Rice farming with crop rotation for smallholder farmers in Indonesia

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Introduction

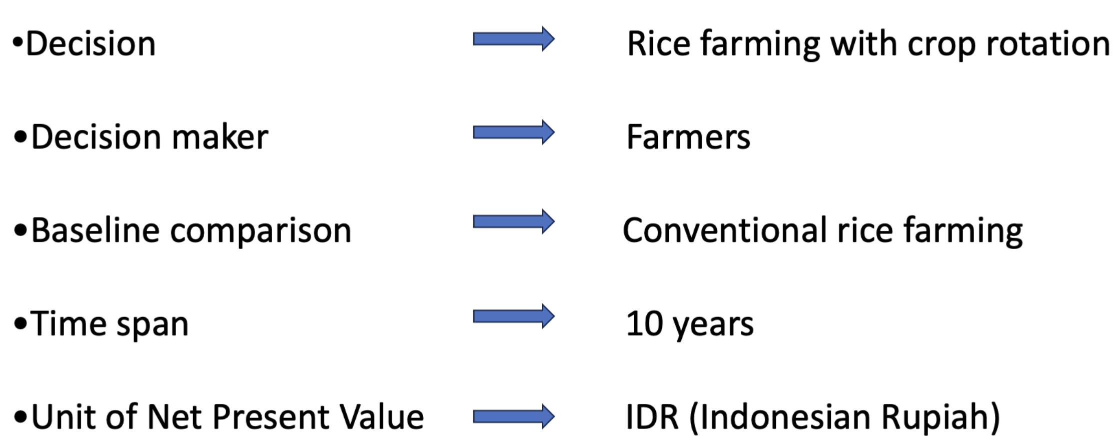
Overview

Indonesia is the largest country in Southeast Asia. Rice is the primary staple food crop with a steady increase in annual production, making Indonesia the third largest rice producer in the world. 93% of Indonesia's total number of farmers are small family farms. Rice is the main crop grown and staple food in Southeast Asia.(Yoshida (1981)) Crop rotation is the practice of planting different crops sequentially on the same plot of land to improve soil health, optimize nutrients in the soil, and combat pest and weed pressure.(Crystal and Whittlesey (2004)) Soybean is a species of legume native to East Asia, widely grown for its edible bean which has numerous uses.(Wright et al. (2005)) Chili is a plant of tropical and subtropical regions for their fleshy fruits.(MOALF (2016))

Motivation

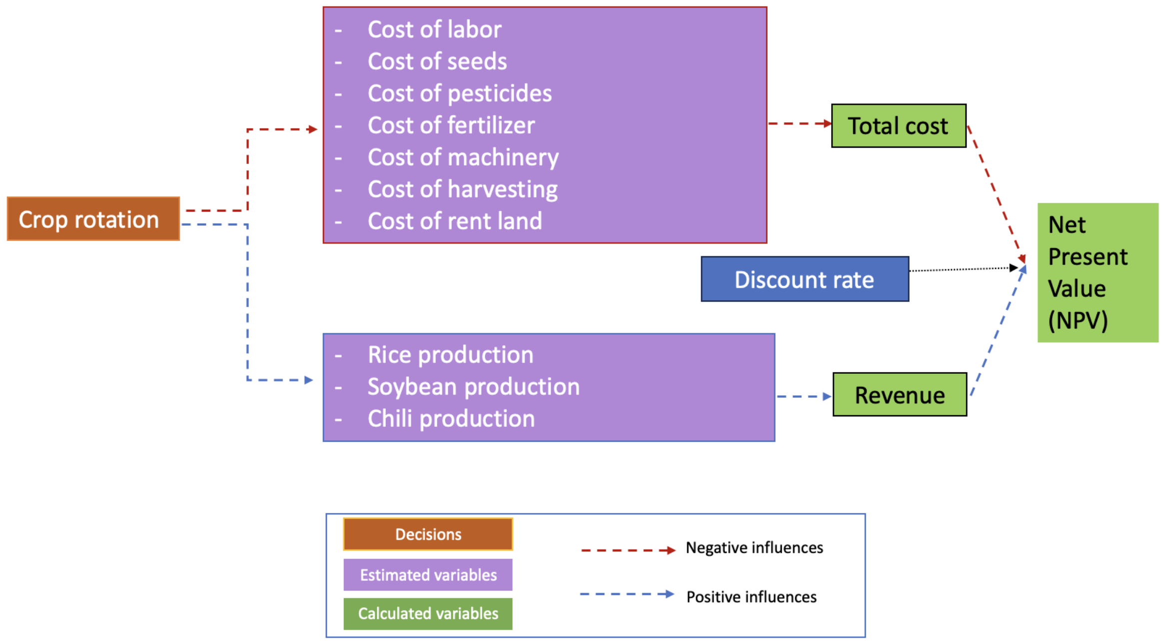
1. Rice is the primary staple food crop with a steady increase in annual production, making Indonesia the third largest rice producer in the world.
2. Crop rotation can increase crop yields and income than monoculture of rice and it can help disrupt the lifecycle of crop pests and reducing chemical use.
3. Soybean can increase soil fertility and give extra income to farmers.
4. Chili cultivation can improve farmers' income because of good market price.

Overview of the project



Conceptual model

This project will analyse the decision of crop rotation (soybean and chili) with rice farming. Total cost is calculated for each crop, which consists of labor, seeds, pesticides, fertilizer, machinery and rent land. The revenues is calculated for each crop production by multiplying the yield of each crop by the selling price of each crop per ha. The total cost, revenues and discount rate are used as variable estimates in order to calculate the Net Present Value (NVP).



Variable used in conceptual model

description	label	variable	distribution	lower	median	upper	unit
Rice production	Rice yield	rice_yield	posnorm	3000		6000	kg/ha
	Rice price	rice_price	posnorm	4000		7000	IDR/kg
Rice cultivation cost	Rent land of rice	rice_land_rental_cost	posnorm	2000000		4000000	IDR/ha
	Cost of rice seeds	rice_seeds_cost	posnorm	400000		600000	IDR/ha
	Cost of fertilizer for rice	rice_fertilizer_cost	posnorm	1000000		1500000	IDR/ha
	Cost of pesticide for rice	rice_pesticide_cost	posnorm	430000		600000	IDR/ha
	Cost of labor for rice	rice_labor_cost	posnorm	5000000		7000000	IDR/ha
	Cost of machinery for rice	rice_machinery_cost	posnorm	200000		500000	IDR/ha
	Cost of harvesting for rice	rice_harvesting_cost	posnorm	100000		200000	IDR/ha
Soybean production	Soybean yield	soybean_yield	posnorm	2000		3000	kg/ha
	Soybean price	soybean_price	posnorm	5000		10000	IDR/kg
Soybean cultivation cost	Rent land of soybean	soybean_land_rental_cost	posnorm	1530000		3000000	IDR/ha
	Cost of seeds for soybean	soybean_seeds_cost	posnorm	500000		650000	IDR/ha
	Cost of fertilizer for soybean	soybean_fertilizer_cost	posnorm	3500000		5500000	IDR/ha
	Cost of pesticide for soybean	soybean_pesticide_cost	posnorm	300000		450000	IDR/ha
	Cost of labor for soybean	soybean_labor_cost	posnorm	3500000		5500000	IDR/ha
	Cost of machinery for soybean	soybean_machinery_cost	posnorm	100000		200000	IDR/ha
	Cost of harvesting for soybean	soybean_harvesting_cost	posnorm	50000		100000	IDR/ha
Chili production	Chili yield	chili_yield	posnorm	8000		10000	kg/ha
	Chili price	chili_price	posnorm	10000		50000	IDR/kg
Chili cultivation cost	Rent land of chili	chili_land_rental_cost	posnorm	3500000		5500000	IDR/ha
	Cost of seeds for chili	chili_seeds_cost	posnorm	2000000		3000000	IDR/ha
	Cost of fertilizer for chili	chili_fertilizer_cost	posnorm	7500000		8500000	IDR/ha
	Cost of pesticide for chili	chili_pesticide_cost	posnorm	4500000		6000000	IDR/ha
	Cost of labor for chili	chili_labor_cost	posnorm	30000000		35000000	IDR/ha
	Cost of machinery for chili	chili_machinery_cost	posnorm	1000000		2700000	IDR/ha
	Cost of mulch	chili_mulch_cost	posnorm	2500000		3500000	IDR/ha
	Cost of growth support (polybag, rope, stick, ne	chili_growing_support_cost	posnorm	2000000		3000000	IDR/ha
	Cost of fuel and electricity	chili_fuel_electricity_cost	posnorm	1000000		3000000	IDR/ha
	Cost of harvesting for chili	chili_harvesting_cost	posnorm	100000		200000	IDR/ha
Discount rate	Discount rate	discount_rate	posnorm	1		5	
Year	Year of observation	n_year	const	1		10	

Variable for rice farm and crop rotation for small holder farmers in Indonesia have 8 mains variables that are consist of rice production, rice cultivation cost, soybean production, soybean cultivation cost, chili production, chili cultivation cost, discount rate and year of system. Overall, there are 33 variables that are used for this decision analysis.

####Source: BPS (2018), Mucharam et al. (2020), Jagung (2017), Fao (2018), BPS (2022), Amirrullah (2019), Crystal and Whittlesey (2004), Jagung (2017), BRIN (2022), USDA (2012), Setiartiti (2021), Antriyandarti (2015), Krisdiana et al. (2021), Harsono et al. (2020), Schilling (1999), Wandschneider et al. (2019), Sundari et al. (2021)

Estimate Calculation

Incomes:
- Rice = Paddy yield * Market price (rice)
- Soybean = Soybean yield * Market price (soybean)
- Chili = Chili yield * Market price (chili)
- Total = Rice income + soybean income + chili income

Costs:
- Rice = Labor cost + seed cost + fertilizer cost + pesticide cost + machinery cost + harvesting cost+ land rent
- Soybean = Labor cost + seed cost + fertilizer cost + pesticide cost + machinery cost + harvesting cost+ land rent
- Chili = Labor cost + seed cost + fertilizer cost + pesticide cost + machinery cost + harvesting cost+ land rent
- Total = Rice cost + soybean cost + chili cost

$$Net\ Present\ Value\ (NPV) = \sum_{n=1}^{N} \frac{(Total\ income)_n - (Total\ cost)_n}{(1-r)^n}$$

- r = discount rate
- n = year of system

NPV (Net Present Value): In financial terms, the NPV the measurement of the profitability of a project or programme. This is achieved by subtracting the current values of expenditure from the current values of income over a period of time. Income can be referred to as benefit and expenditure can be referred to as cost.

Discount Rate: The discount rate is the interest rate used in analysis of discounted cash flow (DCF).

Stantec (2005)

Decision analysis

R code

Do, Luedeling, and Whitney (2020)

```
crop_rotation_decision <- function(){

  # Estimate the income of rice in a normal season
  rice_income <- vv(rice_yield * rice_price, n=n_year, var_CV=100)

  # Estimate the income of soybean in a normal season
  soybean_income <- vv(soybean_yield * soybean_price, n=n_year, var_CV=100)
```

```r
# Estimate the income of chili in a normal season
chili_income <- vv(chili_yield * chili_price, n=n_year, var_CV=100)

#Estimate the cost of rice farm in a normal season
rice_cost_precal <- sum(rice_land_rental_cost, rice_seeds_cost, rice_fertilizer_cost,
                        rice_pesticide_cost, rice_machinery_cost, rice_harvesting_cost)
rice_cost <- vv(rice_cost_precal, n=n_year, var_CV=100)


#Estimate the cost of soybean farm in a normal season
soybean_cost_precal <- sum(soybean_land_rental_cost, soybean_seeds_cost, soybean_fertilizer_cost,
                           soybean_pesticide_cost, soybean_machinery_cost, soybean_harvesting_cost)
soybean_cost <- vv(soybean_cost_precal, n=n_year, var_CV=100)


#Estimate the cost in a normal season
chili_cost_precal <- sum(chili_land_rental_cost, chili_seeds_cost, chili_fertilizer_cost,
                         chili_pesticide_cost, chili_machinery_cost, chili_harvesting_cost)
chili_cost <- vv(chili_cost_precal, n=n_year, var_CV=100)


# Estimate the profit
rice_profit <- vv(rice_income - rice_cost, n=n_year, var_CV=100)
soybean_profit <- vv(soybean_income - soybean_cost, n=n_year, var_CV=100)
chili_profit <- vv(chili_income - chili_cost, n=n_year, var_CV=100)


# Final result
#assuming rice cultivation is 3 times per year
rice_cultivation_result = vv(rice_profit*3, n=n_year, var_CV=100)

#crop rotation decision scenario
#if crop rotation of 3 crops is done in one year
crop_rotation_result = vv(rice_profit + soybean_profit + chili_profit, n=n_year, var_CV=100)

#if crop rotation of rice and soybean is done in one year (rice-soybean-rice)
rice_soybean_result = vv((rice_profit*2) + soybean_profit, n=n_year, var_CV=100)

#if crop rotation of rice and chili is done in one year (rice-chili)
rice_chili_result = vv(rice_profit + chili_profit, n=n_year, var_CV=100)


# NPV
NPV_rice <- discount(rice_cultivation_result, discount_rate, calculate_NPV = TRUE)
NPV_crop_rotation <- discount(crop_rotation_result, discount_rate, calculate_NPV = TRUE)
NPV_rice_soybean <- discount(rice_soybean_result, discount_rate, calculate_NPV = TRUE)
NPV_rice_chili <- discount(rice_chili_result, discount_rate, calculate_NPV = TRUE)


# Cashflow
cashflow_crop_rotation <- crop_rotation_result - rice_cultivation_result
cashflow_rice_soybean <- rice_soybean_result - rice_cultivation_result
cashflow_rice_chili <- rice_chili_result - rice_cultivation_result
```

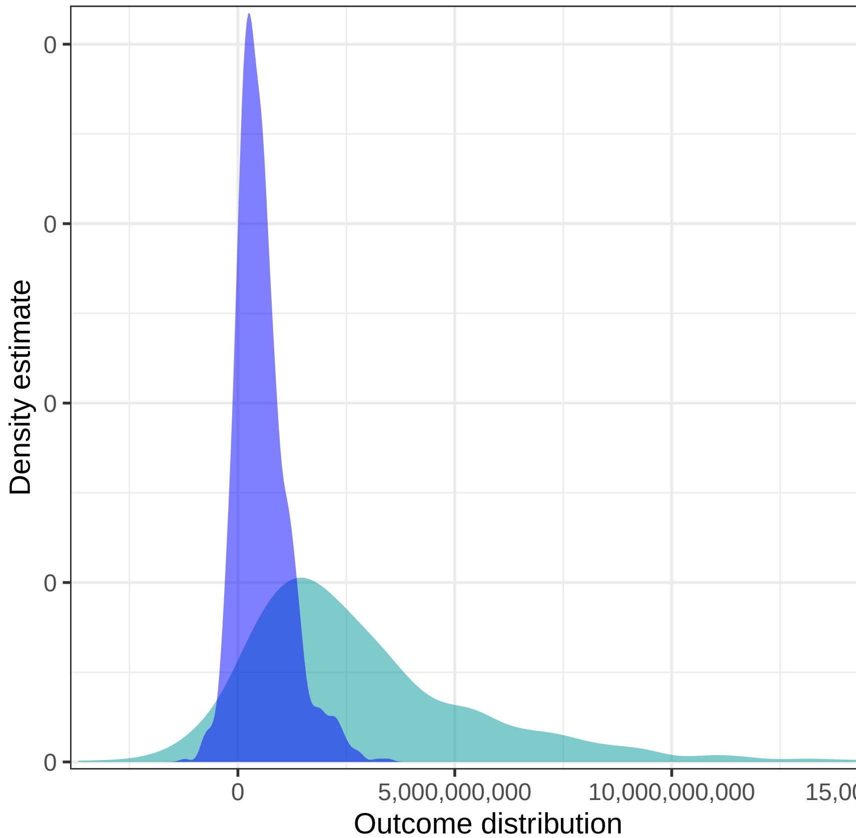
```r
  # Generate the list of outputs from the Monte Carlo simulation
  return(list(Rice_NPV = NPV_rice,
              crop_rotation_NPV = NPV_crop_rotation,
              rice_soybean_NPV = NPV_rice_soybean,
              rice_chili_NPV= NPV_rice_chili,
              NPV_decision_crop_rotation = NPV_crop_rotation - NPV_rice,
              NPV_decision_rice_soybean = NPV_rice_soybean - NPV_rice,
              NPV_decision_rice_chili = NPV_rice_chili - NPV_rice,
              cashflow_crop_rotation = cashflow_crop_rotation,
              cashflow_rice_soybean = cashflow_rice_soybean,
              cashflow_rice_chili = cashflow_rice_chili
  ))
}


make_variables<-function(est,n=1)
{ x<-random(rho=est, n=n)
for(i in colnames(x)) assign(i, as.numeric(x[1,i]),envir=.GlobalEnv)}

make_variables(read.csv("new_variable_estimates.csv"))
```

```
## Warning in assign(i, as.numeric(x[1, i]), envir = .GlobalEnv): NAs introduced
## by coercion
```

```r
# Run the Monte Carlo simulation using the model function
input_estimates <- read.csv("new_variable_estimates.csv", sep=";")

crop_rotation_mc_simulation <- mcSimulation(estimate = as.estimate(input_estimates),
                                            model_function = crop_rotation_decision,
                                            numberOfModelRuns = 1000,
                                            functionSyntax = "plainNames")

# Run the Monte Carlo simulation using the model function
input_estimates <- read.csv("new_variable_estimates.csv", sep=";")

crop_rotation_mc_simulation <- mcSimulation(estimate = as.estimate(input_estimates),
                                            model_function = crop_rotation_decision,
                                            numberOfModelRuns = 1000,
                                            functionSyntax = "plainNames")
```

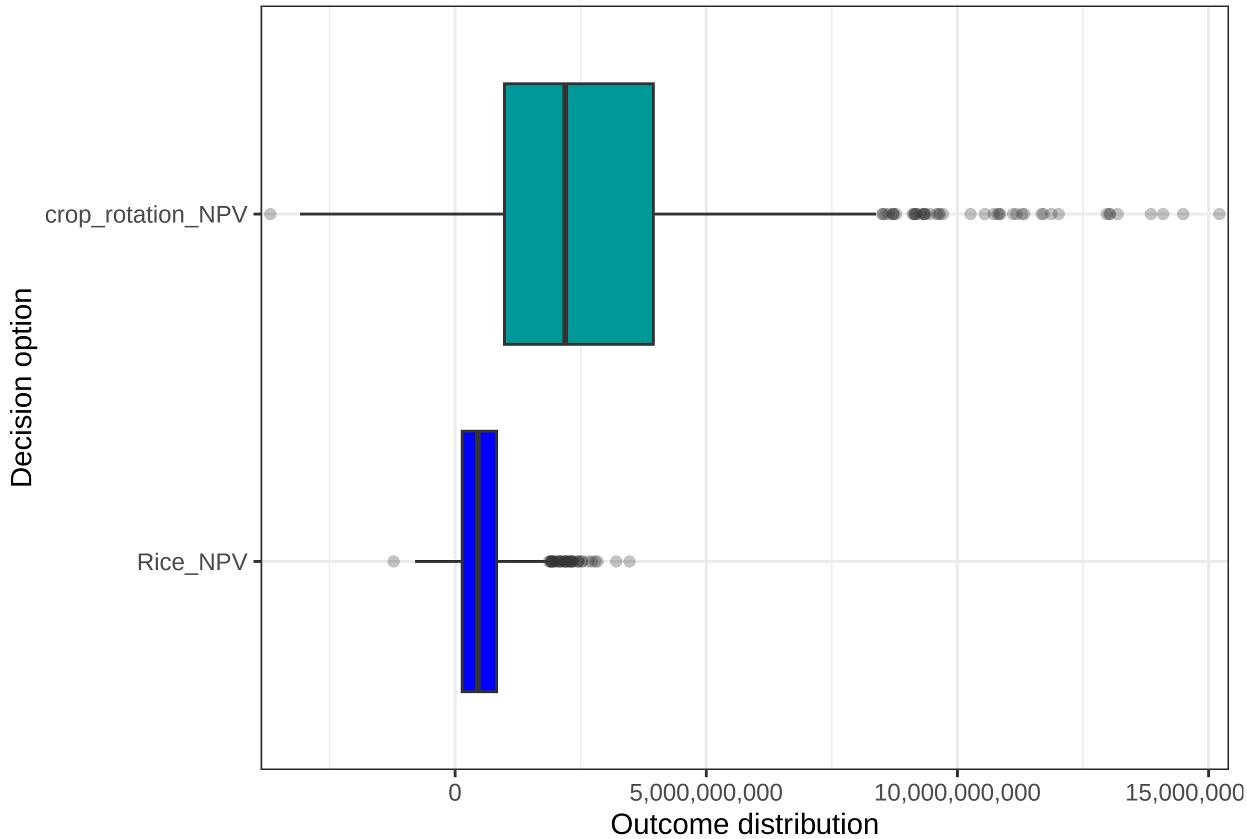
Plot NPV distribution analysis

```r
decisionSupport::plot_distributions(mcSimulation_object = crop_rotation_mc_simulation,
                                    vars = c("crop_rotation_NPV", "Rice_NPV"),
                                    method = 'smooth_simple_overlay')
```



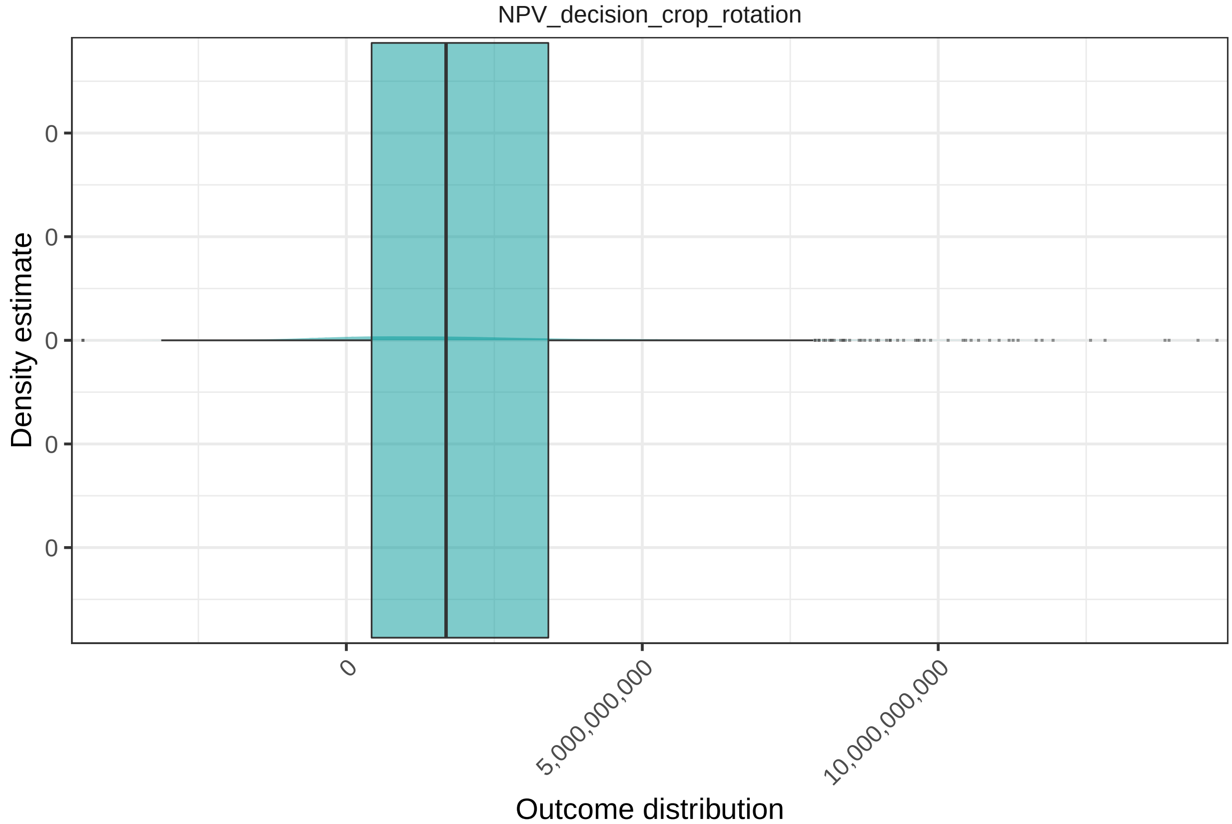
NPV for crop rotation (rice-soybean-chili)

```
decisionSupport::plot_distributions(mcSimulation_object = crop_rotation_mc_simulation,
                                    vars = c("crop_rotation_NPV", "Rice_NPV"),
                                    method = 'boxplot')
```

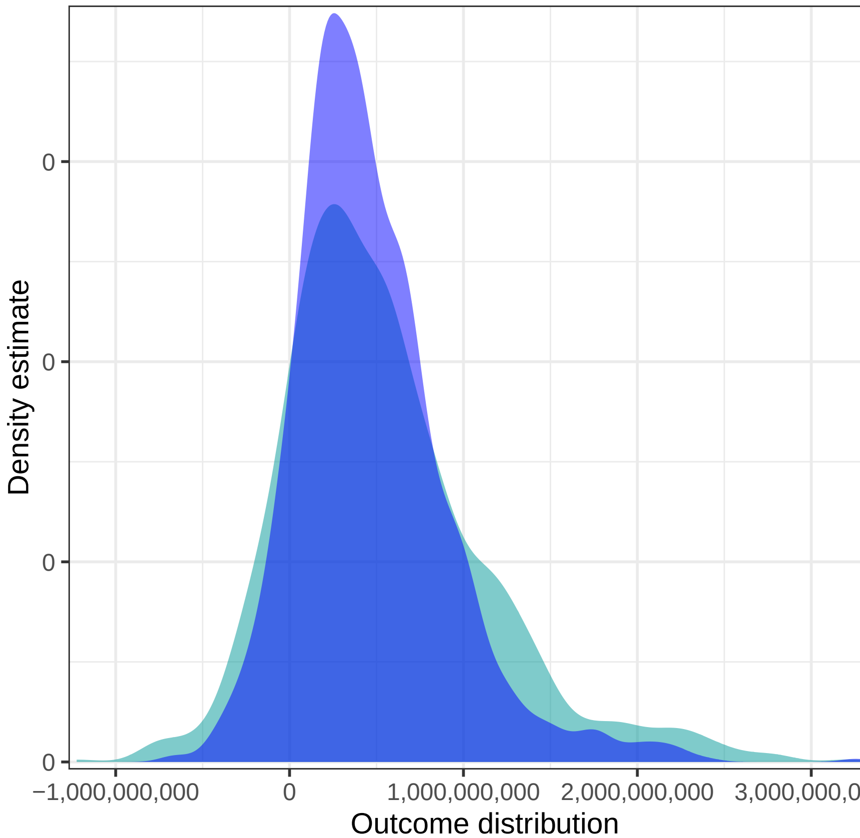



```
decisionSupport::plot_distributions(mcSimulation_object = crop_rotation_mc_simulation,
                                    vars = c("NPV_decision_crop_rotation"),
                                    method = 'boxplot_density')
```

```
## Warning: The following aesthetics were dropped during statistical transformation: x
## i This can happen when ggplot fails to infer the correct grouping structure in
##   the data.
## i Did you forget to specify a `group` aesthetic or to convert a numerical
##   variable into a factor?
```

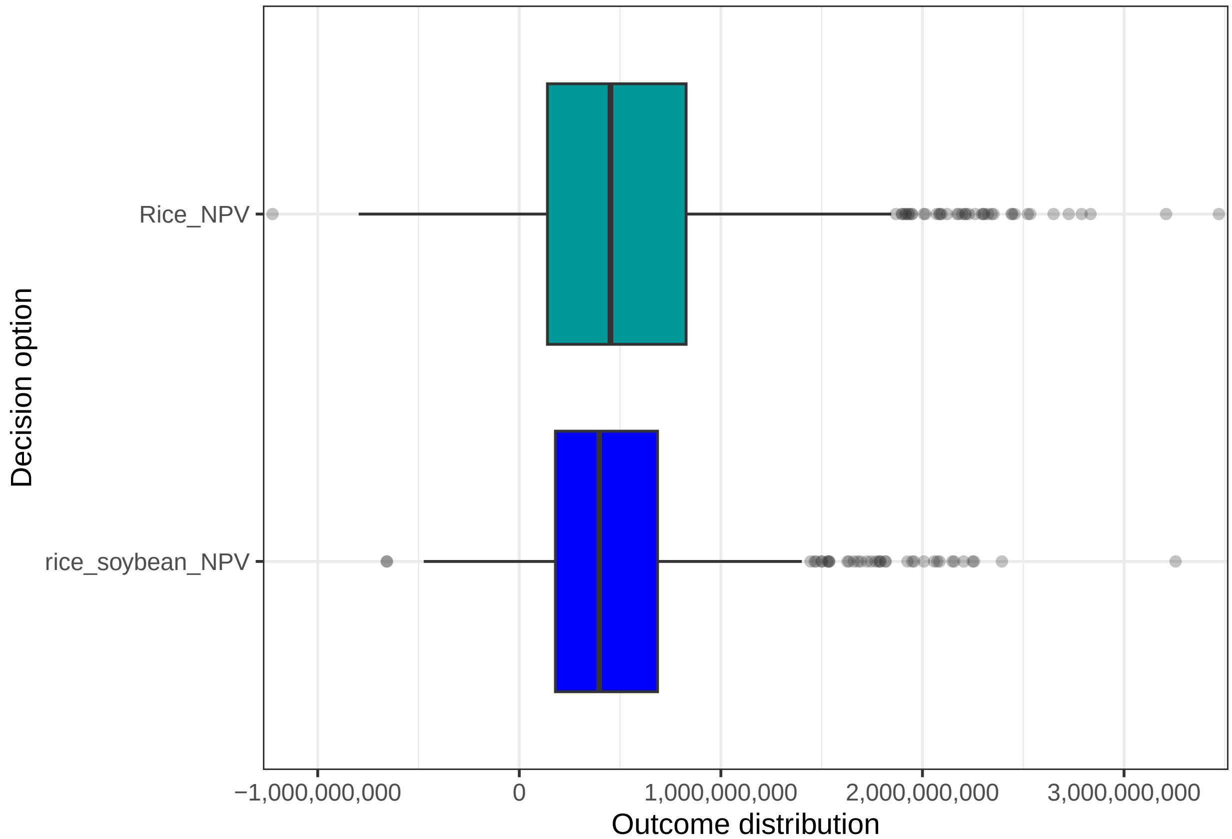



```
decisionSupport::plot_distributions(mcSimulation_object = crop_rotation_mc_simulation,
                                    vars = c("rice_soybean_NPV","Rice_NPV"),
                                    method = 'smooth_simple_overlay')
```



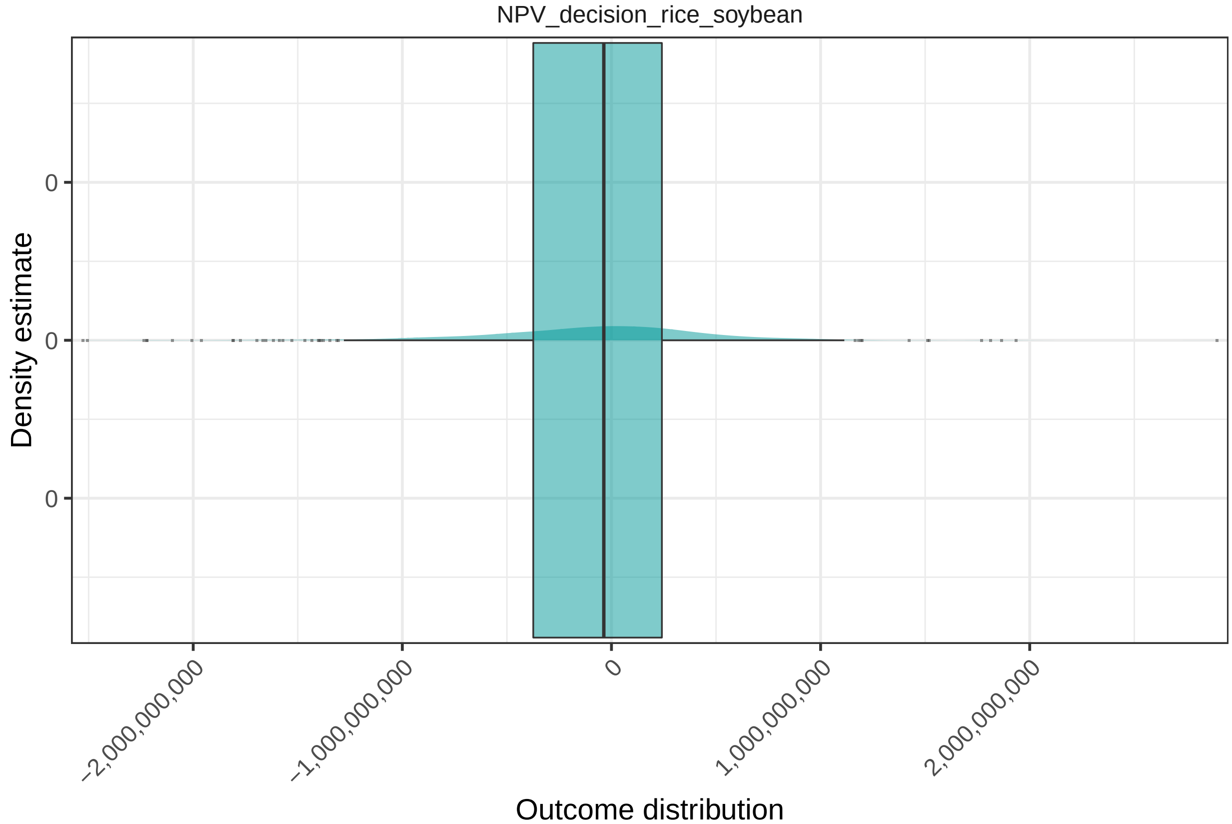
NPV for crop rotation (rice-soybean-rice)

```
decisionSupport::plot_distributions(mcSimulation_object = crop_rotation_mc_simulation,
                                    vars = c("rice_soybean_NPV","Rice_NPV"),
                                    method = 'boxplot')
```

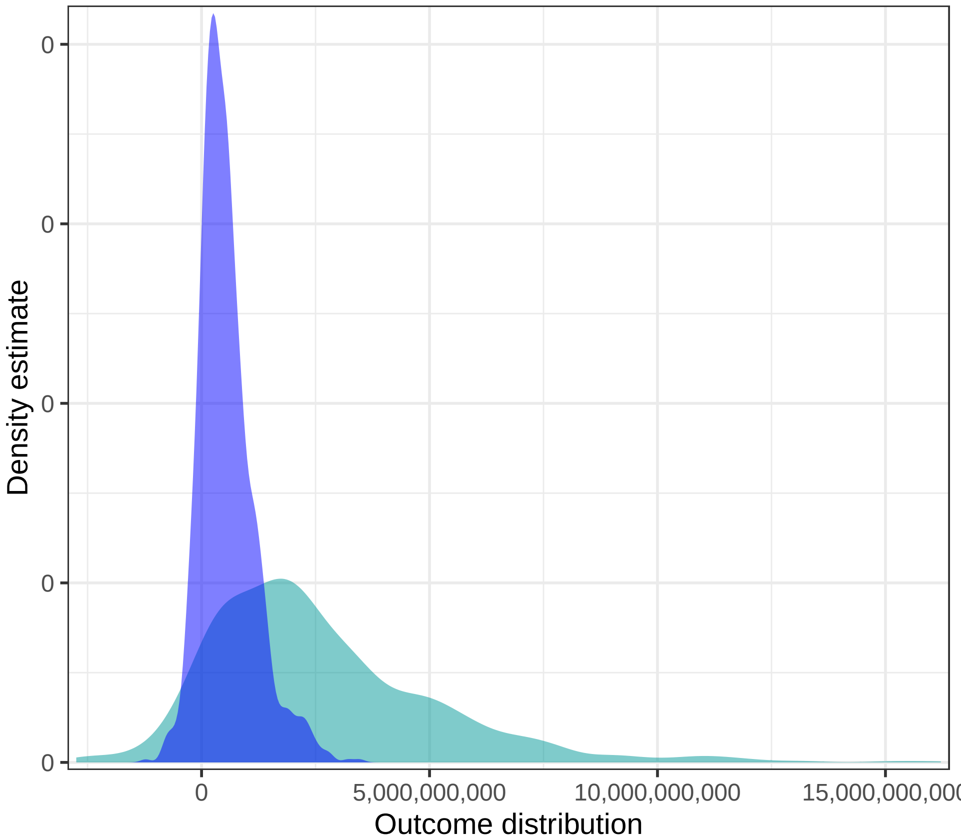



```r
decisionSupport::plot_distributions(mcSimulation_object = crop_rotation_mc_simulation,
                                    vars = c("NPV_decision_rice_soybean"),
                                    method = 'boxplot_density')
```

```
## Warning: The following aesthetics were dropped during statistical transformation: x
## i This can happen when ggplot fails to infer the correct grouping structure in
##   the data.
## i Did you forget to specify a ‘group‘ aesthetic or to convert a numerical
##   variable into a factor?
```

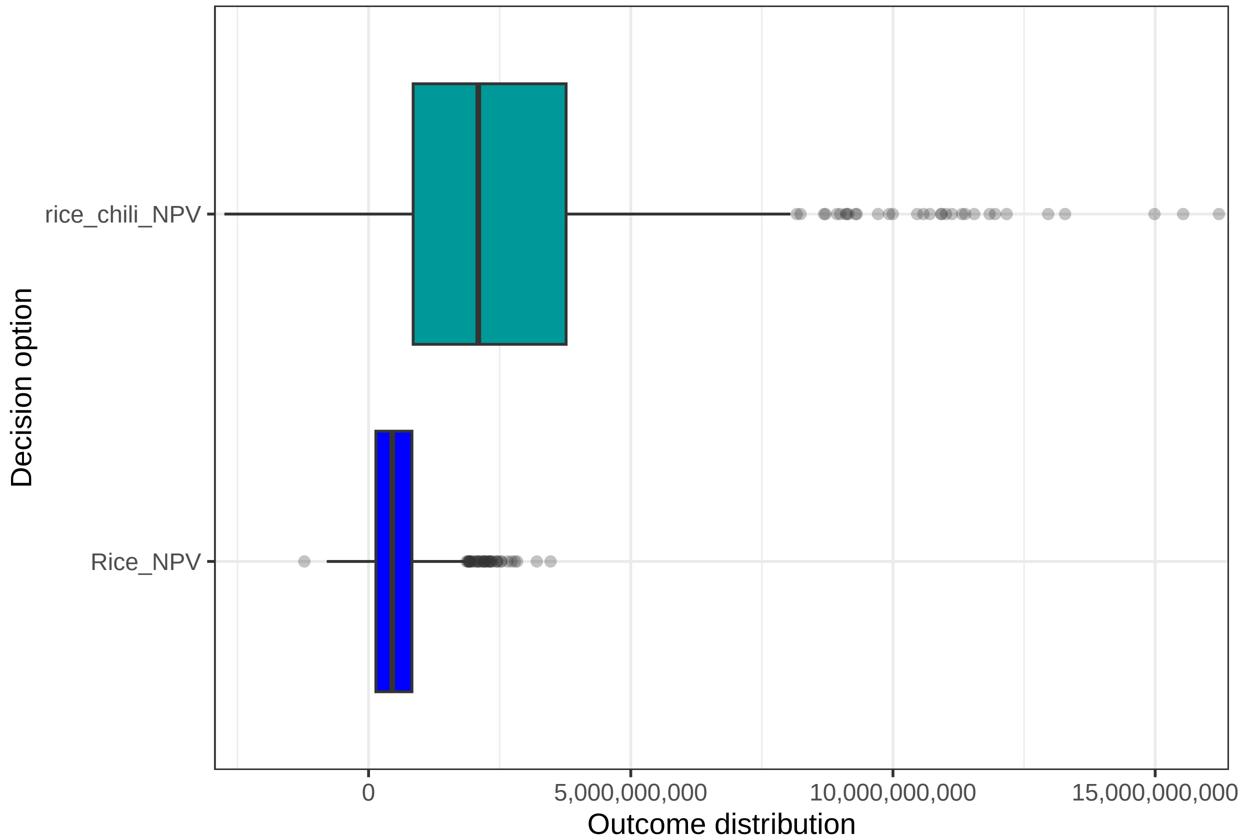



```
decisionSupport::plot_distributions(mcSimulation_object = crop_rotation_mc_simulation,
                                    vars = c("rice_chili_NPV","Rice_NPV"),
                                    method = 'smooth_simple_overlay')
```



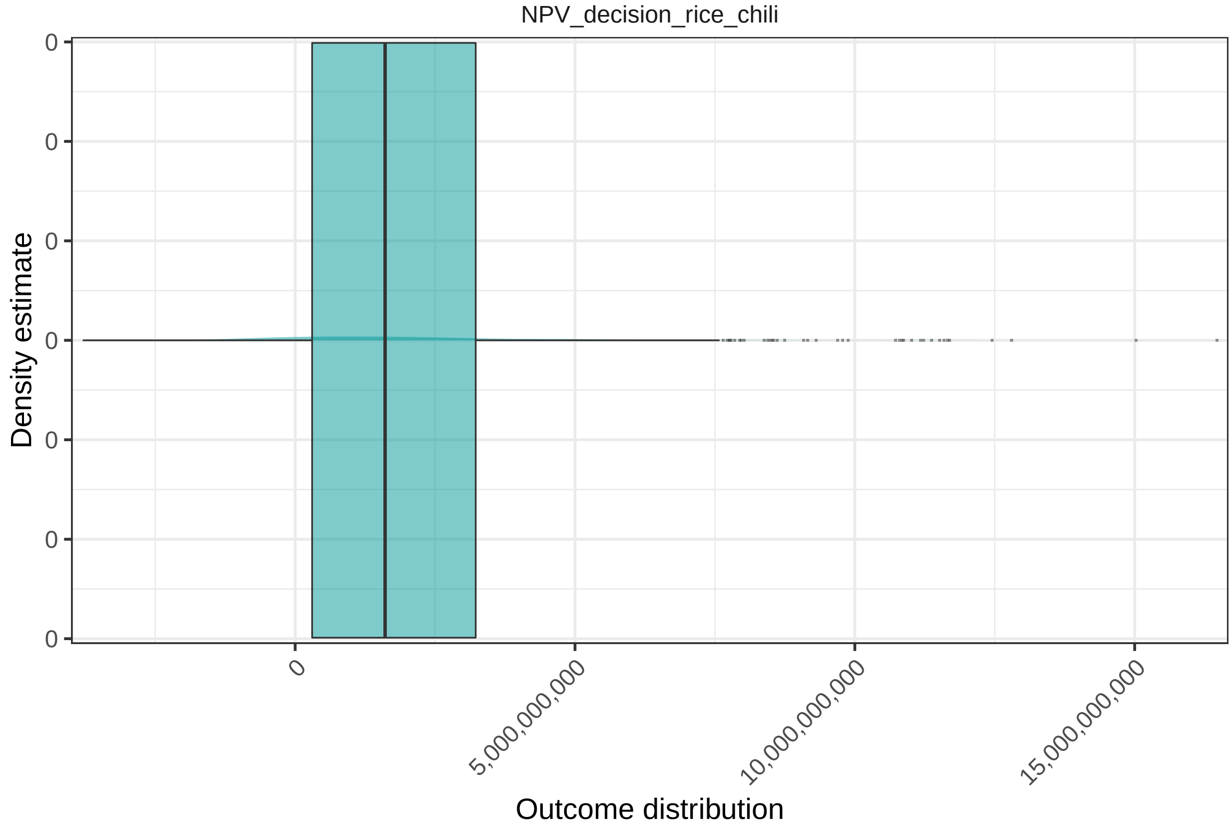
NPV for crop rotation (rice-chilli)

```
decisionSupport::plot_distributions(mcSimulation_object = crop_rotation_mc_simulation,
                                    vars = c("rice_chili_NPV","Rice_NPV"),
                                    method = 'boxplot')
```



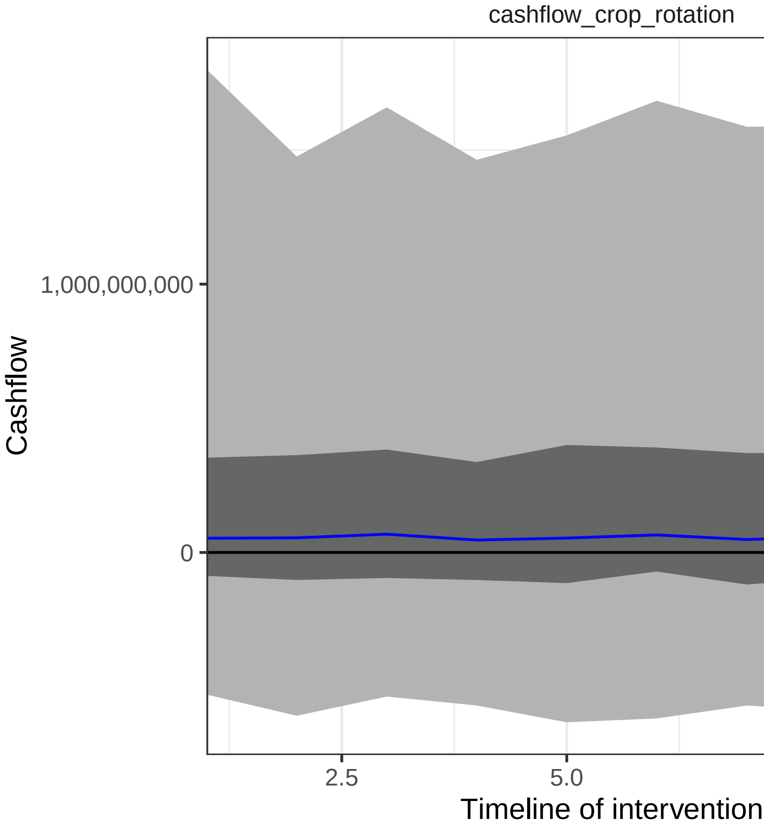

```r
decisionSupport::plot_distributions(mcSimulation_object = crop_rotation_mc_simulation,
                                    vars = c("NPV_decision_rice_chili"),
                                    method = 'boxplot_density')
```

```
## Warning: The following aesthetics were dropped during statistical transformation: x
## i This can happen when ggplot fails to infer the correct grouping structure in
##   the data.
## i Did you forget to specify a `group` aesthetic or to convert a numerical
##   variable into a factor?
```



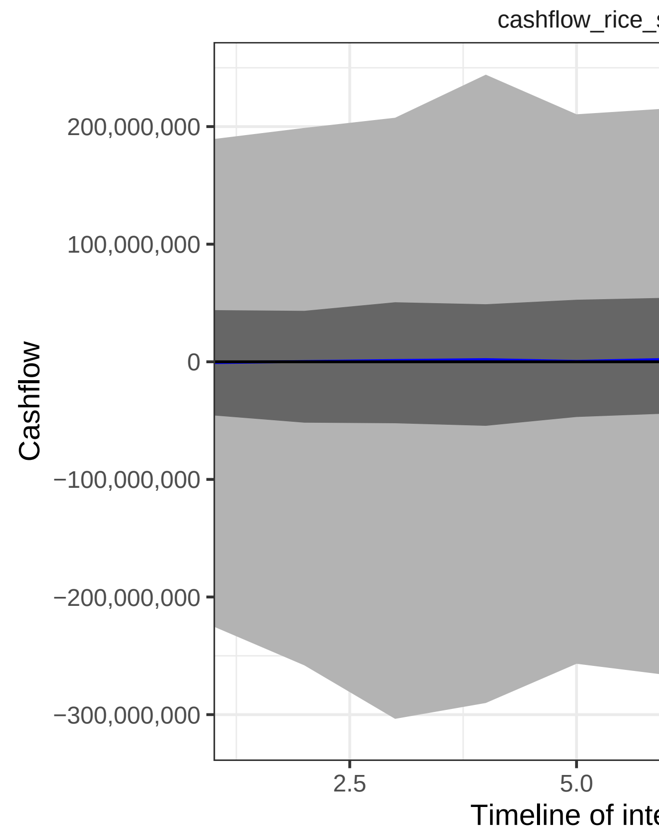
Cashflow analysis

```
plot_cashflow(mcSimulation_object = crop_rotation_mc_simulation, cashflow_var_name = "cashflow_crop_rota
```



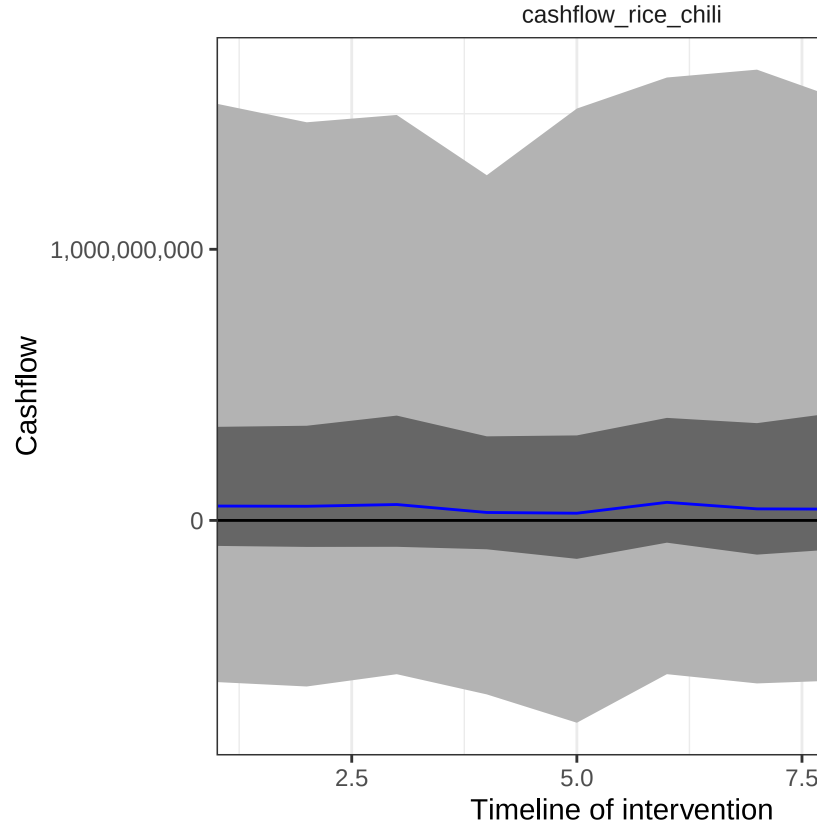
With crop rotation of 3 crops (rice-soybean-chili)

```
plot_cashflow(mcSimulation_object = crop_rotation_mc_simulation, cashflow_var_name = "cashflow_rice_soyb
```



With crop rotation of rice and soybean (rice-soybean-rice)

```
plot_cashflow(mcSimulation_object = crop_rotation_mc_simulation, cashflow_var_name = "cashflow_rice_chil
```



With crop rotation of rice and chili (rice-chili)

Value of Information (VoI) analysis

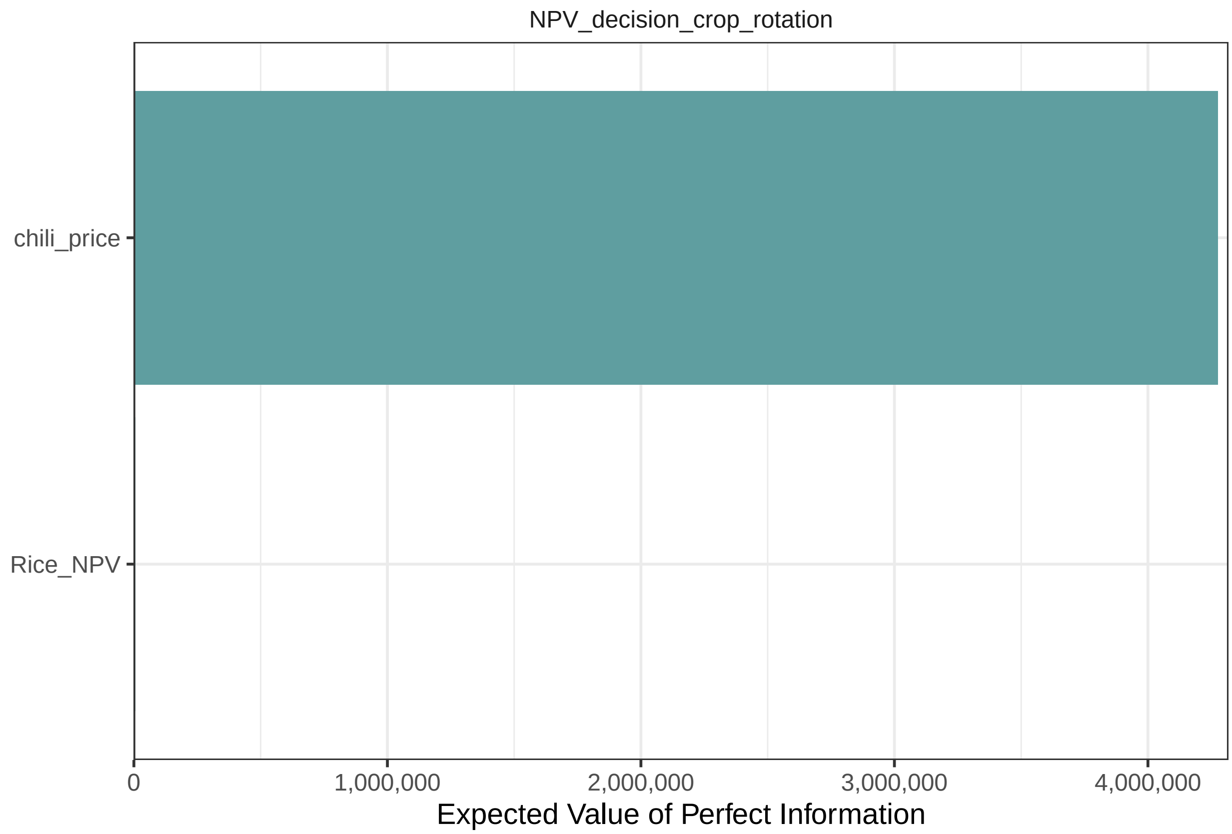
```
mcSimulation_table <- data.frame(crop_rotation_mc_simulation$x, crop_rotation_mc_simulation$y[1:7])
```

```
evpi_crop_rotation <- multi_EVPI(mc = mcSimulation_table, first_out_var = "crop_rotation_NPV")
```

EVPI crop rotation

```
## [1] "Processing 6 output variables. This can take some time."
## [1] "Output variable 1 (crop_rotation_NPV) completed."
## [1] "Output variable 2 (rice_soybean_NPV) completed."
## [1] "Output variable 3 (rice_chili_NPV) completed."
## [1] "Output variable 4 (NPV_decision_crop_rotation) completed."
## [1] "Output variable 5 (NPV_decision_rice_soybean) completed."
## [1] "Output variable 6 (NPV_decision_rice_chili) completed."
```

```
plot_evpi(evpi_crop_rotation, decision_vars = "NPV_decision_crop_rotation")
```

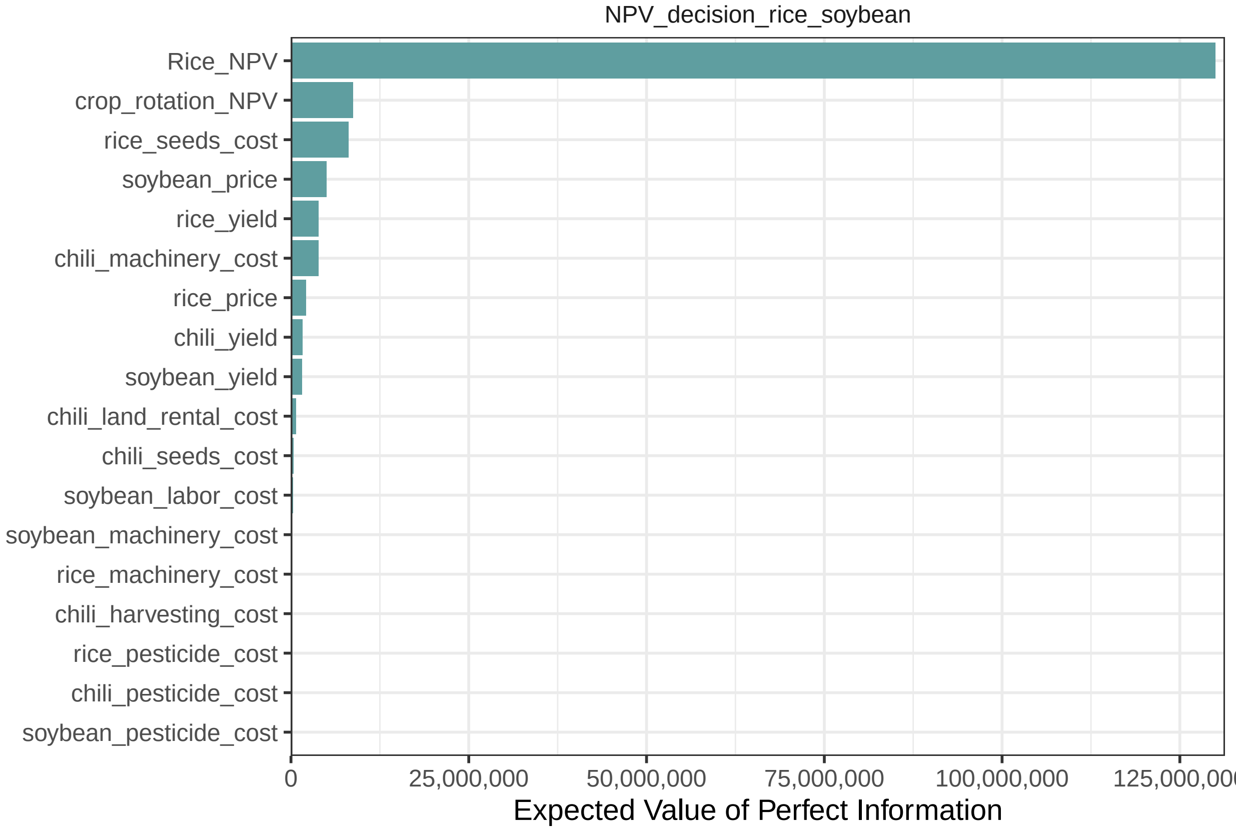



```
evpi_rice_soybean <- multi_EVPI(mc = mcSimulation_table, first_out_var = "rice_soybean_NPV")
```

EVPI rice and soybean

```
## [1] "Processing 5 output variables. This can take some time."
## [1] "Output variable 1 (rice_soybean_NPV) completed."
## [1] "Output variable 2 (rice_chili_NPV) completed."
## [1] "Output variable 3 (NPV_decision_crop_rotation) completed."
## [1] "Output variable 4 (NPV_decision_rice_soybean) completed."
## [1] "Output variable 5 (NPV_decision_rice_chili) completed."
```

```
plot_evpi(evpi_rice_soybean, decision_vars = "NPV_decision_rice_soybean")
```

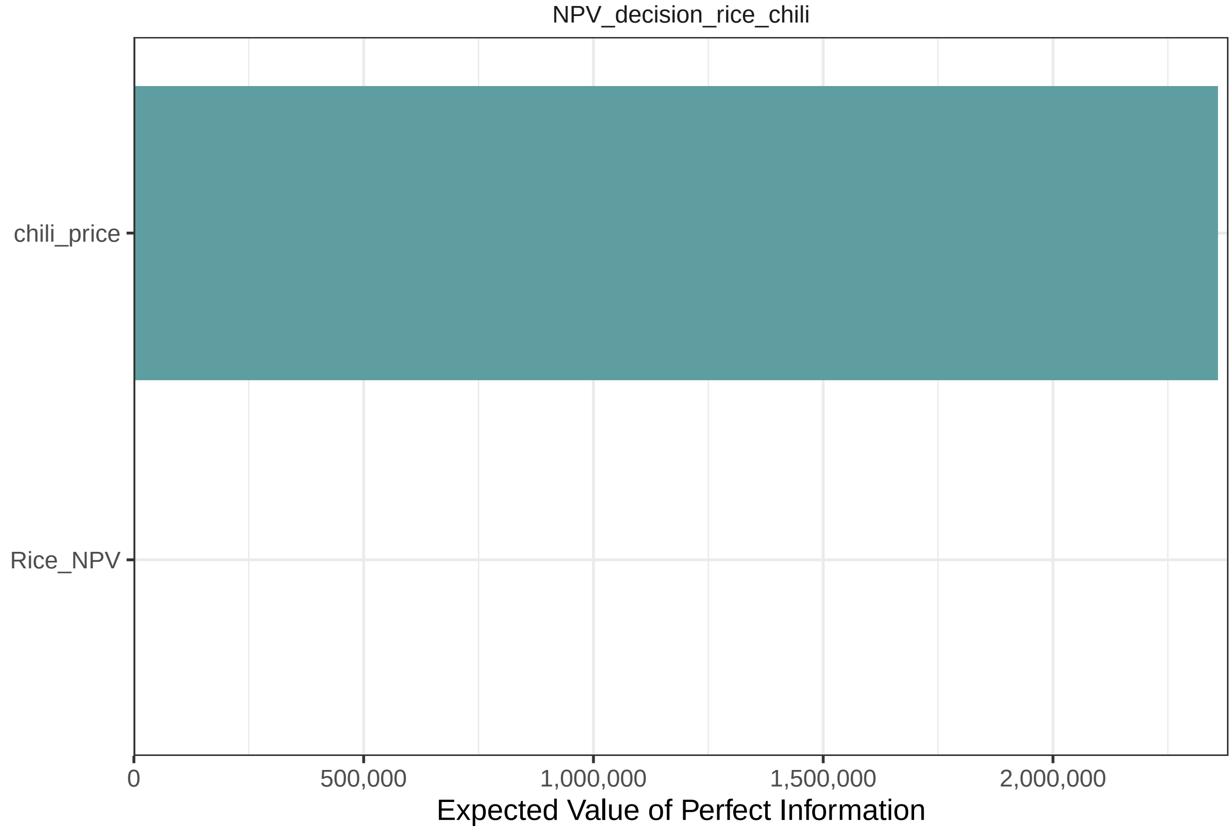



```r
evpi_rice_chili <- multi_EVPI(mc = mcSimulation_table, first_out_var = "rice_chili_NPV")
```

EVPI rice and chilli

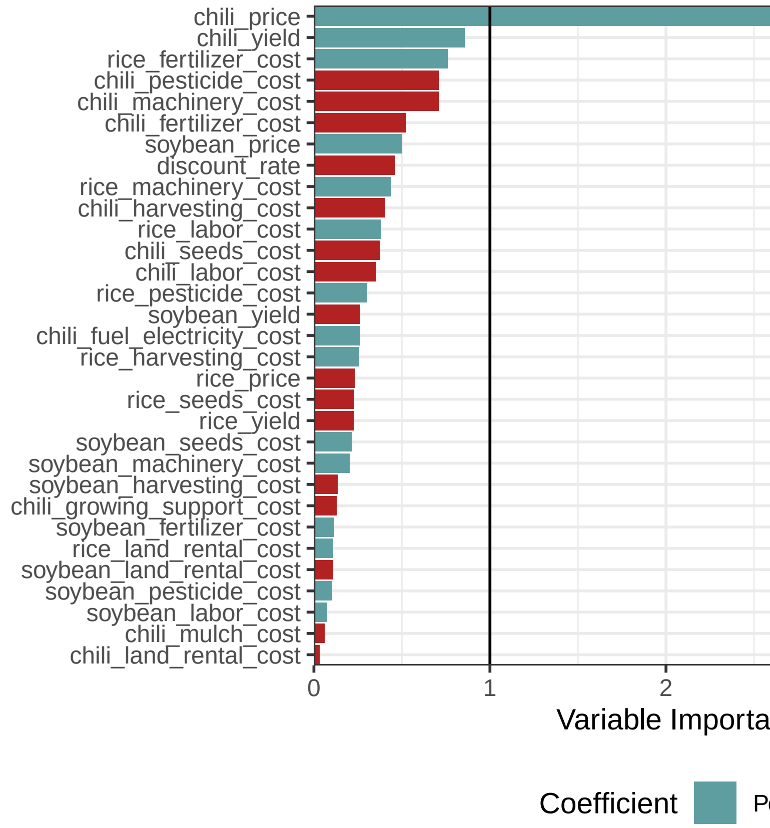
```
## [1] "Processing 4 output variables. This can take some time."
## [1] "Output variable 1 (rice_chili_NPV) completed."
## [1] "Output variable 2 (NPV_decision_crop_rotation) completed."
## [1] "Output variable 3 (NPV_decision_rice_soybean) completed."
## [1] "Output variable 4 (NPV_decision_rice_chili) completed."
```

```r
plot_evpi(evpi_rice_chili, decision_vars = "NPV_decision_rice_chili")
```



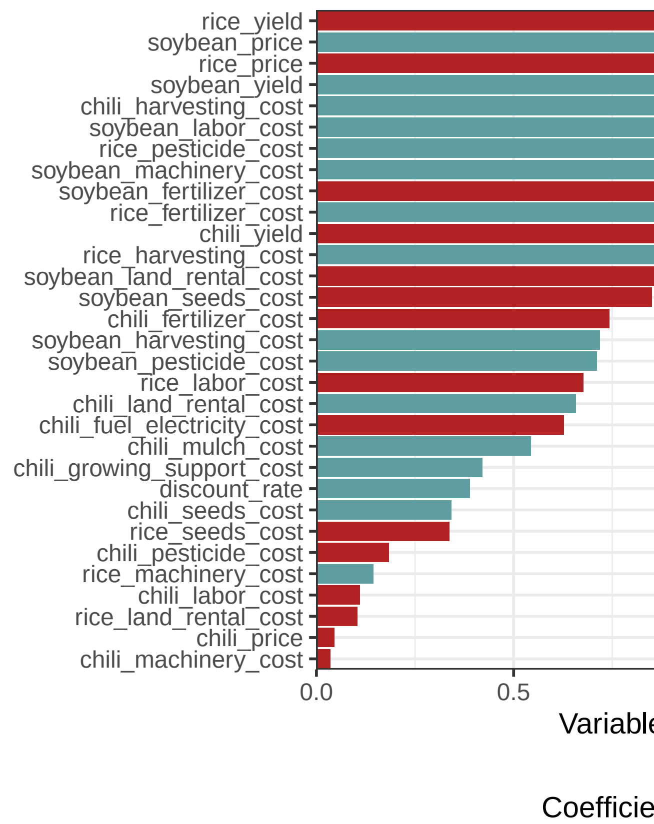
Projection to Latent Structures (PLS) analysis

```
pls_result_crop_rotation <- plsr.mcSimulation(object = crop_rotation_mc_simulation,
                                              resultName = names(crop_rotation_mc_simulation$y)[5], ncom
plot_pls(pls_result_crop_rotation, threshold = 0)
```



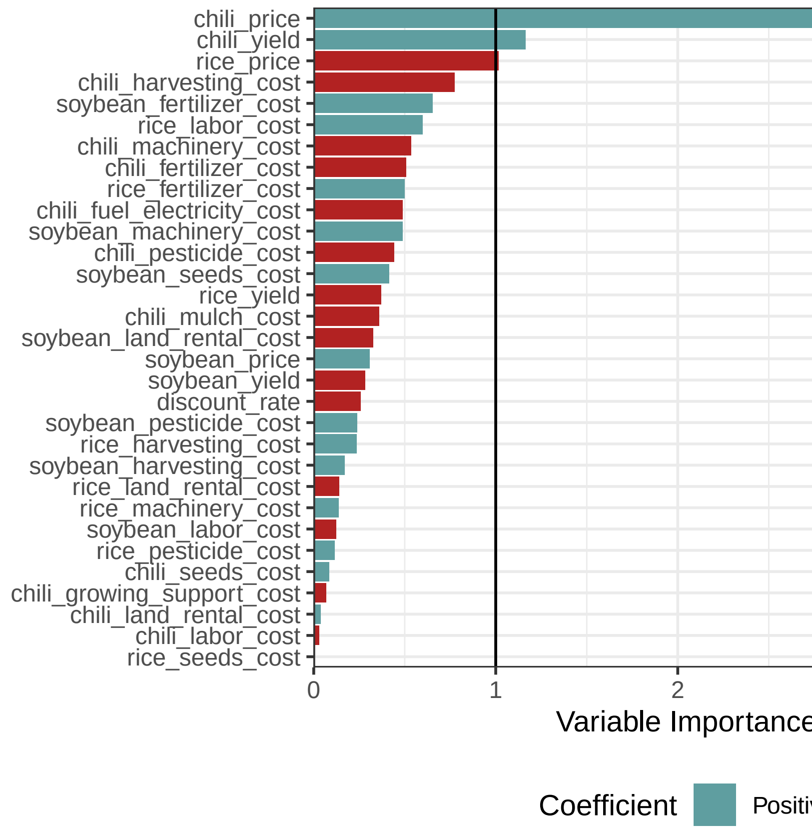
With crop rotation of 3 crops (rice-soybean-chili)

```
pls_result_rice_soybean <- plsr.mcSimulation(object = crop_rotation_mc_simulation,
                                             resultName = names(crop_rotation_mc_simulation$y)[6], ncom
plot_pls(pls_result_rice_soybean, threshold = 0)
```



With crop rotation of rice and soybean (rice-soybean-rice)

```
pls_result_rice_chili <- plsr.mcSimulation(object = crop_rotation_mc_simulation,
                                           resultName = names(crop_rotation_mc_simulation$y)[7], ncomp =
plot_pls(pls_result_rice_chili, threshold = 0)
```

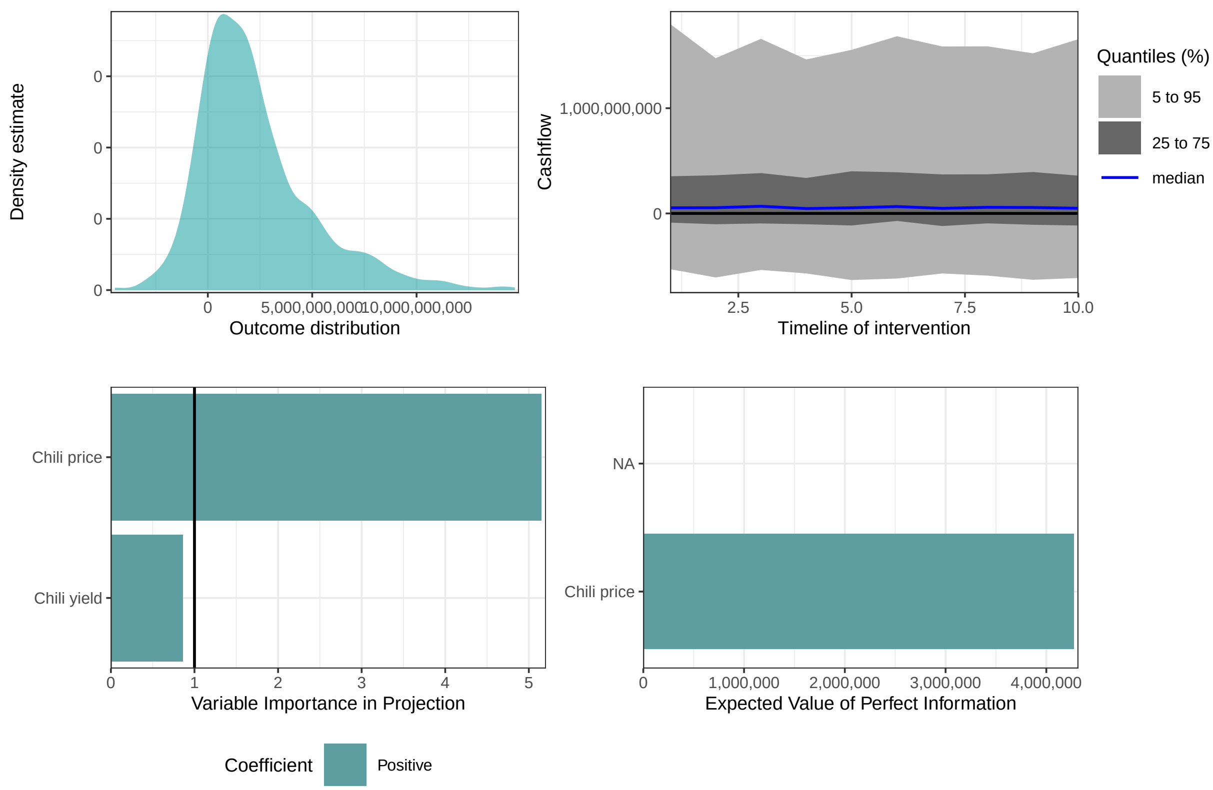


With crop rotation of rice and chili (rice-chili)

Results

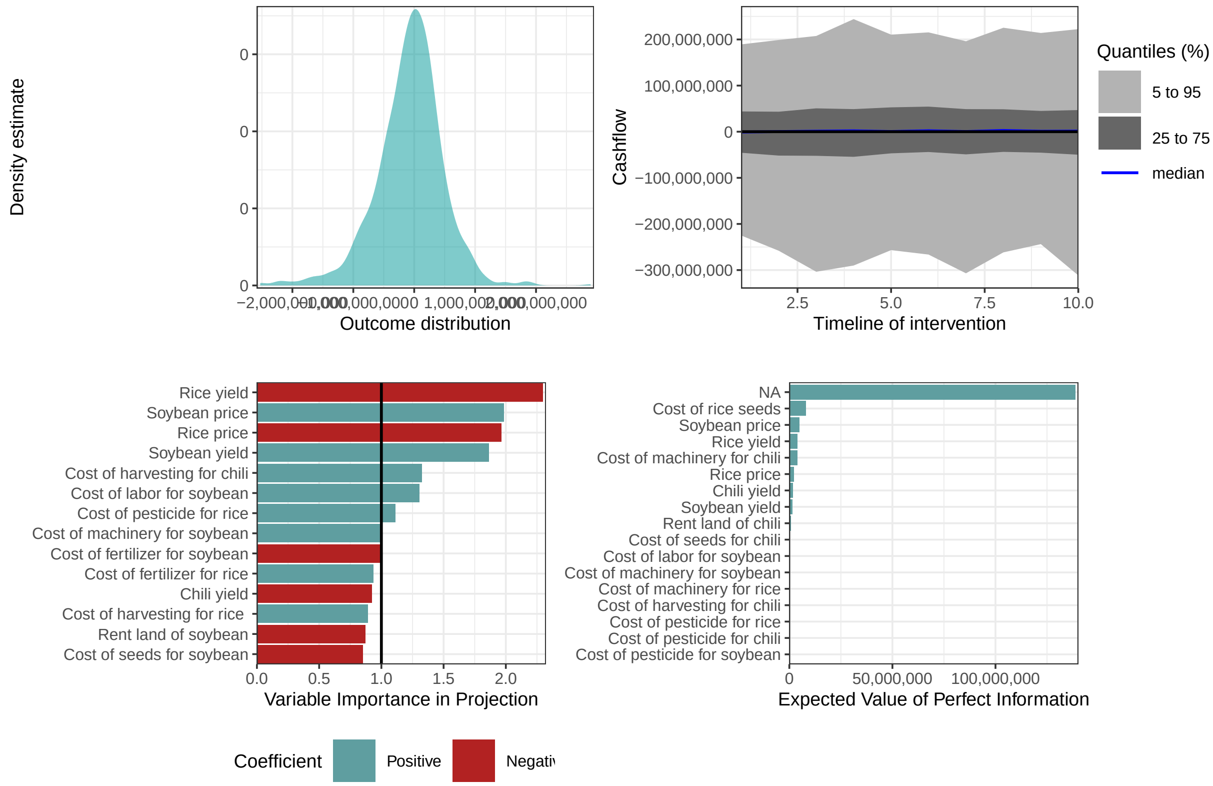
With crop rotation of 3 crops (rice-soybean-chili)

```r
compound_figure(mcSimulation_object = crop_rotation_mc_simulation,
                input_table = input_estimates, plsrResults = pls_result_crop_rotation,
                EVPIresults = evpi_crop_rotation, decision_var_name = "NPV_decision_crop_rotation",
                cashflow_var_name = "cashflow_crop_rotation",
                base_size = 7)
```



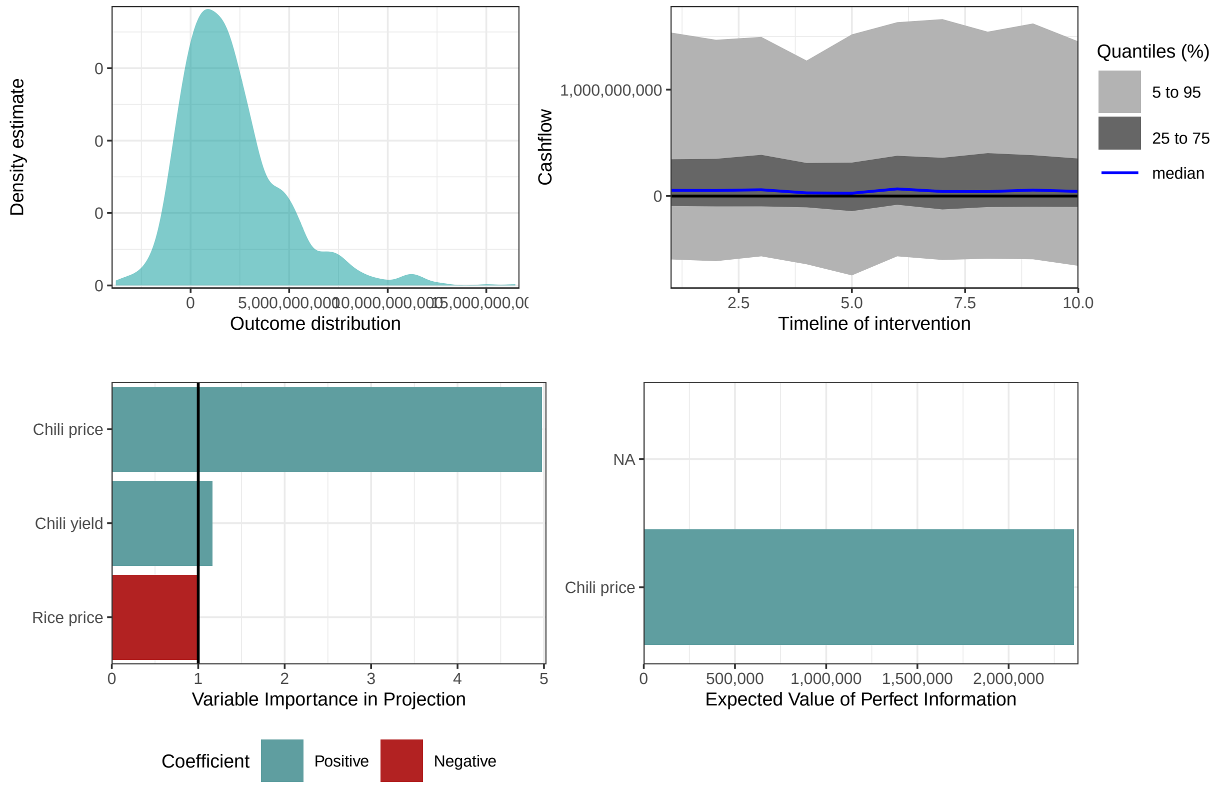
With crop rotation of rice and soybean (rice-soybean-rice)

```
compound_figure(mcSimulation_object = crop_rotation_mc_simulation,
                input_table = input_estimates, plsrResults = pls_result_rice_soybean,
                EVPIresults = evpi_rice_soybean, decision_var_name = "NPV_decision_rice_soybean",
                cashflow_var_name = "cashflow_rice_soybean",
                base_size = 7)
```



With crop rotation of rice and chili (rice-chili)

```r
compound_figure(mcSimulation_object = crop_rotation_mc_simulation,
                input_table = input_estimates, plsrResults = pls_result_rice_chili,
                EVPIresults = evpi_rice_chili, decision_var_name = "NPV_decision_rice_chili",
                cashflow_var_name = "cashflow_rice_chili",
                base_size = 7)
```



Conclusion

1. This project has proven that selecting the appropriate crop rotation between rice, soybean, and chili seem profitable for achieving optimal results with respect to higher income for rice farming.
2. The decision to rotate crops between rice and chili is still applicable with slightly smaller profits.
3. Crop rotation between rice, soybean, and rice is less efficient than other options with respect to sustainable income.

Recommendtion

1.We **recommend** Indonesian smallholder farmers to implement crop rotation either for three crops **(rice, soybean, and chili)** or two crops **(rice and chili)** as it seems more profitable than growing rice only all year around.

2.However, we would **not recommend** to implement crop rotation between **rice and soybean** as it seems not so profitable.

What we have learned from this project?

1. Rice farming with crop rotation of soybean and chili can be implemented by Indonesian smallholder farmers to get higher income.
2. However, not every crops are profitable to be rotated with rice.
3. There are more uncertainties in crop rotation of rice and soybean compared to other scenarios. Thus, further data and research still needed.

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