# Core Model Proposal #373: Add Exogenous Shutdown Decider

**Product:** Global Change Analysis Model (GCAM)

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**Related sector:** energy

**Type of development:** C++ code

**Purpose:** This core model proposal adds an exogenous shutdown decider that can scale the output of a vintaged technology in years after its initial operating period. The output can be scaled above or below the technology vintage's original output. This proposal also includes code changes to disable the behavior of the s-curve shutdown decider and profit shutdown decider in calibration periods. The proposal does not include any changes to data to utilize the new exogenous shutdown decider (it only introduces the capability). **It should be noted that the exogenous shutdown decider and s-curve shutdown decider serve similar functions and generally should not be used together; however, the exogenous shutdown decider and profit shutdown decider reflect different dynamics and can be used in combination.**

# Description of Changes

This proposal adds a new `ExogenousShutdownDecider` class as a subclass of `IShutdownDecider`. This class is nearly identical to the other subclasses of `IShutdownDecider` (`ProfitShutdownDecider` and `S_CurveShutdownDecider`), with the following exceptions:

- It requires only one parameter (output-scalar), a double greater than or equal to zero, which is a TechVintageVector type, meaning that for any vintage year, the scalar can be read in for all subsequent model periods. The scalar cannot be applied for the technology's initial operating period.
- Its calcShutdownCoef function simply checks that the output scalar is greater than or equal to zero and returns it.

As with the other subclasses of `IShutdownDecider`, the ExogenousShutdownDecider simply scales the future output (output in years beyond the initial operating period) of a vintaged technology, in this case by the value of the output-scalar. The ExogenousShutdownDecider works in conjunction with the existing natural retirement function (S_CurveShutdownDecider) and economic shutdown function (ProfitShutdownDecider). **It should be noted that the ExogenousShutdownDecider and S_CurveShutdownDecider serve similar functions and in most cases should not be used together.**

The purpose of this new ExogenousShutdownDecider class is to provide GCAM users with finer control over the future output of a vintaged technology. While this proposal does not include any data changes to leverage this new capability, potential use cases include:

- Better matching announced future retirements of a historical technology vintage, such as coal or nuclear power. Rather than having to try and tune the natural retirement function (S_CurveShutdownDecider) parameters to replicate the expected output of the technology vintage (e.g., USA nuclear Gen II 2015), users can simply specify the fraction of the original production level expected from that vintage going forward.
- Reflecting expected future increases in output of a vintaged technology. Technologies do not always operate at their maximum capacity factors historically. Below are two examples of when this could be relevant:
    - **Hydropower**: If the final calibration year is an unusually dry year, hydropower output in a region may be lower than its historical average due to unusual climate conditions. If, in the future, climate conditions are expected to normalize (leading to higher hydropower production from existing capacity), the ExogenousShutdownDecider can capture this effect because the output-scalar can be greater than 1. Currently, GCAM would not be able to reflect this possibility (because it tracks only technology production, not capacity), and it is not possible to increase technology output with the existing Shutdown Decider classes.
    - **Coal**: U.S. coal capacity factors have been declining (e.g., https://www.eia.gov/todayinenergy/detail.php?id=44976). As with hydropower, coal power generation in a region for the final historical year (currently 2015) may not reflect maximum possible utilization of coal capacity. If a model scenario

entails conditions under which coal utilization would be expected to increase relative to historical levels (e.g., high electricity demand or high gas prices), the ExogenousShutdownDecider capability could be used to reflect this.
    - NOTE: This feature (scaling future year output above a technology vintage's original output level) is best used to represent increased utilization (capacity factor) of existing capacity. To represent installation of new capacity for a given technology, a policy mechanism (e.g., subsidy or RES target) or "fixed-output" technology is a more appropriate approach.
- Enabling more detailed historical vintaging of a technology. Currently, GCAM's calibration year vintages reflect the production of all units of that technology operating in that model period. We only "vintage" (assign a lifetime) to the final calibration period (2015). However, this 2015 vintage often reflects units that were built over many decades, not necessarily in the years of the 2015 model period (2011-2015). Currently, it's difficult at best to vintage earlier calibration years (e.g., 2010, 2005; data limitations aside) because it's difficult to control the output of these technologies in future calibration periods and thus ensure that global and regional energy balances are maintained. This is because (1) there was not a way to precisely reflect the fact that some fraction of a vintage's output was retired or otherwise reduced by the subsequent year (e.g., not all power plants built between 1976-1990 are still operating by 2005), and (2) the existing natural retirement and economic shutdown functions would operate in calibration periods, leading to less predictable declines in technology output. This proposal alleviates both issues by introducing the ExogenousShutdownDecider (which provides users with finer control over the future output of a vintaged technology) and disabling the behavior of the natural retirement and economic shutdown functions in calibration periods.

Using this ExogenousShutdownDecider capability instead of a "fixed-output" to represent changing technology production over time has two main benefits. First (and most importantly), the ExogenousShutdownDecider and ProfitShutdownDecider can be used in tandem, while the ProfitShutdownDecider will not operate on a fixed-output. Second, using ExogenousShutdownDecider for technologies that operate historically allows them to be considered in the calibration process, while share weights aren't calibrated for fixed-output technologies. Note that neither of these approaches impact sector prices (fixed-outputs don't factor in price calculations, nor do older technology vintages - only new investments).

The files changed by this proposal include:

- cvs/objects/build/vc10/
    - objects.vcxproj (add ExogenousShutdownDecider files to Visual Studios project file)
    - objects.vcxproj.filters (add ExogenousShutdownDecider files to Visual Studios project file)
- cvs/objects/build/vc10/xcode3/objects.xcodeproj
    - project.pbxproj (add ExogenousShutdownDecider files to Xcode project file)
- cvs/objects/technologies/include/
    - exogenous_shutdown_decider.h (add ExogenousShutdownDecider class)

    - ishutdown_decider.h (declare ExogenousShutdownDecider as subclass of IShutdownDecider)
- cvs/objects/technologies/source/
    - exogenous_shutdown_decider.cpp (add ExogenousShutdownDecider class)
    - profit_shutdown_decider.cpp (disable ProfitShutdownDecider behavior in calibration periods)
    - s_curve_shutdown_decider.cpp (disable S_CurveShutdownDecider behavior in calibration periods)
- cvs/objects/util/base/include/
    - gcam_data_containers.h (#include "technologies/include/exogenous_shutdown_decider.h")

# Validation

## Anomaly Detector

The standard set of validation scenarios (GCAM reference & SSPs; no policy & 2.6w/$m^2$ radiative forcing target) were run. The "anomaly detector" figures show that this proposal does not alter model results when no exogenous shutdown decider is utilized (the default configuration).

## Model Experiments

We ran three experiments to test the new ExogenousShutdownDecider:

1) 2015 USA electricity production from coal (conv pul) is scaled from 2020 forward, with no other shutdown deciders for that vintage. We compare this to a reference run with no ExogenousShutdownDecider or other shutdown deciders for the 2015 coal (conv pul) vintage. Below is the output-scalar used in each year, the reference amount, the output of the scenario using the ExogenousShutdownDecider, and the ratio of the output from the two scenarios for each year.

The Reference scenario produces a constant output until 2070, after which it retires all its capacity.

| year | scalar | Reference | ExogenousShutdownDecider | ratio |
|---|---|---|---|---|
| 2015 | NA | 5.23608 | 5.23608 | 1.00 |
| 2020 | 0.95 | 5.23608 | 4.97427 | 0.95 |
| 2025 | 1.1 | 5.23608 | 5.75968 | 1.10 |
| 2030 | 0.5 | 5.23608 | 2.61804 | 0.50 |
| 2035 | 0.3 | 5.23608 | 1.57082 | 0.30 |
| 2040 | 0.1 | 5.23608 | 0.523608 | 0.10 |

| | | | | |
|---|---|---|---|---|
| 2045 | 0 | 5.23608 | 0 | 0 |
| 2050 | 0 | 5.23608 | 0 | 0 |
| 2055 | 0 | 5.23608 | 0 | 0 |
| 2060 | 0 | 5.23608 | 0 | 0 |
| 2065 | 0 | 5.23608 | 0 | 0 |
| 2070 | 0 | 5.23608 | 0 | 0 |
| 2075 | 0 | 0 | 0 | NA |

2) 2015 USA electricity production from coal (conv pul) is scaled from 2020 forward, with the default shutdown deciders for that vintage still active. We compare this to a reference run with no ExogenousShutdownDecider but other shutdown deciders for the 2015 coal (conv pul) vintage still in place. In this case, we expect that output may be less than what is specified in coal_USA2015_exoshutdown.xml because the other shutdown deciders may further reduce output. Below is the output-scalar used in each year, the reference amount, the output of the scenario using the ExogenousShutdownDecider, and the ratio of the output from the two scenarios for each year.

Here, even though the Reference amount changes over time, the ratio matches the scalar, since the other shutdown deciders apply to both scenarios.

| year | scalar | Reference | ExogenousShutdownDecider | ratio |
|---|---|---|---|---|
| 2015 | NA | 5.23608 | 5.23608 | 1.00 |
| 2020 | 0.95 | 4.83797 | 4.5961 | 0.95 |
| 2025 | 1.1 | 4.61116 | 5.07225 | 1.10 |
| 2030 | 0.5 | 4.27995 | 2.14004 | 0.50 |
| 2035 | 0.3 | 3.8269 | 1.14812 | 0.30 |
| 2040 | 0.1 | 3.25832 | 0.325849 | 0.10 |
| 2045 | 0 | 2.61722 | 0 | 0 |
| 2050 | 0 | 1.97617 | 0 | 0 |
| 2055 | 0 | 1.40768 | 0 | 0 |
| 2060 | 0 | 0.954784 | 0 | 0 |
| 2065 | 0 | 0.623853 | 0 | 0 |

| | | | | |
|---|---|---|---|---|
| 2070 | 0 | 0.39698 | 0 | 0 |
| 2075 | 0 | 0 | 0 | NA |

3) 2005 USA electricity production from coal (conv pul) is scaled from 2010 forward. We add a lifetime, ProfitShutdownDecider, and S_CurveShutdownDecider to the 2005 vintage, in addition to the ExogenousShutdownDecider. As well, we adjust the 2010 and 2015 calibrated output to account for the vintaged 2005 output in those years. This also tests our code changes to ensure that the ProfitShutdownDecider, and S_CurveShutdownDecider do not activate prior to 2020, as that would make calibration very challenging. We compare this to a reference run with the standard vintaging, with no lifetime for 2005 coal electricity. In this case, we expect that output may be less than what is specified in coal_USA2005_exoshutdown.xml because the other shutdown deciders may further reduce output. Below is the output-scalar used in each year, the output of the scenario using the ExogenousShutdownDecider, and the ratio of the output between each year and the 2005 output.

| year | scalar | Reference (2005 amount) | output | ratio |
|---|---|---|---|---|
| 2005 | NA | 7.68019 | 7.68019 | 1.00 |
| 2010 | 0.5 | 7.68019 | 3.8401 | 0.50 |
| 2015 | 0.5 | 7.68019 | 3.8401 | 0.50 |
| 2020 | 0.4 | 7.68019 | 2.51122 | 0.33 |
| 2025 | 0.3 | 7.68019 | 1.68415 | 0.22 |
| 2030 | 0.2 | 7.68019 | 0.955929 | 0.12 |
| 2035 | 0.1 | 7.68019 | 0.383919 | 0.050 |
| 2040 | 0 | 7.68019 | 0 | 0 |