In [1]:
```
using DataFrames, Plots, Statistics, JSON, Clp
plotlyjs()
include(joinpath(dirname(pwd()),"src/TuLiPa.jl")); # using Dates, JuMP, HiGHS, CSV,
```

The WebIO Jupyter extension was not detected. See the WebIO Jupyter integration documentation for more information.

```
┌ Warning: backend `PlotlyJS` is not installed.
└ @ Plots C:\Users\jgrc\.julia\packages\Plots\bMtsB\src\backends.jl:43
```

Demo 5 - Two-stage stochastic hydro

This demo uses the same data as Demo 4, but we build a two-stage stochastic optimisation problem where the Aurland watercourse is optimized against an exogen area. This is possible to do directly in TuLiPa:

- We make different modelobjects for the first-stage problem, and for each scenario in the second stage problem. They all have unique names.
- The horizons in the second-stage modelobjects have offset so that they read different time-series data given the same problem time. Example: The datatime is 2025 and the scenariotime is 1981. First-stage problems last eight weeks and have offset of 0, and will read time-series data starting from the problem time. Second-stage scenario 1 have offset of eight weeks, and will read time-series data starting from 2025 and week 8 in 1981. Second-stage scenario 2 have offset of 1 year and two weeks, and will read time-series data starting from 2025 and week 8 in 1982.
  - We actually use the problem time PhaseinTwoTime() so that the second stage problems phase in their scenario with the first stage scenario. The second stage problems will therefore start with the same scenario, and slowly transition into a unique scenario.
- Incomes and costs in second-stage scenarios are altered so that they contribute to the objective function based on the scenario weight. In this demo second-stage scenarios are weighted equally.
- Storages in first-stage are connected to second-stage storages. In addition, the start-storages of the first-stage problem equals the end storages in every second stage scenario.
- At last all modelobjects are put into one list, and a problem is built, updated and solved. We also look at results.

Make modelobjects for first stage, and second stage scenarios

Function that read data and make modelobjects with different horizons. The function can specify the length of the horizon and the offset.

- Length of the horizons gives possibility to make a short first stage horizon and longer second stage horizons.

- Offset in the horizons makes it possible for modelobjects to read different time-series data given the same problem time.
- Time resolutions are the same to easier connect the first-stage and second stage problems together.
  - Hydro storages, bypass and spill have weekly time resolution, while hydro production (release) have a daily resolution

In [2]:
```
function makemodelobjects(weeks::Int,offset::Union{Offset,Nothing})

    # Read dataelements from json-files
    sti_dynmodelldata = "dataset_vassdrag"
    price = JSON.parsefile("priceDMK.json")
    detdprice = getelements(price);
    tidsserie = JSON.parsefile(joinpath(sti_dynmodelldata, "tidsserier_detd.json"))
    detdseries = getelements(tidsserie, sti_dynmodelldata);
    dst = JSON.parsefile(joinpath(sti_dynmodelldata, "dataset_detd_AURLAND_H.json"
    detdstructure = getelements(dst);

    elements = vcat(detdseries,detdprice,detdstructure)

    # Add horizons to the dataset
    scenarioyearstart = 1981
    scenarioyearstop = 1996 # price series only goes to 1995
    hydro_horizon = SequentialHorizon(weeks, Hour(168); offset)
    power_horizon = SequentialHorizon(7*weeks, Hour(24); offset)
    push!(elements, getelement(COMMODITY_CONCEPT, "BaseCommodity", "Power",
            (HORIZON_CONCEPT, power_horizon)))
    push!(elements, getelement(COMMODITY_CONCEPT, "BaseCommodity", "Hydro",
            (HORIZON_CONCEPT, hydro_horizon)))

    # Select which scenarios to include from the time-series
    push!(elements, getelement(TIMEPERIOD_CONCEPT, "ScenarioTimePeriod", "Scenario
            ("Start", getisoyearstart(scenarioyearstart)), ("Stop", getisoyearstar

    # Add an exogenous price area that the plants and pumps can interact with. All
    push!(elements, getelement(BALANCE_CONCEPT, "ExogenBalance", "PowerBalance_NO5
            (COMMODITY_CONCEPT, "Power"),
            (PRICE_CONCEPT, "PriceDMK")))

    # Generate modelobjects from dataelements and add boundary conditions to storag
    return getmodelobjects(elements)
end;
```

In [3]:
```
# Total problem length is 105 weeks = approx 2 years, and first stage problem is e
totalweeks = 105
firstweeks = 8

# Make modelobjects for first stage problem
firstobjects = makemodelobjects(firstweeks, nothing)

# Make modelobjects for 10 second stage scenarios. Each scenario start eight weeks
numscen = 10

secondobjects = []
for i in 1:numscen
    offset = ScenarioOffset(MsTimeDelta(Week(firstweeks)), MsTimeDelta(getisoyears
    push!(secondobjects, makemodelobjects(totalweeks-firstweeks, offset))
end
```

Unique instancenames for each scenario in second stage

Add the scenarionumber to the instancenames in second stage modelobjects

In [4]:
```
for i in 1:numscen
    secondobjectsscen = collect(values(secondobjects[i]))

    # Toplevel objects
    for obj in secondobjectsscen
        id = getid(obj)
        concept = getconceptname(id)
        instance = string(i,"_",getinstancename(id))
        obj.id = Id(concept, instance)

        # Lowlevel objects
        # (SegmentedArrows need unique names aswell, equation that connects main va
        if obj isa Flow
            for arrow in getarrows(obj)
                if arrow isa SegmentedArrow
                    id = getid(arrow)
                    concept = getconceptname(id)
                    instance = string(i,"_",getinstancename(id))
                    arrow.id = Id(concept, instance)
                end
            end
        end
    end
end
```

Costs in second stage must be weighted

Incomes and costs in second-stage scenarios are altered so that they contribute to the objective function based on the scenario weight. In this demo second-stage scenarios are weighted equally (10 %).

- We replace cost parameters with the TwoProductParam containing the original parameter and a constant weight.

In [5]:
```
# General fallback
cost_percentage!(::Any, ::Param) = nothing

# CostTerms in the Flows
function cost_percentage!(flow::Flow, per::Param) # not used in this demo
    if !isnothing(getcost(flow))
        for term in getcost(flow).terms
            if !startswith(getinstancename(getid(term)),"ExCost_") # Exogencosts ar
                term.param = TwoProductParam(term.param, per)
            end
        end
    end
end

# Price in the ExogenBalances
function cost_percentage!(balance::ExogenBalance, per::Param)
    balance.price.param = TwoProductParam(balance.price.param, per)
end

# Penalty for breaching SoftBounds
function cost_percentage!(obj::SoftBound, per::Param)
    obj.penalty = TwoProductParam(obj.penalty, per)
end;
```

In [6]:
```
# Every scenario is weighted equally (10 %)
per = ConstantParam(0.1)

for i in 1:numscen
    secondobjectsscen = secondobjects[i]
    for obj in collect(values(secondobjectsscen))
        cost_percentage!(obj, per)
    end
end
```

Storages in first stage must be connected to second stage

Storages in first-stage are connected to second-stage storages. In addition, the start-storages of the first-stage problem equals the end storages in every second stage scenario.

In [7]:
```
connectobjects = []
for j in eachindex(collect(values(firstobjects)))
    firstobject = collect(values(firstobjects))[j] # first stage version of modelol
    if firstobject isa Storage
        for i in 1:numscen
            secondobject = collect(values(secondobjects[i]))[j] # second stage vers
            push!(connectobjects, ConnectTwoObjects(firstobject, secondobject)) # 
            push!(connectobjects, ConnectTwoObjects(secondobject, firstobject)) # 
        end
    end
end
```

Add all modelobjects together

In [8]:
```
modelobjects = vcat(connectobjects, collect(values(firstobjects)))
for secondobjectsscen in secondobjects
    modelobjects = vcat(modelobjects, collect(values(secondobjectsscen)))
end
```

Run model

Initialize problem, update for chosen scenario and collect results

In [9]:
```
@time prob = HiGHS_Prob(modelobjects)

datayear = getisoyearstart(2025)
scenarioyear = getisoyearstart(1981)

# We use a PhaseinTwoTime to get smooth transitions between the first stage and sec
phaseinoffset = Millisecond(Week(firstweeks)) # phase in straight away from second
phaseindelta = Millisecond(Week(26)) # Phase in the second stage scenario over hal
phaseinsteps = 25 # Phase in second stage scenario in 25 steps

t = PhaseinTwoTime(datayear, scenarioyear, scenarioyear, phaseinoffset, phaseindel

@time update!(prob, t)

@time solve!(prob)
println(getobjectivevalue(prob))
```

```
  3.383624 seconds (5.25 M allocations: 299.115 MiB, 8.93% gc time, 94.74% compila
tion time)
  3.709991 seconds (15.42 M allocations: 759.134 MiB, 15.22% gc time, 97.85% compi
lation time)
  2.725279 seconds
-3.7810716869856954e8
```

Plot some results

We plot the price (€/MWh), levels of a reservoir (Mm3) and the release of a power plant (Mm3). See that the second stage scenarios are very similar in the start, before they deviate more and more after half a year.

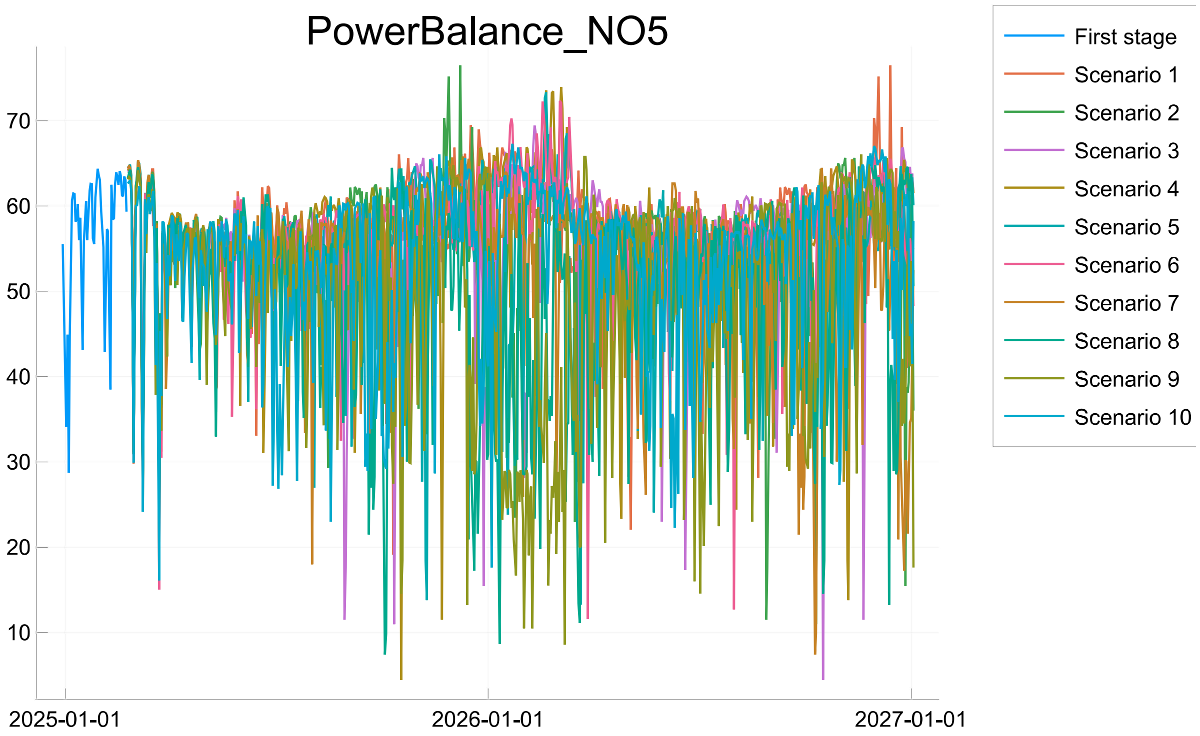
See demo 4 for more results from this watercourse and how to plot more detailed results

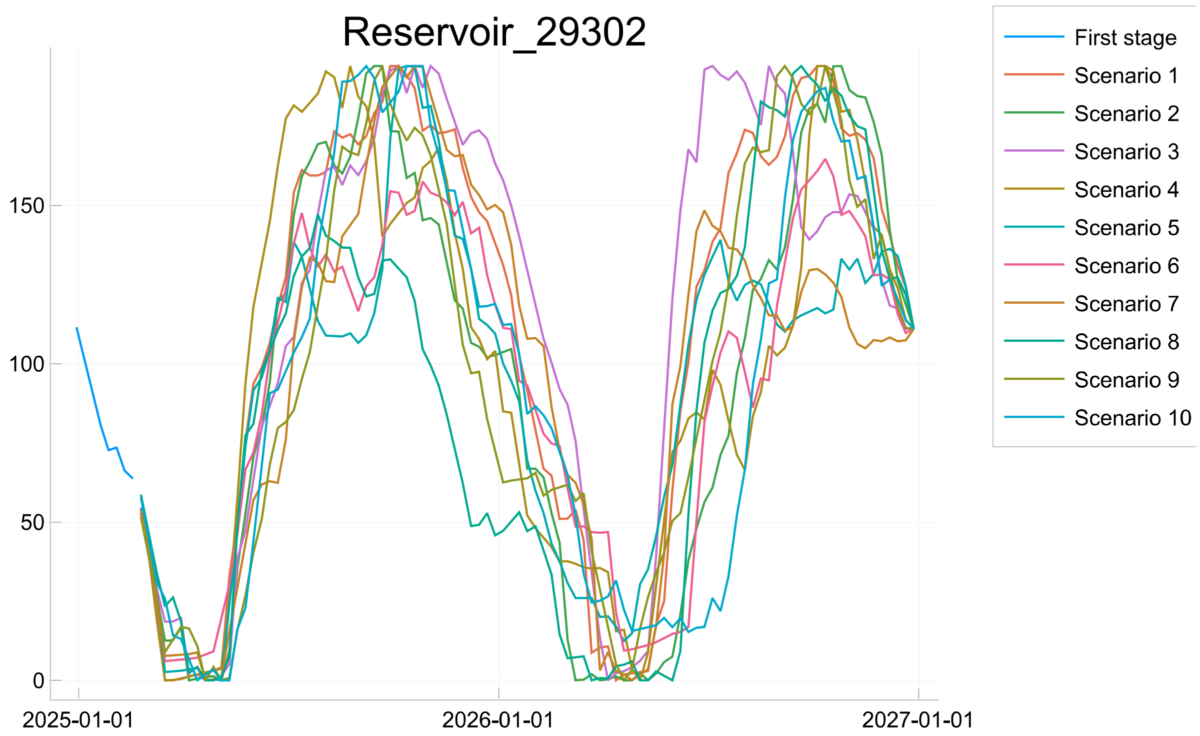
In [10]:
```
function plot_var(prob, id, datayear)
    obj = firstobjects[id]
    horizon = gethorizon(obj)

    x = [datayear + getstartduration(horizon, t) for t in 1:getnumperiods(horizon)
    y = [getvarvalue(prob, id, t) for t in 1:getnumperiods(horizon)]
    plot(x,y,label="First stage", title=getinstancename(id))

    for i in 1:numscen
        newid = Id(concept, string(i, "_", instance))
        obj = secondobjects[i][id]
        horizon = gethorizon(obj)
        x1 = [datayear + Millisecond(Week(firstweeks)) + getstartduration(horizon,
        y1 = [getvarvalue(prob, newid, t) for t in 1:getnumperiods(horizon)]
        plot!(x1,y1,label=string("Scenario ", i),legend=:outertopright)
    end

    display(plot!())
end

function plot_price(prob, id, t)
    obj = firstobjects[id]
    horizon = gethorizon(obj)
    price = getprice(obj)
    datayear = getdatatime(t)

    probtimes = [t + getstartduration(horizon, j) for j in 1:getnumperiods(horizon
    x = [datayear + getstartduration(horizon, j) for j in 1:getnumperiods(horizon)
    y = [getparamvalue(price, probtimes[j], gettimedelta(horizon, j)) for j in 1:g
    plot(x,y,label="First stage",title=getinstancename(id),legend=:outertopright)

    for i in 1:numscen
        newid = Id(concept, string(i, "_", instance))
        obj = secondobjects[i][id]
        horizon = gethorizon(obj)
        probtimes1 = [getoffsettime(t,getoffset(horizon)) + getstartduration(horiz
        x1 = [datayear + Millisecond(Week(firstweeks)) + getstartduration(horizon,
        y1 = [getparamvalue(price, probtimes1[j], gettimedelta(horizon, j)) for j
        plot!(x1,y1,label=string("Scenario ", i))
    end

    display(plot!())
end
```

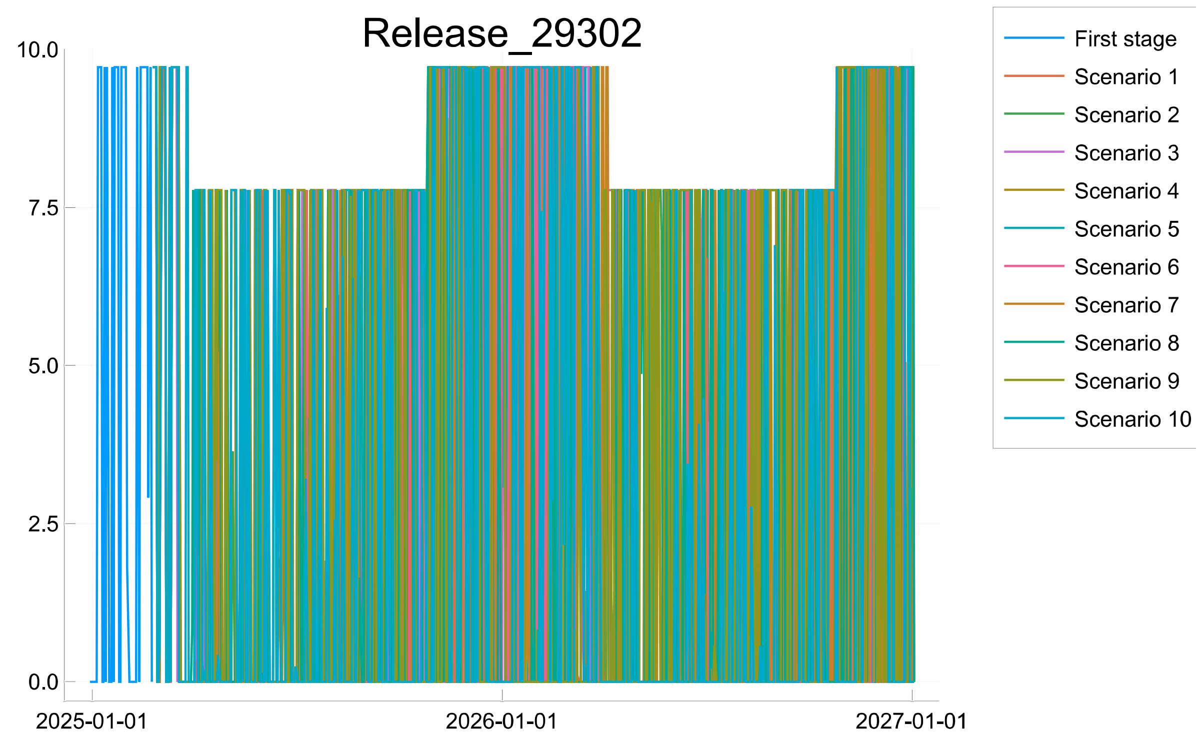
Out[10]:
```
plot_price (generic function with 1 method)
```

In [11]:

```
concept = BALANCE_CONCEPT
instance = "PowerBalance_NO5"
id = Id(concept, instance)

plot_price(prob, id, t)

concept = STORAGE_CONCEPT
instance = "Reservoir_29302"
id = Id(concept, instance)

plot_var(prob, id, datayear)

concept = FLOW_CONCEPT
instance = "Release_29302"
id = Id(concept, instance)

plot_var(prob, id, datayear)
```







If we instead use FixedDataTwoTime see that the scenarios are not smoothed between first-stage and second stage problems

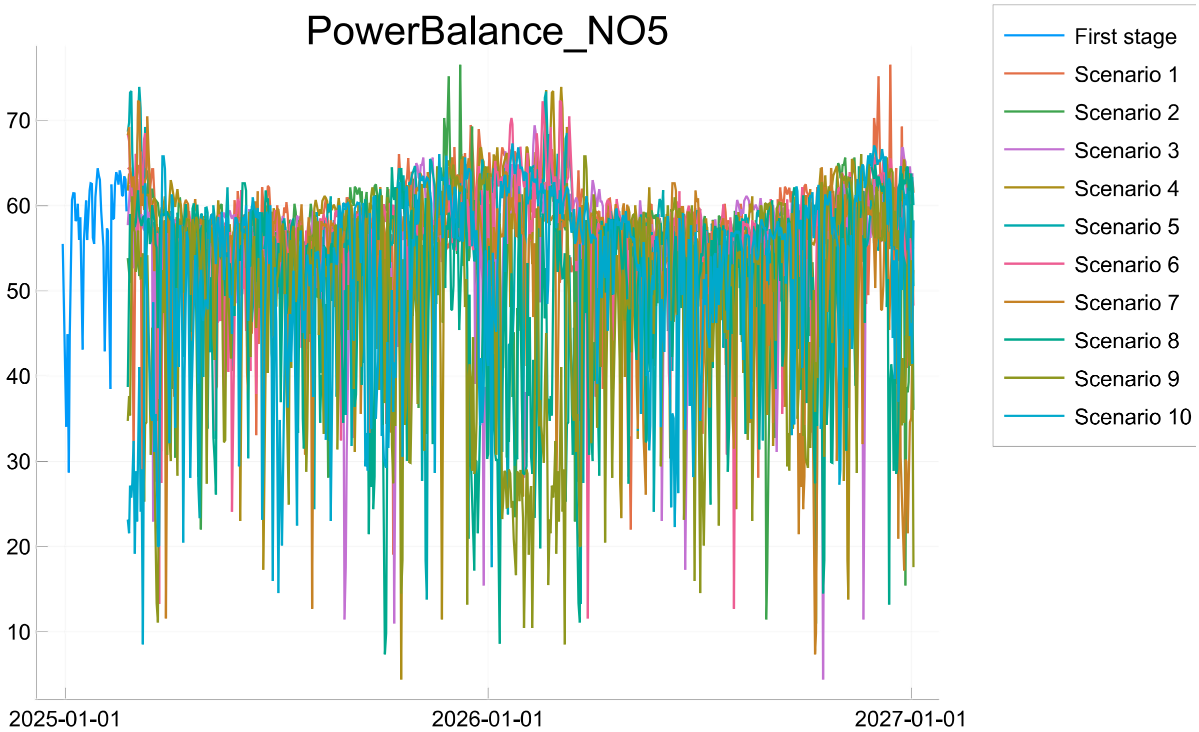
In [12]:

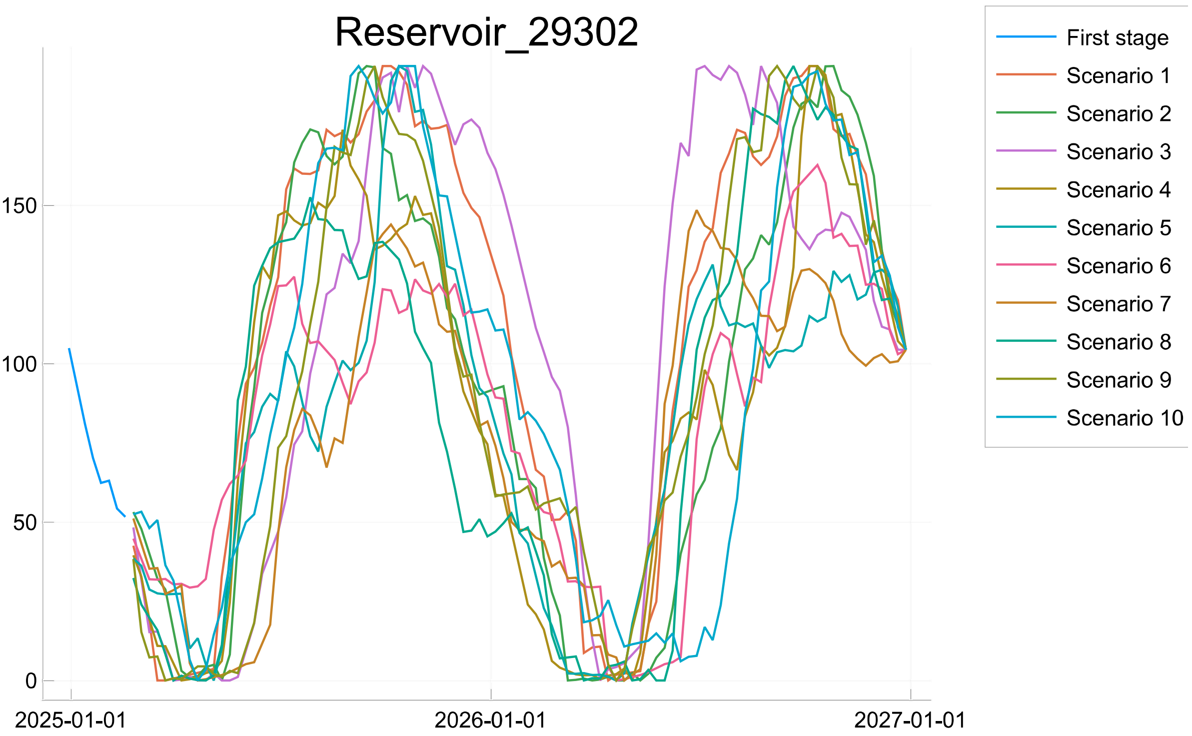
```
datayear = getisoyearstart(2025)
scenarioyear = getisoyearstart(1981)
t = FixedDataTwoTime(datayear, scenarioyear)

@time update!(prob, t)

@time solve!(prob)
println(getobjectivevalue(prob))
```

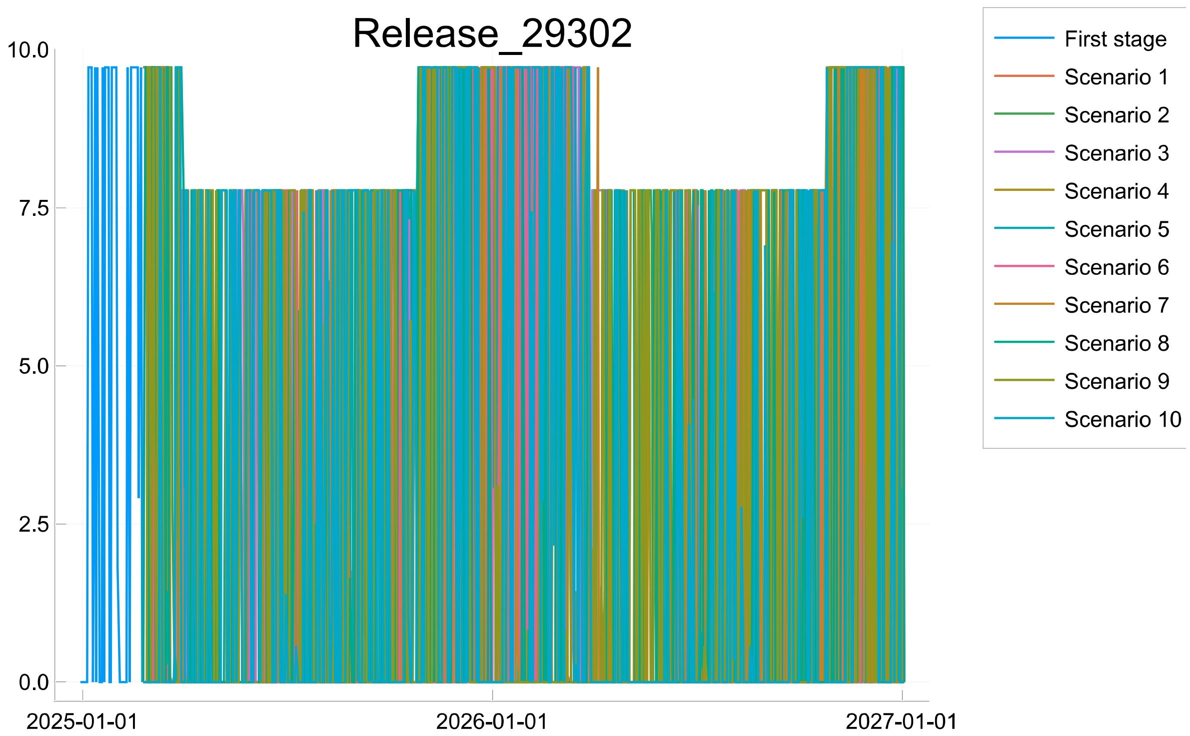
```
  0.855190 seconds (1.29 M allocations: 42.349 MiB, 7.44% gc time, 93.73% compilat
ion time)
  0.622772 seconds
-3.73528526582669e8
```

In [13]:

```
concept = BALANCE_CONCEPT
instance = "PowerBalance_NO5"
id = Id(concept, instance)

plot_price(prob, id, t)

concept = STORAGE_CONCEPT
instance = "Reservoir_29302"
id = Id(concept, instance)

plot_var(prob, id, datayear)

concept = FLOW_CONCEPT
instance = "Release_29302"
id = Id(concept, instance)

plot_var(prob, id, datayear)
```




Reservoir_29302
150
100
50
0
2025-01-01
2026-01-01
2027-01-01
First stage
Scenario 1
Scenario 2
Scenario 3
Scenario 4
Scenario 5
Scenario 6
Scenario 7
Scenario 8
Scenario 9
Scenario 10


Release_29302
10.0
7.5
5.0
2.5
0.0
2025-01-01
2026-01-01
2027-01-01
First stage
Scenario 1
Scenario 2
Scenario 3
Scenario 4
Scenario 5
Scenario 6
Scenario 7
Scenario 8
Scenario 9
Scenario 10

In [ ]: