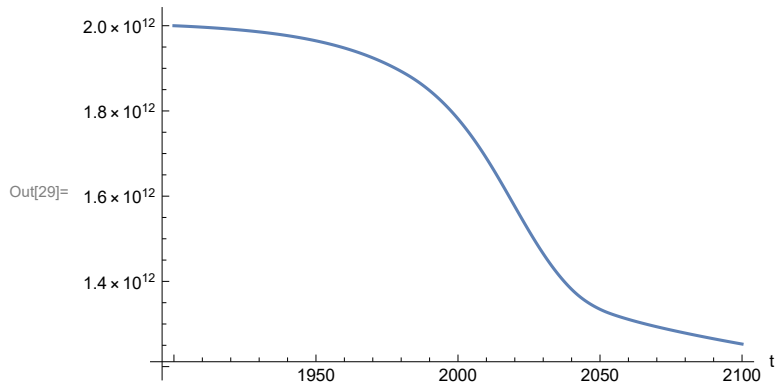
```
In[28]:= MinAndMax[basestrsim[{"Pollution_Dynamics1.PPoll_Index.y"}]]
```

Maximum is 8.3902

Minimum is 0.0150836

Plot non-renewable resources remaining.

```
In[29]:= SystemModelPlot[basestransim, {"NR_Resource_Utilization1.NR_Resources.y"}]
```



APPENDIX 52. BENCHMARK SCENARIO 7, Accelerated Land Fertility Degradation Rate

Define a function that extracts range data from scenario data. (The right-hand-side of this definition is specific to a *World3* data structure and assumes that the function whose range is being extracted is globally (i.e., not piecewise) defined.)

```
In[1]:= RangeData[data_] := data[[1]][[4]][[3]];
```

Define a procedure to determine and print minimum and maximum of “y” values.

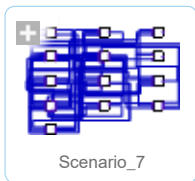
```
In[2]:= MinAndMax[data_] := (myscenseries = RangeData[data];
    Print["Maximum is ", Max[myscenseries]]; Print["Minimum is ", Min[myscenseries]])
```

Here are some high-level properties of Benchmark Scenario 7.

```
In[3]:=
```

```
mysim = SystemModel["SystemDynamics.WorldDynamics.World3.Scenario_7"]
```

```
Out[3]=
```



```
In[4]:=
```

```
mysummary = mysim["Summary"]
```

```
Out[4]=
```

ModelName	SystemDynamics.WorldDynamics.World3.Scenario_7
Description	More abundant non-recoverable natural resources and birth control
SimulationModel	True
Plots	0
Components	106
Balanced	True
SystemEquations	1583
SystemVariables	1583
Domain	

Show Land_Fertility1.Land_Fert_Degr_Rt.y_vals in original scenario.

```
In[5]:= SystemModel[mysim][{"ParameterValues", "Land_Fertility1.Land_Fert_Degr_Rt.y_vals[1]"}]
```

```
Out[5]= {Land_Fertility1.Land_Fert_Degr_Rt.y_vals[1] → 0}
```

```
In[6]:= SystemModel[mysim][{"ParameterValues", "Land_Fertility1.Land_Fert_Degr_Rt.y_vals[2]"}]
```

```
Out[6]= {Land_Fertility1.Land_Fert_Degr_Rt.y_vals[2] → 0.1}
```

```
In[7]:= SystemModel[mysim][{"ParameterValues", "Land_Fertility1.Land_Fert_Degr_Rt.y_vals[3]"}]
```

```
Out[7]= {Land_Fertility1.Land_Fert_Degr_Rt.y_vals[3] → 0.3}
```

```
In[8]:= SystemModel[mysim][{"ParameterValues", "Land_Fertility1.Land_Fert_Degr_Rt.y_vals[4]"}]
```

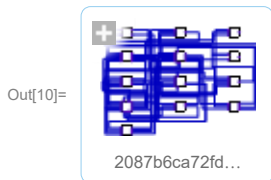
```
Out[8]= {Land_Fertility1.Land_Fert_Degr_Rt.y_vals[4] → 0.5}
```

```
In[9]:= SystemModel[mysim][{"ParameterValues", "Land_Fertility1.Land_Fert_Degr_Rt.y_vals[5]"}]
```

```
Out[9]= {Land_Fertility1.Land_Fert_Degr_Rt.y_vals[5] → 0.5}
```

Change scenario land fertility rates.

```
In[10]:= strsim = SystemModel[mysim, <|"ParameterValues" ->
      {"Land_Fertility1.Land_Fert_Degr_Rt.y_vals" -> {0.0, 0.3, 0.5, 0.7, 0.7}}|>]
```



```
In[11]:= basestrsim = SystemModelSimulate[strsim]
```

```
Out[11]= SystemModelSimulationData[  Model: W2087b6ca72fd4da6beeb91d0f54bbce1  
Time:  $1.90 \times 10^3$  to  $2.10 \times 10^3$  ]
```

Show changed Land_Fertility1.Land_Fert_Degr_Rt.y_vals.

```
In[12]:= SystemModel[basestrsim][{"ParameterValues", "Land_Fertility1.Land_Fert_Degr_Rt.y_vals[1]"}]
```

```
Out[12]= {Land_Fertility1.Land_Fert_Degr_Rt.y_vals[1] → 0}
```

```
In[13]:= SystemModel[basestrsim][{"ParameterValues", "Land_Fertility1.Land_Fert_Degr_Rt.y_vals[2]"}]
```

```
Out[13]= {Land_Fertility1.Land_Fert_Degr_Rt.y_vals[2] → 0.3}
```

```
In[14]:= SystemModel[basestrsim][{"ParameterValues", "Land_Fertility1.Land_Fert_Degr_Rt.y_vals[3]"}]
```

```
Out[14]= {Land_Fertility1.Land_Fert_Degr_Rt.y_vals[3] → 0.5}
```

```
In[15]:= SystemModel[strsim][{"ParameterValues", "Land_Fertility1.Land_Fert_Degr_Rt.y_vals[4]"}]
```

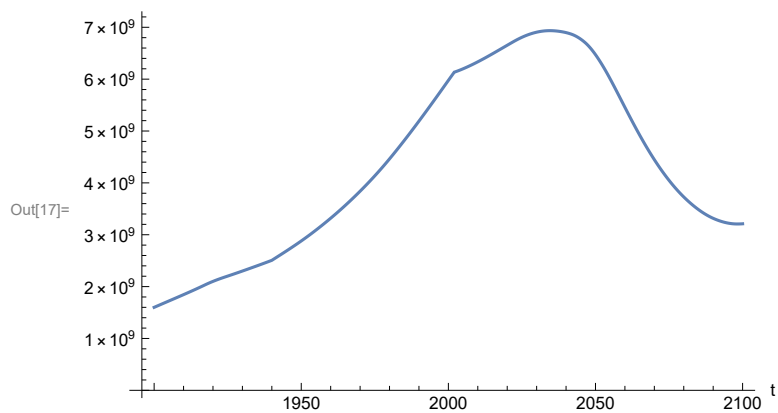
```
Out[15]= {Land_Fertility1.Land_Fert_Degr_Rt.y_vals[4] → 0.7}
```

```
In[16]:= SystemModel[strsim][{"ParameterValues", "Land_Fertility1.Land_Fert_Degr_Rt.y_vals[5]"}]
```

```
Out[16]= {Land_Fertility1.Land_Fert_Degr_Rt.y_vals[5] → 0.7}
```

Plot the world population, people.

```
In[17]:= SystemModelPlot[basestransim, {"Population_Dynamics1.Birth_Rate.pop"}]
```



Find max and min of y values.

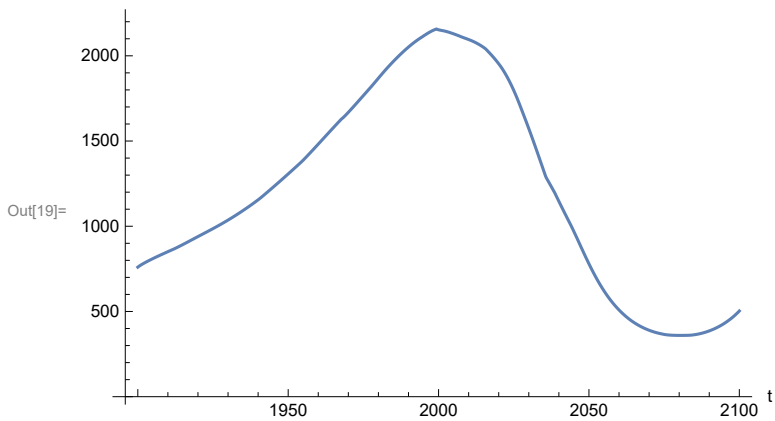
```
In[18]:= MinAndMax[basestransim[{"Population_Dynamics1.Birth_Rate.pop"}]]
```

```
Maximum is  $6.93513 \times 10^9$ 
```

```
Minimum is  $1.6 \times 10^9$ 
```

Plot land yield.

In[19]:= **SystemModelPlot**[basestrsim, {"Food_Production1.Land_Yield.y"}]



Find max and min of y values.

In[20]:= **MinAndMax**[basestrsim[{"Food_Production1.Land_Yield.y"}]]

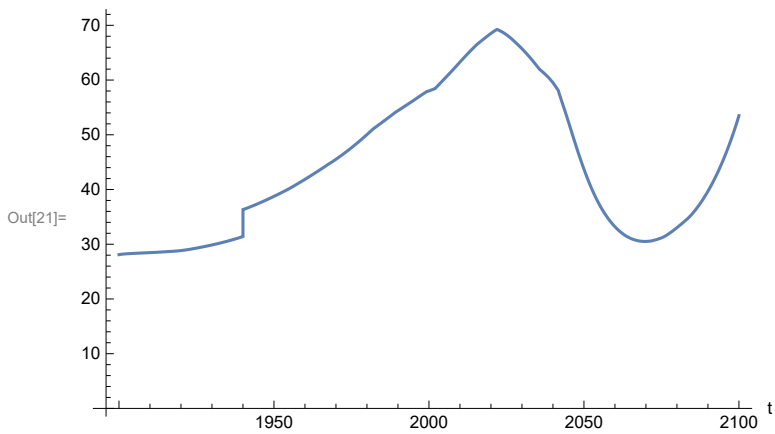
Maximum is 2157.07

Minimum is 359.59

Plot multiplier of air pollution on land yield.

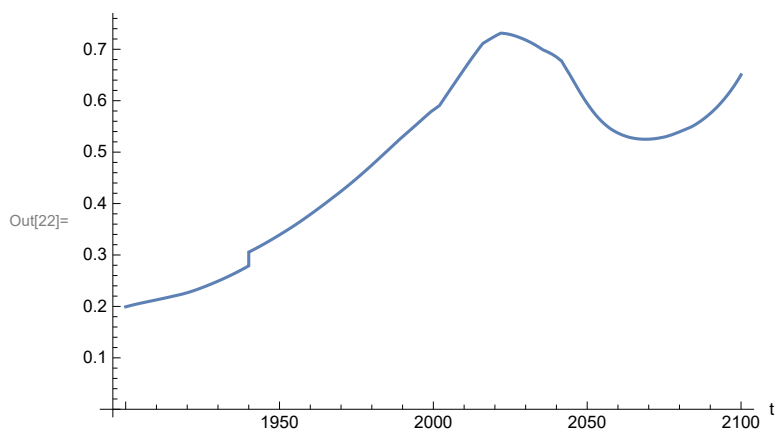
Plot life expectancy, in years.

In[21]:= **SystemModelPlot**[basestrsim, {"Life_Expectancy1.Life_Expectancy.y"}]



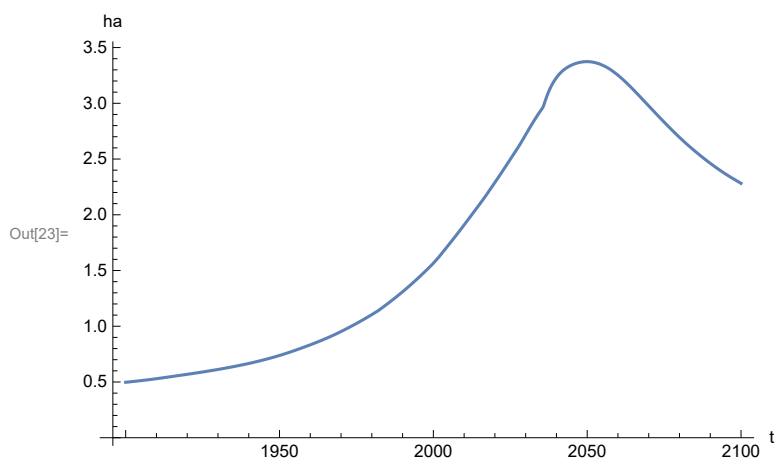
Plot the human welfare index.

```
In[22]:= SystemModelPlot[basestransim,
  {"Human_Welfare_Index1.HWI_Human_Welfare_Index.hwi_human_welfare_index"}]
```



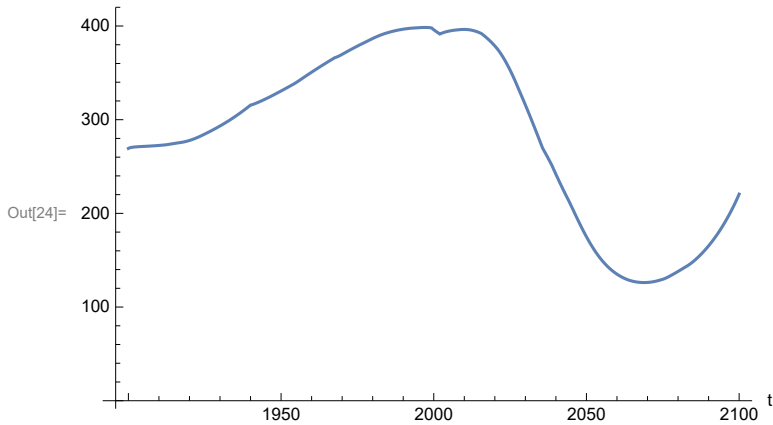
Plot the human ecological footprint, in hectares.

```
In[23]:= SystemModelPlot[basestransim,
  {"Human_Ecological_Footprint1.HEF_Human_Ecological_Footprint.hef_human_ecological_footprint"}]
```



Plot per capita food production, kg/year.

```
In[24]:= SystemModelPlot[basestransim, {"Food_Production1.Food_PC.y"}]
```



Find max and min of y values.

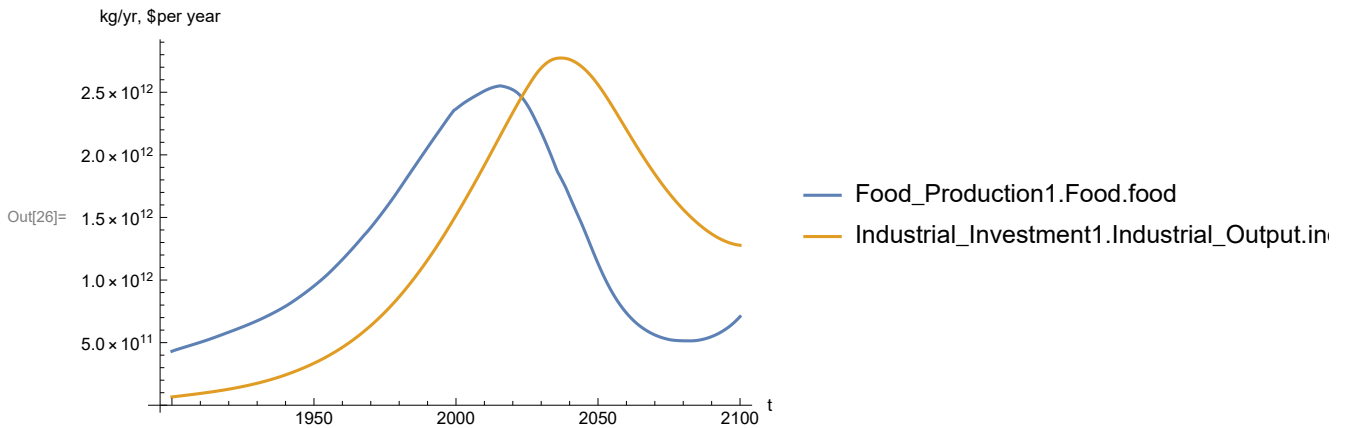
```
In[25]:= MinAndMax[basestransim[{"Food_Production1.Food_PC.y"}]]
```

Maximum is 398.474

Minimum is 126.139

Plot total food production (kg/yr) and industrial output (in dollars).

```
In[26]:= SystemModelPlot[basestransim, {"Food_Production1.Food.food",
    "Industrial_Investment1.Industrial_Output.industrial_output"}]
```



Find max and min of y values.

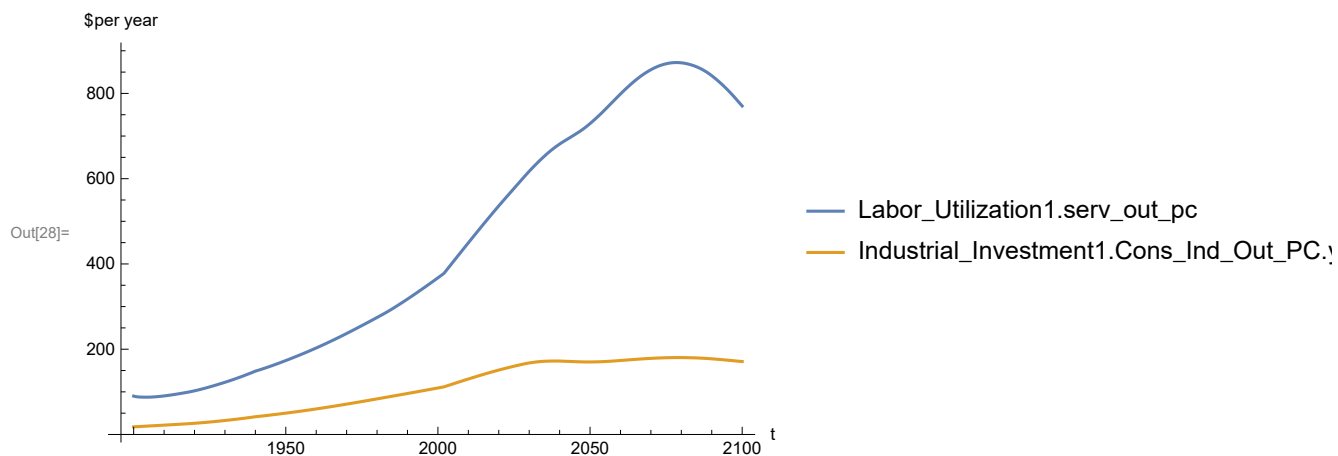
```
In[27]:= MinAndMax[basestransim[{"Industrial_Investment1.Industrial_Output.industrial_output"}]]
```

Maximum is 2.77356×10^{12}

Minimum is 6.65×10^{10}

Plot consolidated industrial output per capita (dollars/year).

```
In[28]:= SystemModelPlot[basestransim,
  {"Labor_Utilization1.serv_out_pc", "Industrial_Investment1.Cons_Ind_Out_PC.y"}]
```



Find max and min of y values.

```
In[29]:= MinAndMax[basestransim[{"Labor_Utilization1.serv_out_pc"}]]
```

Maximum is 872.382

Minimum is 87.4733

Find max and min of y values.

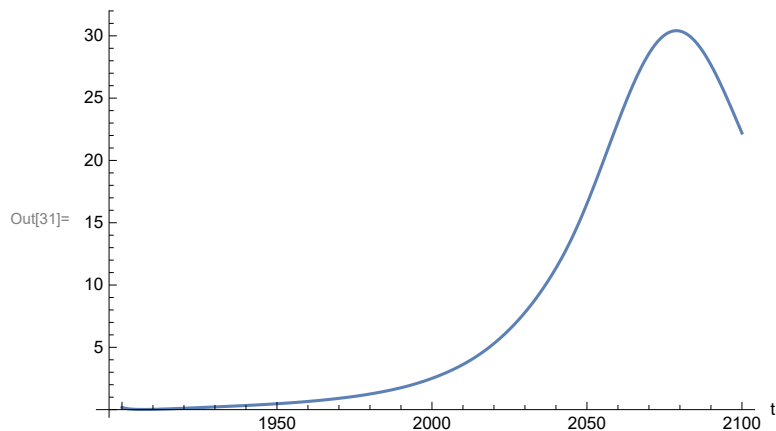
```
In[30]:= MinAndMax[basestransim[{"Industrial_Investment1.Cons_Ind_Out_PC.y"}]]
```

Maximum is 180.385

Minimum is 17.8719

Plot persistent pollution index (normalized to 1970 value).

```
In[31]:= SystemModelPlot[basestransim, {"Pollution_Dynamics1.PPoll_Index.y"}]
```



Find max and min of y values.

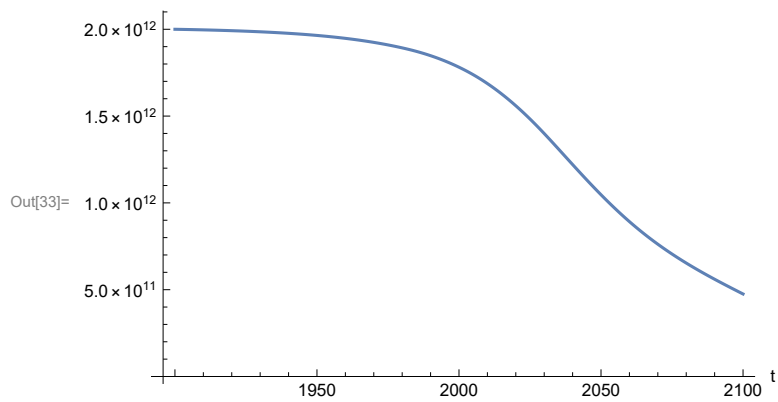
```
In[32]:= MinAndMax[basestransim[{"Pollution_Dynamics1.PPoll_Index.y"}]]
```

Maximum is 30.4116

Minimum is 0.0150836

Plot non-renewable resources remaining.

```
In[33]:= SystemModelPlot[basestransim, {"NR_Resource_Utilization1.NR_Resources.y"}]
```



APPENDIX 53. BENCHMARK SCENARIO 8, Accelerated Land Fertility Degradation Rate

Define a function that extracts range data from scenario data. (The right-hand-side of this definition is specific to a *World3* data structure and assumes that the function whose range is being extracted is globally (i.e., not piecewise) defined.)

```
In[1]:= RangeData[data_] := data[[1]][[4]][[3]];
```

Define a procedure to determine and print minimum and maximum of “y” values.

```
In[2]:= MinAndMax[data_] := (myscenseries = RangeData[data];
    Print["Maximum is ", Max[myscenseries]]; Print["Minimum is ", Min[myscenseries]])
```

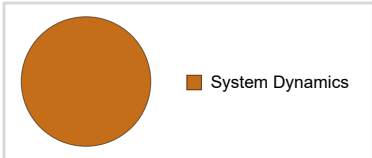
Here are some high-level properties of Benchmark Scenario 8.

```
In[3]:= mysim = SystemModel["SystemDynamics.WorldDynamics.World3.Scenario_8"]
```



```
In[4]:= mysummary = mysim["Summary"]
```

Out[4]=

ModelName	SystemDynamics.WorldDynamics.World3.Scenario_8
Description	More abundant non-recoverable natural resources, birth control, and stable industrial o
SimulationModel	True
Plots	0
Components	106
Balanced	True
SystemEquations	1583
SystemVariables	1583
Domain	

Show Land_Fertility1.Land_Fert_Degr_Rt.y_vals in original scenario.

```
In[5]:= SystemModel[mysim][{"ParameterValues", "Land_Fertility1.Land_Fert_Degr_Rt.y_vals[1]"}]
```

```
Out[5]= {Land_Fertility1.Land_Fert_Degr_Rt.y_vals[1] → 0}
```

```
In[6]:= SystemModel[mysim][{"ParameterValues", "Land_Fertility1.Land_Fert_Degr_Rt.y_vals[2]"}]
```

```
Out[6]= {Land_Fertility1.Land_Fert_Degr_Rt.y_vals[2] → 0.1}
```

```
In[7]:= SystemModel[mysim][{"ParameterValues", "Land_Fertility1.Land_Fert_Degr_Rt.y_vals[3]"}]
```

```
Out[7]= {Land_Fertility1.Land_Fert_Degr_Rt.y_vals[3] → 0.3}
```

```
In[8]:= SystemModel[mysim][{"ParameterValues", "Land_Fertility1.Land_Fert_Degr_Rt.y_vals[4]"}]
```

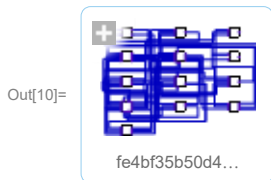
```
Out[8]= {Land_Fertility1.Land_Fert_Degr_Rt.y_vals[4] → 0.5}
```

```
In[9]:= SystemModel[mysim][{"ParameterValues", "Land_Fertility1.Land_Fert_Degr_Rt.y_vals[5]"}]
```

```
Out[9]= {Land_Fertility1.Land_Fert_Degr_Rt.y_vals[5] → 0.5}
```

Change scenario land fertility rates.

```
In[10]:= strsim = SystemModel[mysim, <|"ParameterValues" ->
      {"Land_Fertility1.Land_Fert_Degr_Rt.y_vals" -> {0.0, 0.3, 0.5, 0.7, 0.7}}|>]
```



```
In[11]:= basestrsim = SystemModelSimulate[strsim]
```

```
Out[11]= SystemModelSimulationData[  Model: Wfe4bf35b50d44b24ad9b7ba271bb2adb  
Time:  $1.90 \times 10^3$  to  $2.10 \times 10^3$  ]
```

Show changed Land_Fertility1.Land_Fert_Degr_Rt.y_vals.

```
In[12]:= SystemModel[strsim][{"ParameterValues", "Land_Fertility1.Land_Fert_Degr_Rt.y_vals[1]"}]
```

```
Out[12]= {Land_Fertility1.Land_Fert_Degr_Rt.y_vals[1] → 0}
```

```
In[13]:= SystemModel[strsim][{"ParameterValues", "Land_Fertility1.Land_Fert_Degr_Rt.y_vals[2]"}]
```

```
Out[13]= {Land_Fertility1.Land_Fert_Degr_Rt.y_vals[2] → 0.3}
```

```
In[14]:= SystemModel[strsim][{"ParameterValues", "Land_Fertility1.Land_Fert_Degr_Rt.y_vals[3]"}]
```

```
Out[14]= {Land_Fertility1.Land_Fert_Degr_Rt.y_vals[3] → 0.5}
```

```
In[15]:= SystemModel[strsim][{"ParameterValues", "Land_Fertility1.Land_Fert_Degr_Rt.y_vals[4]"}]
```

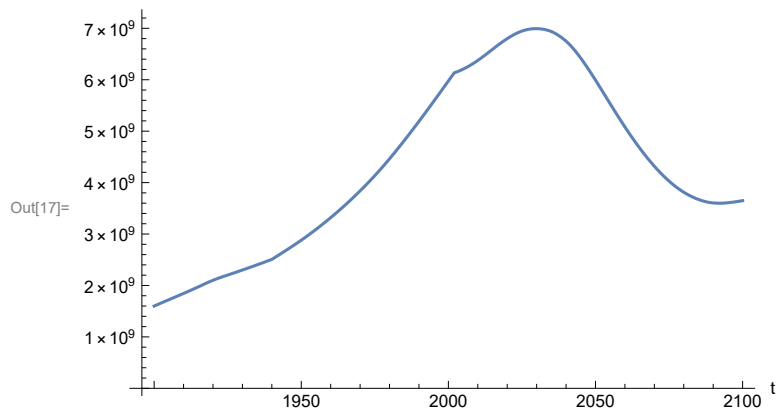
```
Out[15]= {Land_Fertility1.Land_Fert_Degr_Rt.y_vals[4] → 0.7}
```

```
In[16]:= SystemModel[strsim][{"ParameterValues", "Land_Fertility1.Land_Fert_Degr_Rt.y_vals[5]"}]
```

```
Out[16]= {Land_Fertility1.Land_Fert_Degr_Rt.y_vals[5] → 0.7}
```

Plot the world population, people.

```
In[17]:= SystemModelPlot[basestransim, {"Population_Dynamics1.Birth_Rate.pop"}]
```



Find max and min of y values.

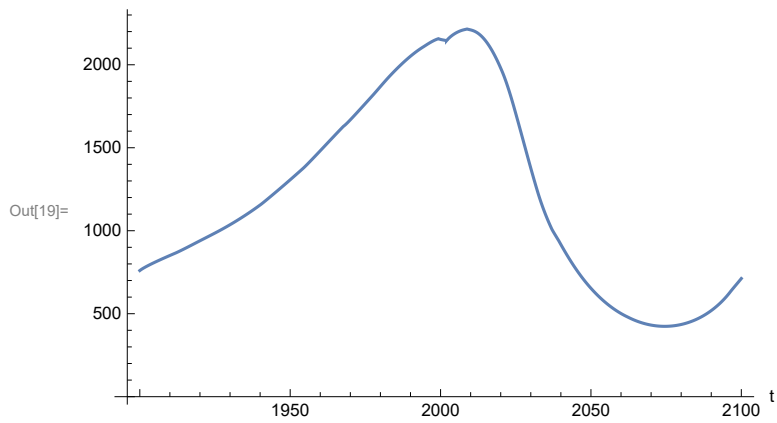
```
In[18]:= MinAndMax[basestransim[{"Population_Dynamics1.Birth_Rate.pop"}]]
```

```
Maximum is 6.9933 × 109
```

```
Minimum is 1.6 × 109
```

Plot land yield.

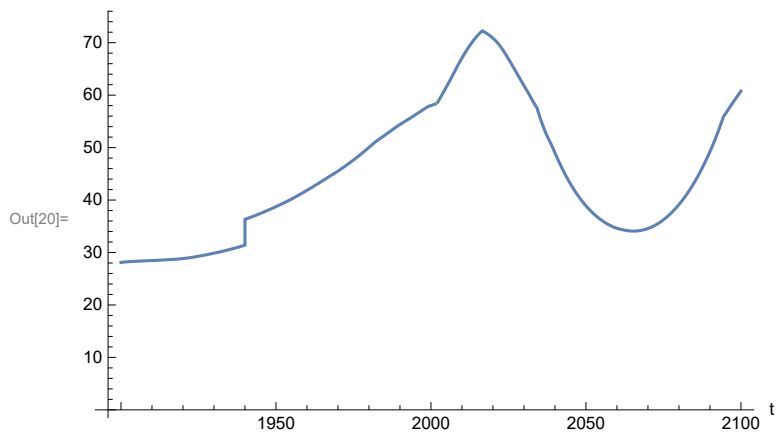
```
In[19]:= SystemModelPlot[basestransim, {"Food_Production1.Land_Yield.y"}]
```



Plot multiplier of air pollution on land yield.

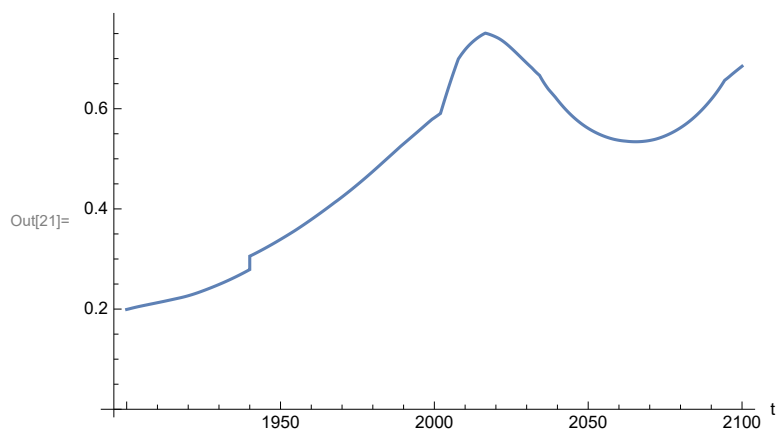
Plot life expectancy, in years.

```
In[20]:= SystemModelPlot[basestransim, {"Life_Expectancy1.Life_Expectancy.y"}]
```



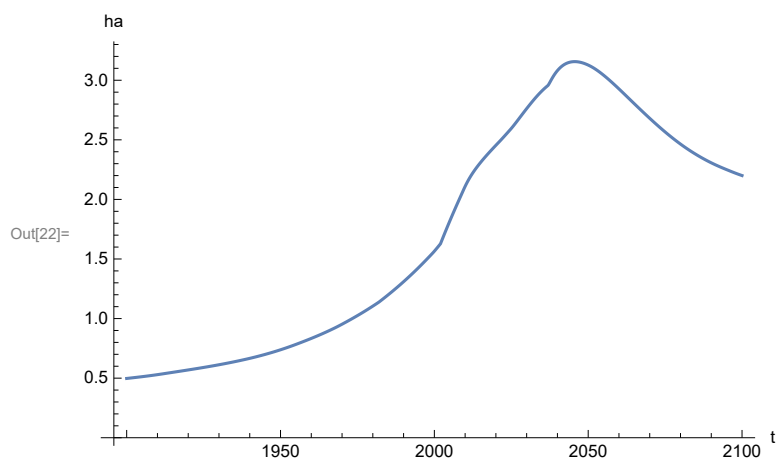
Plot the human welfare index.

```
In[21]:= SystemModelPlot[basestransim,
  {"Human_Welfare_Index1.HWI_Human_Welfare_Index.hwi_human_welfare_index"}]
```



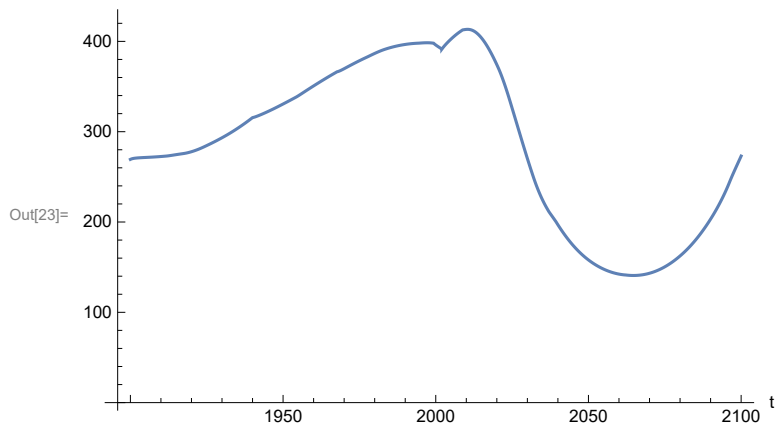
Plot the human ecological footprint, in hectares.

```
In[22]:= SystemModelPlot[basestransim,
  {"Human_Ecological_Footprint1.HEF_Human_Ecological_Footprint.hef_human_ecological_footprint"}]
```



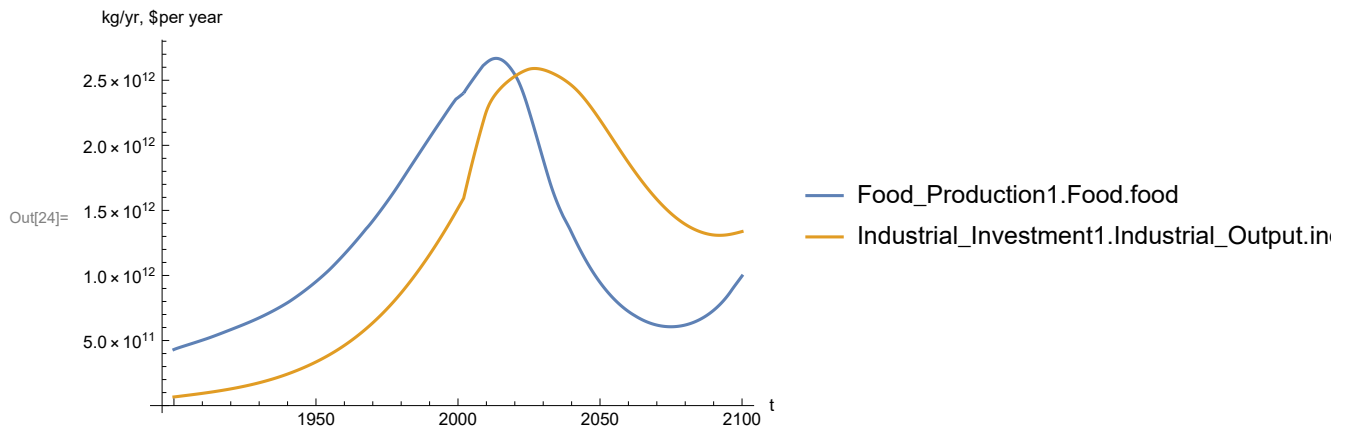
Plot per capita food production, kg/year.

In[23]:= SystemModelPlot[basestransim, {"Food_Production1.Food_PC.y"}]



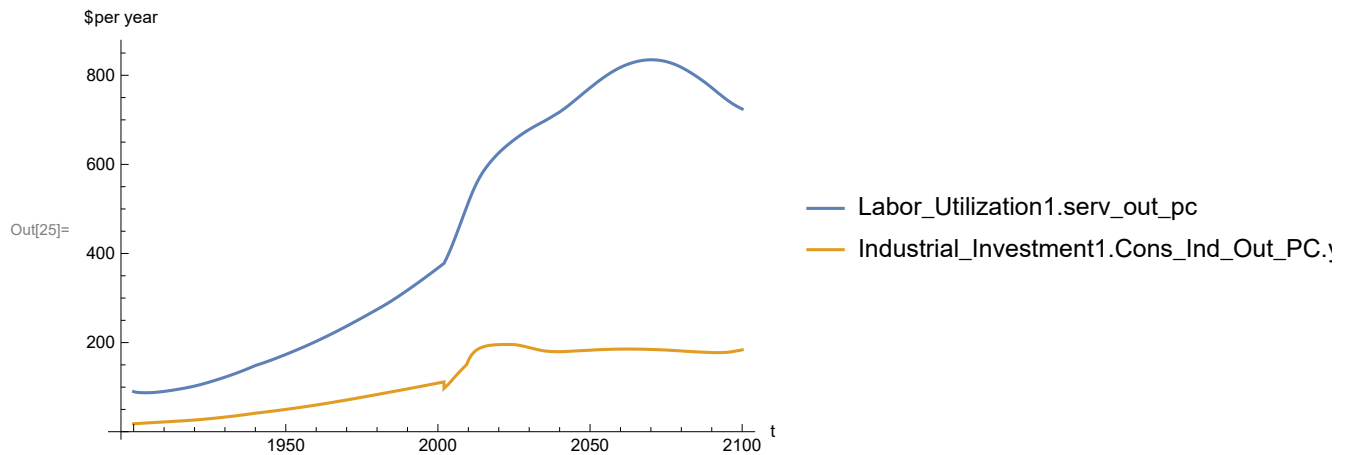
Plot total food production (kg/yr) and industrial output (in dollars).

In[24]:= SystemModelPlot[basestransim, {"Food_Production1.Food.food", "Industrial_Investment1.Industrial_Output.industrial_output"}]



Plot consolidated industrial output per capita (dollars/year).

```
In[25]:= SystemModelPlot[basestrsim,
  {"Labor_Utilization1.serv_out_pc", "Industrial_Investment1.Cons_Ind_Out_PC.y"}]
```



Find max and min of y values.

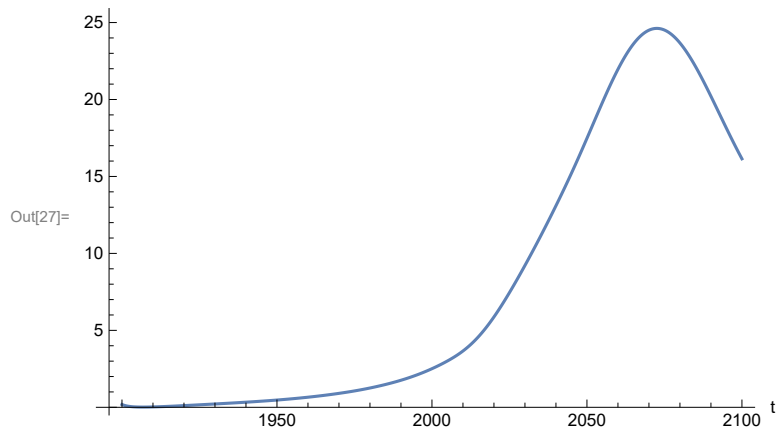
```
In[26]:= MinAndMax[basestrsim[{"Labor_Utilization1.serv_out_pc"}]]
```

Maximum is 834.843

Minimum is 87.4733

Plot persistent pollution index (normalized to 1970 value).

```
In[27]:= SystemModelPlot[basestrsim, {"Pollution_Dynamics1.PPoll_Index.y"}]
```



Find max and min of y values.

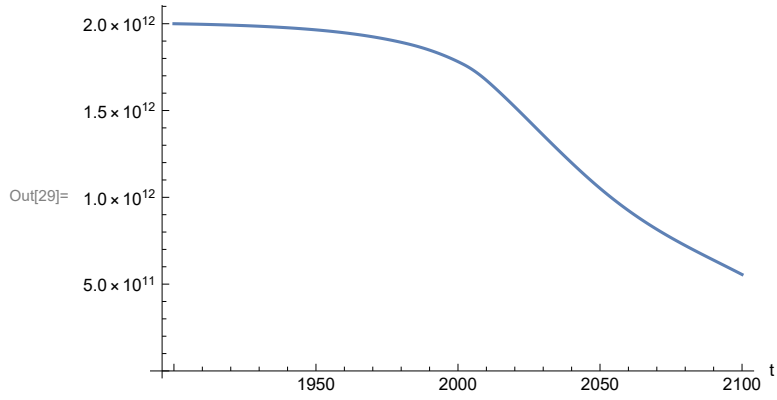
```
In[28]:= MinAndMax[basestrsim[{"Pollution_Dynamics1.PPoll_Index.y"}]]
```

Maximum is 24.6199

Minimum is 0.0150836

Plot non-renewable resources remaining.

```
In[29]:= SystemModelPlot[basestransim, {"NR_Resource_Utilization1.NR_Resources.y"}]
```



APPENDIX 54. BENCHMARK SCENARIO 9, Accelerated Land Fertility Degradation Rate

Define a function that extracts range data from scenario data. (The right-hand-side of this definition is specific to a *World3* data structure and assumes that the function whose range is being extracted is globally (i.e., not piecewise) defined.)

```
In[1]:= RangeData[data_] := data[[1]][[4]][[3]];
```

Define a procedure to determine and print minimum and maximum of “y” values.

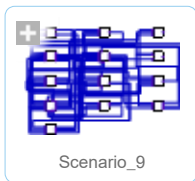
```
In[2]:= MinAndMax[data_] := (myscenseries = RangeData[data];
    Print["Maximum is ", Max[myscenseries]]; Print["Minimum is ", Min[myscenseries]])
```

Here are some high-level properties of Benchmark Scenario 9.

```
In[3]:=
```

```
mysim = SystemModel["SystemDynamics.WorldDynamics.World3.Scenario_9"]
```

```
Out[3]=
```



```
In[4]:= mysummary = mysim["Summary"]
```

```
Out[4]=
```

ModelName	SystemDynamics.WorldDynamics.World3.Scenario_9
Description	Combining the measures of Scenarios #6 and #8
SimulationModel	True
Plots	0
Components	106
Balanced	True
SystemEquations	1583
SystemVariables	1583
Domain	

Show Land_Fertility1.Land_Fert_Degr_Rt.y_vals in original scenario.

```
In[5]:= SystemModel[mysim][{"ParameterValues", "Land_Fertility1.Land_Fert_Degr_Rt.y_vals[1]"}]
```

```
Out[5]= {Land_Fertility1.Land_Fert_Degr_Rt.y_vals[1] → 0}
```

```
In[6]:= SystemModel[mysim][{"ParameterValues", "Land_Fertility1.Land_Fert_Degr_Rt.y_vals[2]"}]
```

```
Out[6]= {Land_Fertility1.Land_Fert_Degr_Rt.y_vals[2] → 0.1}
```

```
In[7]:= SystemModel[mysim][{"ParameterValues", "Land_Fertility1.Land_Fert_Degr_Rt.y_vals[3]"}]
```

```
Out[7]= {Land_Fertility1.Land_Fert_Degr_Rt.y_vals[3] → 0.3}
```

```
In[8]:= SystemModel[mysim][{"ParameterValues", "Land_Fertility1.Land_Fert_Degr_Rt.y_vals[4]"}]
```

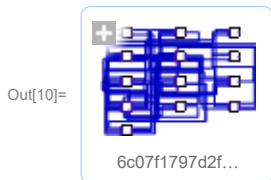
```
Out[8]= {Land_Fertility1.Land_Fert_Degr_Rt.y_vals[4] → 0.5}
```

```
In[9]:= SystemModel[mysim][{"ParameterValues", "Land_Fertility1.Land_Fert_Degr_Rt.y_vals[5]"}]
```

```
Out[9]= {Land_Fertility1.Land_Fert_Degr_Rt.y_vals[5] → 0.5}
```

Change scenario land fertility rates.

```
In[10]:= strsim = SystemModel[mysim, <|"ParameterValues" ->
      {"Land_Fertility1.Land_Fert_Degr_Rt.y_vals" -> {0.0, 0.3, 0.5, 0.7, 0.7}}|>]
```



```
In[11]:= basestrsim = SystemModelSimulate[strsim]
```

```
Out[11]= SystemModelSimulationData[  Model: W6c07f1797d2f4c2390dc41e377230016
      Time: 1.90 × 103 to 2.10 × 103 ]
```

Show changed Land_Fertility1.Land_Fert_Degr_Rt.y_vals.

```
In[12]:= SystemModel[strsim][{"ParameterValues", "Land_Fertility1.Land_Fert_Degr_Rt.y_vals[1]"}]
```

```
Out[12]= {Land_Fertility1.Land_Fert_Degr_Rt.y_vals[1] → 0}
```

```
In[13]:= SystemModel[strsim][{"ParameterValues", "Land_Fertility1.Land_Fert_Degr_Rt.y_vals[2]"}]
```

```
Out[13]= {Land_Fertility1.Land_Fert_Degr_Rt.y_vals[2] → 0.3}
```

```
In[14]:= SystemModel[strsim][{"ParameterValues", "Land_Fertility1.Land_Fert_Degr_Rt.y_vals[3]"}]
```

```
Out[14]= {Land_Fertility1.Land_Fert_Degr_Rt.y_vals[3] → 0.5}
```

```
In[15]= SystemModel[strsim][{"ParameterValues", "Land_Fertility1.Land_Fert_Degr_Rt.y_vals[4]"}]
```

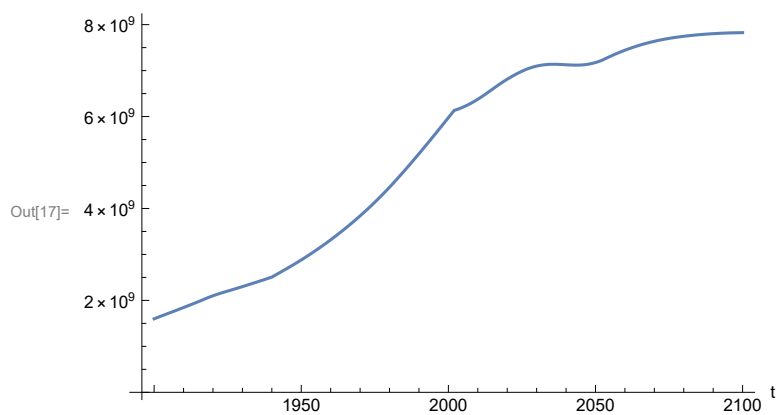
```
Out[15]= {Land_Fertility1.Land_Fert_Degr_Rt.y_vals[4] → 0.7}
```

```
In[16]= SystemModel[strsim][{"ParameterValues", "Land_Fertility1.Land_Fert_Degr_Rt.y_vals[5]"}]
```

```
Out[16]= {Land_Fertility1.Land_Fert_Degr_Rt.y_vals[5] → 0.7}
```

Plot the world population, people.

```
In[17]= SystemModelPlot[basestrsim, {"Population_Dynamics1.Birth_Rate.pop"}]
```



Find max and min of y values.

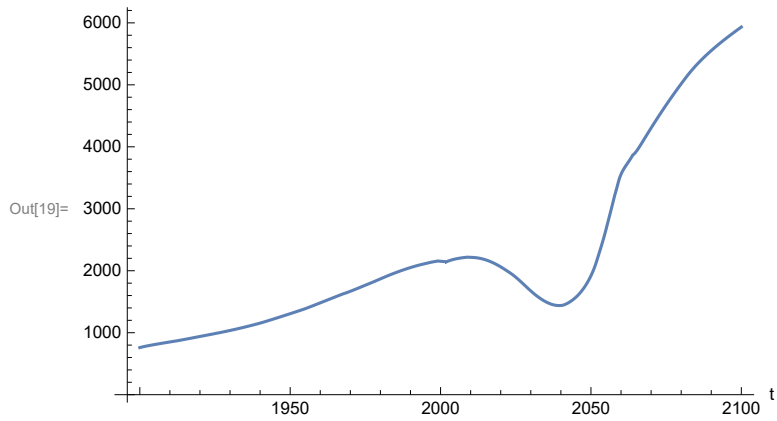
```
In[18]= MinAndMax[basestrsim[{"Population_Dynamics1.Birth_Rate.pop"}]]
```

```
Maximum is  $7.82553 \times 10^9$ 
```

```
Minimum is  $1.6 \times 10^9$ 
```

Plot land yield.

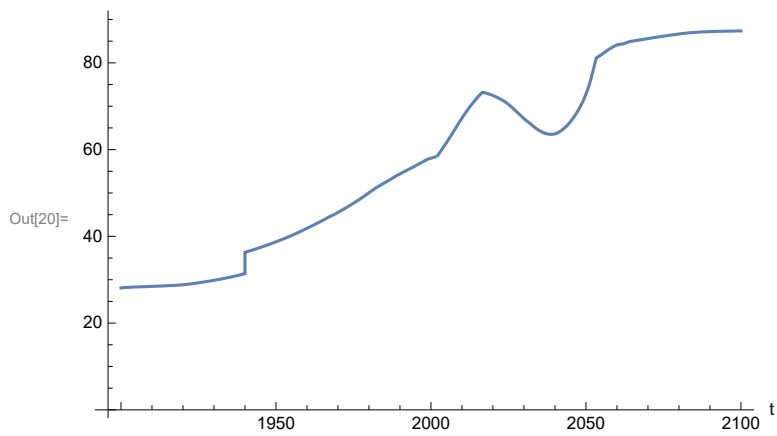
```
In[19]:= SystemModelPlot[basestransim, {"Food_Production1.Land_Yield.y"}]
```



Plot multiplier of air pollution on land yield.

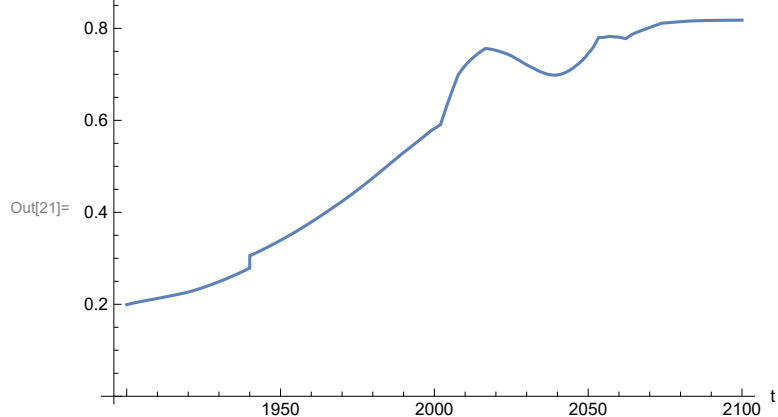
Plot life expectancy, in years.

```
In[20]:= SystemModelPlot[basestransim, {"Life_Expectancy1.Life_Expectancy.y"}]
```



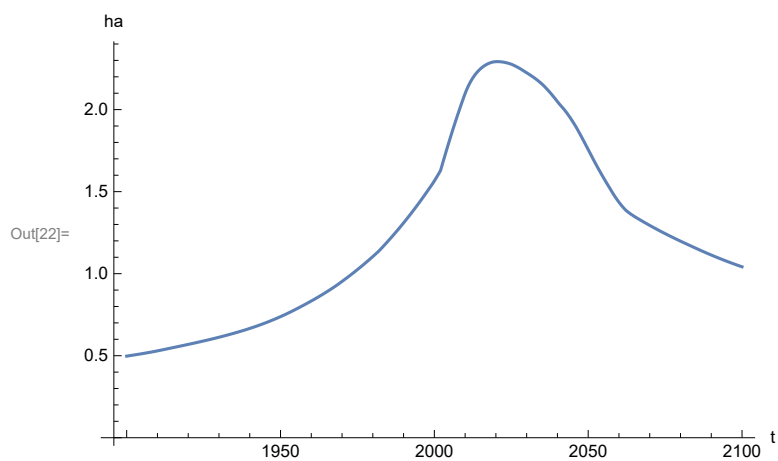
Plot the human welfare index.

```
In[21]:= SystemModelPlot[basestrsim,
  {"Human_Welfare_Index1.HWI_Human_Welfare_Index.hwi_human_welfare_index"}]
```



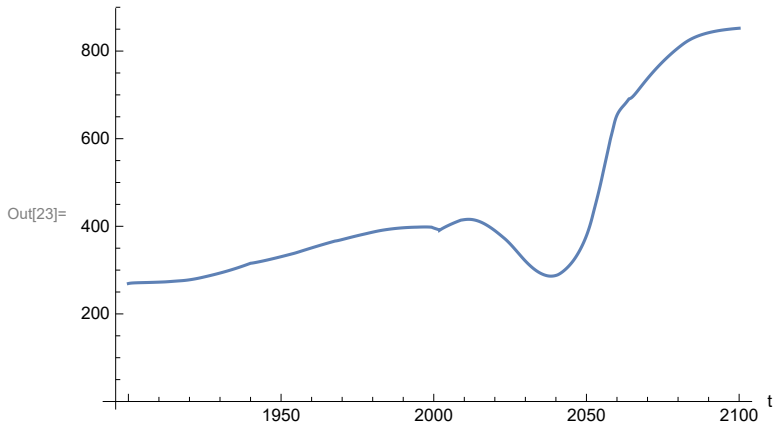
Plot the human ecological footprint, in hectares.

```
In[22]:= SystemModelPlot[basestrsim,
  {"Human_Ecological_Footprint1.HEF_Human_Ecological_Footprint.hef_human_ecological_
    _footprint"}]
```



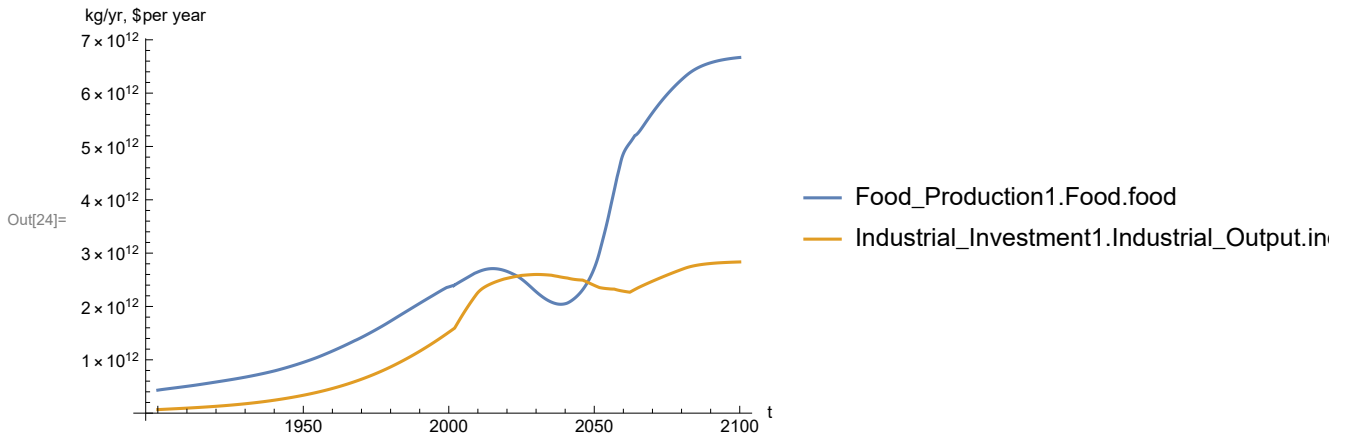
Plot per capita food production, kg/year.

In[23]:= `SystemModelPlot[basestransim, {"Food_Production1.Food_PC.y"}]`



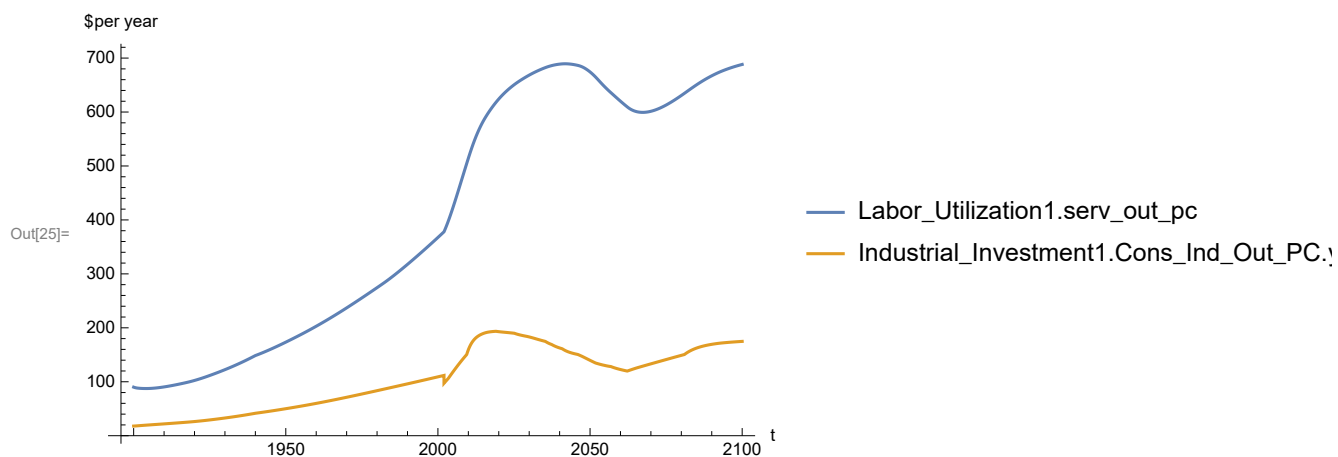
Plot total food production (kg/yr) and industrial output (in dollars).

In[24]:= `SystemModelPlot[basestransim, {"Food_Production1.Food.food", "Industrial_Investment1.Industrial_Output.industrial_output"}]`



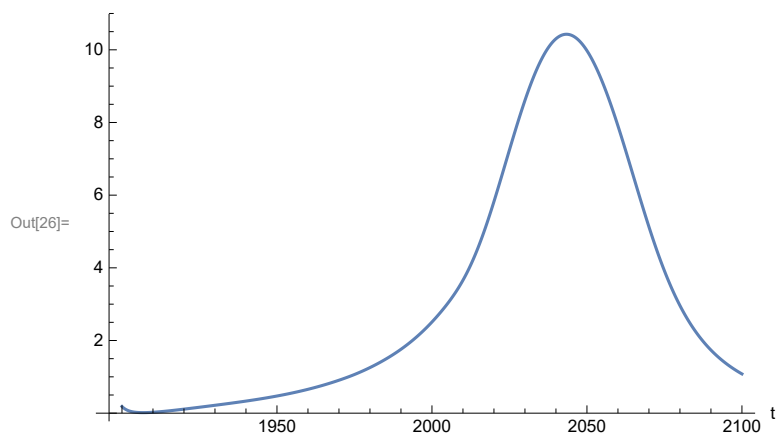
Plot consolidated industrial output per capita (dollars/year).

```
In[25]:= SystemModelPlot[basestransim,
  {"Labor_Utilization1.serv_out_pc", "Industrial_Investment1.Cons_Ind_Out_PC.y"}]
```



Plot persistent pollution index (normalized to 1970 value).

```
In[26]:= SystemModelPlot[basestransim, {"Pollution_Dynamics1.PPoll_Index.y"}]
```



Find max and min of y values.

```
In[27]:= MinAndMax[basestransim[{"Pollution_Dynamics1.PPoll_Index.y"}]]
```

Maximum is 10.4283

Minimum is 0.0150836

Plot non-renewable resources remaining.

In[28]:= SystemModelPlot[basestransim, {"NR_Resource_Utilization1.NR_Resources.y"}]

