THDC India Ltd.

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Monetization of Hydropower Dam Projects

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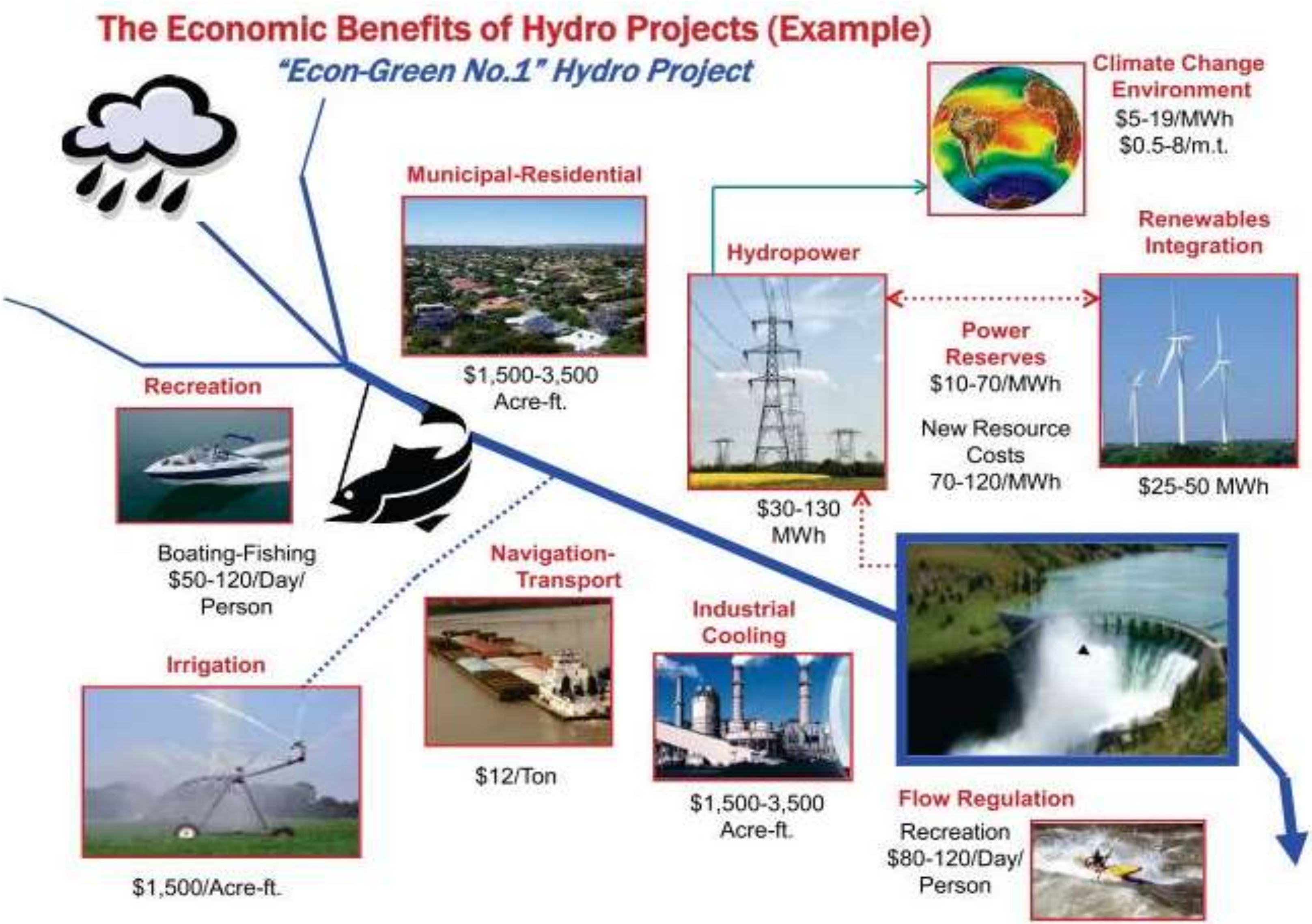
HYDROPOWER

- Hydropower is a non-consumptive use of water, water flowing through a turbine can be used again for other purposes.
- Hydropower is the largest renewable source of energy connected to grid.



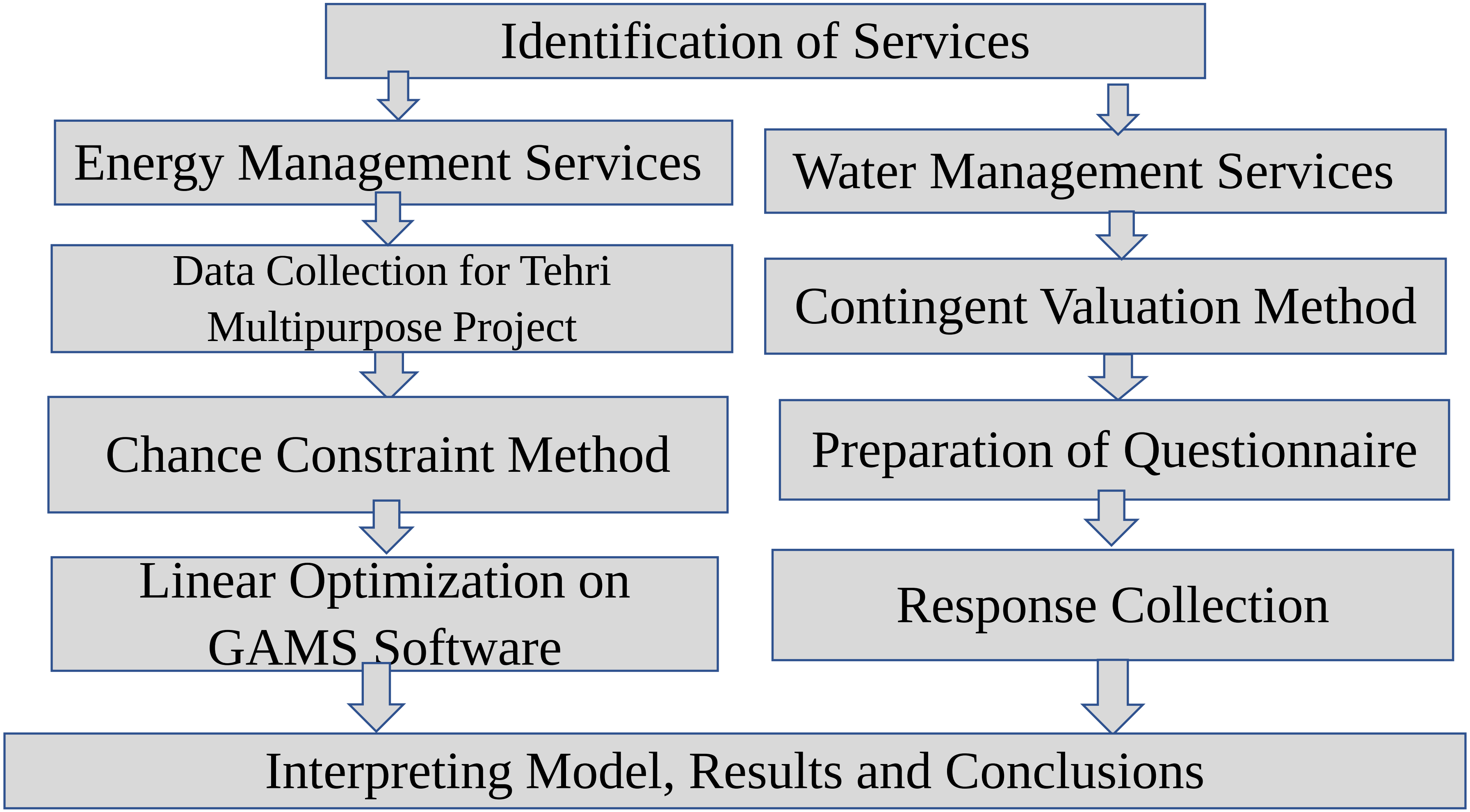
Services Provided by Hydropower

Source: West et al, 2010, Technology Review: Quantifying The Non-Energy Benefits of Hydropower

Past studies / Reports

Sr. No.	Title	Authors /Organization/ Dates
1	Valuing Hydropower Services	IEA Hydro / October 2017
2	Flexible hydropower value to RE integration	IEA / October 2019
3	Flexible Operation of Hydropower	EPRI / may 2017
4	Reclamation Hydrogenerator Start / Stop Costs	U.S. Dept of the Interior Bureau of Reclamation / June 2014
5	Quantifying The Non-Energy Benefits of Hydropower	CEATI International Inc. / February 2010
6	hydropower status report	International Hydropower Association /2021
7	Hydropower Vision. A New Chapter for America's Renewable Electricity Source	US Department of Energy / 2018
8	Renewable Energy and Jobs - Annual Review 2018	IRENA/ December 2018

Schematic Diagram of the Methodology Used



ENERGY MANAGEMENT SERVICES	WATER MANAGEMENT SERVICES
• Bulk power services and generating capacity	• Flood & drought control, proper and timely water supply
• Ancillary and Reliability Services	• Water free from major trash, proper sediment management, oxygenation level, acts as a barrier to saline water intrusion
• Integration of variable renewable system and fast ramping up/down	• Regional development- tourism, navigation, fisheries, food, irrigation, industries, roads
	• CSR in health, education, sanitation, domestic power, new economic activities
	• Environmental -reduction of GHG emission,

Study Area

- Tehri Multipurpose Project
- 1,000 MW hydropower project and water release for the irrigation and municipality water supply,

  Downstream of which is Koteshwar HEP-400 MW and

  PSP- 1000MW capacity under construction.
- This study is focused on the Phase 1 of the project i.e. Tehri Dam of capacity 1000 MW project.

Linear Optimization

Steps to optimize

- Describe the objective function
- Define the decision variables
- Describe the constraints
- Maximize with GAMS software
- Variables considered

In(t) = random inflow
St(t+1) = Storage
R(t) = Downstream water release
St(t) = Storage at the starting
Ep(t) = Evaporation loss
IR(t) = Irrigation release

$$In(t) + St(t) - Ep(t) - IR(t) - R(t) = St(t+1)$$

$$Ep(t) = a(t) + b(t)(St(t) + St(t+1))$$

$$IR(t) = In(t) + (1 - b(t))\, St(t) + (1 + b(t))\, St(t+1) - R(t) - a(t)$$

RESERVOIR RELEASE POLICY

The probability (Prb) of release of irrigation release in the time period t equalled or exceeded the irrigation demand, is not less than the specified value taken as P where P is defined as the reliability level.

Prb[IR(t) >=ID(t)] > = P

IR(t) is the irrigation release at time t and ID(**t**) is the irrigation demand for time period t, and P is taken as the specified reliability level.

Prb [(1 + $\beta\tau$) St(t+1) - (1 - $\beta\tau$) St(t) + R(t) + $\alpha\tau$ + ID(t) <= In(t)] > = P

IR(t) = St(t) + In(t) – R(t) – Ep(t) – b(t)

bt is a non-negative operating policy parameter.

LINEAR-DECISION RULE FOR CHANCE-CONSTRAINT OPTIMIZATION

IR(t) = St(t) + In(t) – R(t) – {$\alpha\tau + \beta\tau$(St(t) + St(t+1))} – b(t)

IR(t) = St(t) + In(t) – R(t) – $\alpha\tau$ – $\beta\tau$(St(t) + St(t+1))} – b(t)

By comparing

St(t+1) = b(t)

(1 + $\beta\tau$) b(t) - (1 - $\beta\tau$) b(t-1)+ R(t) + $\alpha\tau$ + ID(t) < = In(t-1)**{(1-P)}**

- Other Constraints
- **Power Plant Constraint:** E(t) < = MP
- **Storage Constraint:** b(t-1) < = Tl

  b(t-1) > = Td

  b(0) = b(12)
- **Head Storage Relationship:** Ht = ϒ((bt-1 + bt)/2) + **λ**

Where ϒ is the slope of the elevation storage curve and **λ** is the intercept.

- **Sreenivasan and Vedula** have approximated nonlinear power production term as a linear power production term.
- E(t) = c[R(t) (H(t0) – Btail) + R(t0)(Ht – Btail) – R(t0)(H(t0) – Btail)]
- Btail is the bed level of the turbine placed and the value of c is 0.002268 where Et is expressed in the units of million kWh and Rt is also been given in millions cubic metres.

Maximize summation of E(t)

Irrigation Demand

S. No.	Month	Irrigation Release for 2009-10 (Mm3)	Irrigation Release for 2018-19 (Mm3)
1	January	797.04	833.63
2	February	823.82	861.65
3	March	877.17	917.45
4	April	751.35	785.85
5	May	549.18	574.39
6	June	655.99	686.11
7	July	442.47	462.79
8	August	392.79	410.83
9	September	327.99	343.05
10	October	446.25	466.74
11	November	434.80	454.77
12	December	541.62	566.49

Source: Uttar Pradesh Irrigation Department

- The maximum energy generated for the one year duration considering 730 hours a month at PLF as 0.60 is 438 Million units per months that gives annual generation of 5,256 million units of generation- considered as the maximum limit for the generation.

- The value of a and b are been derived from the storage vs surface area covered by the water in the Tehri reservoir. The average value of these are 3.86 and 0.0158 respectively.

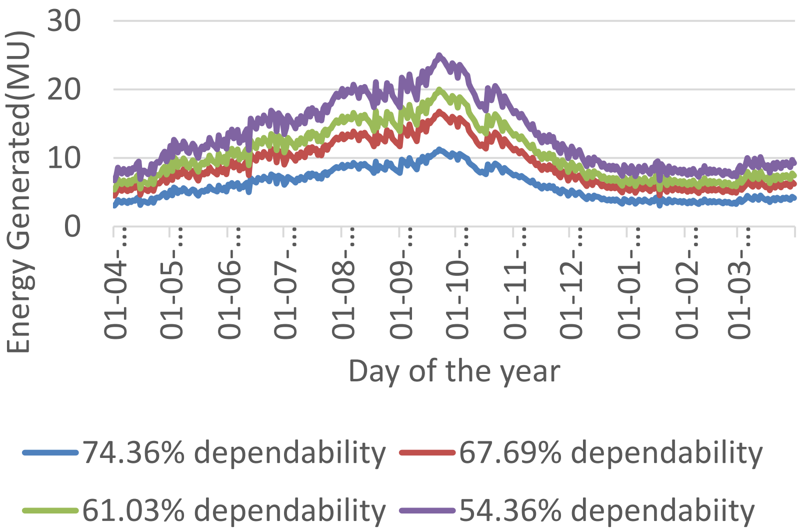
- The model is been made and solved on General Algebraic Modelling System (GAMS) software for mathematical optimization

Downstream water release from Tehri for energy generation on GAMS

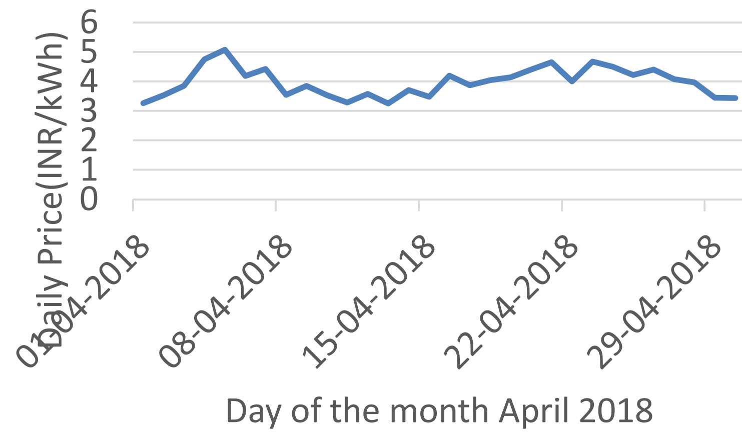
S. No.	Month	Downstream water release (Mm3)
1	January	198.36
2	February	171.77
3	March	114.83
4	April	242.50
5	May	420.95
6	June	301.09
7	July	524.49
8	August	572.34
9	September	654.39
10	October	539.27
11	November	564.18

Reliability Levels and their Energy Generation on GAMS

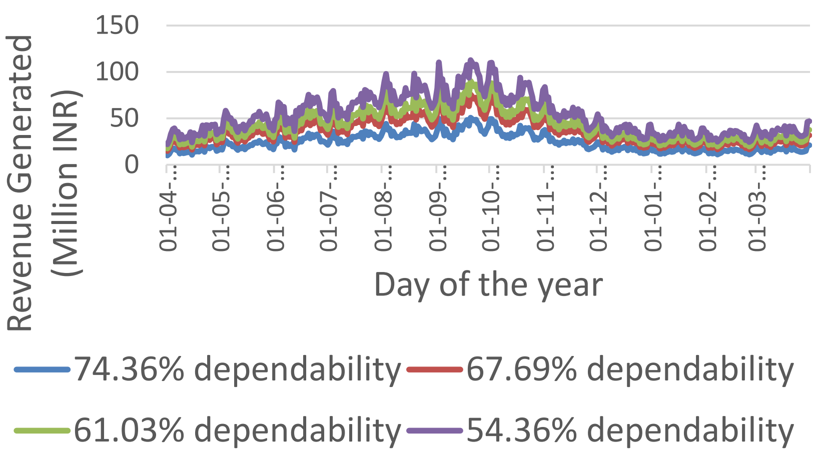
S. No.	Reliability of meeting irrigation demand (%)	Energy generated (Million units)
1	74.36	2,195
2	67.69	3,280
3	61.03	3,910
4	54.36	4,888



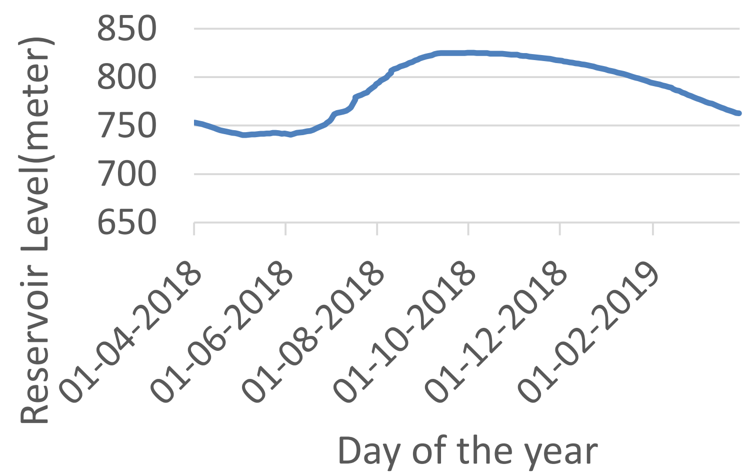
Energy generation for different dependability levels



Source: Indian Energy Exchange



Revenues For Different Reliability



Reservoir Level Variation

Ancillary Services: RRAS parameters of Tehri hydropower projects

S.No.	Parameter	Data
1	Maximum Possible Ex-bus Injection(MW)	At reservoir level EL 789.0 m – 865 MW At reservoir level EL 779.18m – 597 MW
2	Technical Minimum	125 MW
3	Fixed Cost (INR/kWh)	2.99
4	Variable Cost (INR/kWh)	2.99
5	Ramp Up rate(MW/min) for each unit	94
6	Ramp down rate(MW/min) for each unit	114

Source: Northern Regional Power Committee, New Delhi Format AS3: RRAS Provider Parameters By NRPC, 2017

Ramping up and Ramping Down for year 2018-19

Cases	Apr 2018-March 19	Regulation Up (MU)	Price for Regulation Up (Million INR)	Regulation Down (MU)	Price for Regulation Down (Million INR)
THDC generation (2,797 MU)	Energy Despatch	62.33	373.35	7.57	34.06
	Average energy despatch per day	0.16	0.71	0.02	0.10
74.36% dependability (2,195 MU)	Energy Despatch	48.91	293.00	5.94	26.73
	Average energy despatch per day	0.12	0.56	0.02	0.08
67.69% dependability (3,280 MU)	Energy Despatch	73.09	437.82	8.88	39.94
	Average energy despatch per day	0.18	0.83	0.03	0.12
61.03% dependability (3,910 MU)	Energy Despatch	87.13	521.92	10.58	47.61
	Average energy despatch per day	0.22	0.99	0.03	0.14
54.36% dependability (4,888 MU)	Energy Despatch	108.93	652.47	13.23	59.52
	Average energy despatch per day	0.28	1.24	0.04	0.18

Increase in Production(Tonnes) if water released from Tehri Dam for Irrigation

S.No.	Crops	Increase in production(tonnes)		
		Eastern Ganga Canal	Eastern Yamuna Canal	Agra Canal
1	Sugarcane	13,24,911	16,80,162	4,121
2	Wheat	42,896	58,791	31,412
3	Potato	13,647	20,617	26,418
4	Mustard	501	1,323	1,419

Price per ton for year 2018-19 Source: https://agmarknet.gov.in

S.No.	Crop	Prices (INR/tonn)
1	Sugarcane	2,750
2	Wheat	17,350
3	Potato	12,486
4	Mustard	68,456

Source: Arora and Mishra, 2017, "Role Of Tehri Dam In Increasing Food Production In Its Command Area"

Results and Discussion

%Dependability	Energy generated(MU)	Revenue generated for energy sold(Million Rs.)	Revenue generated (INR/kWh)
74.36	2,195	8,741	3.98
67.69	3,280	13,059	3.98
61.03	3,910	15,571	3.98
54.36	4,888	19,464	3.98

% Dependability	Units ramped Up (MU)	Revenue Generated (Million INR)	Per Unit Ramping Cost (INR/kWh)	Units Ramped Down(MU)	Revenue Generated (Million INR)	Per unit Ramping down cost (INR/kWh)
74.36	48.91	293.00	6	5.94	26.73	4.50
67.69	73.09	437.82	6	8.88	39.94	4.50
61.03	87.13	521.92	6	10.58	47.61	4.50
54.36	108.93	652.47	6	13.22	59.52	4.50

Dependability (%)	Energy Generated (MU)	Revenue Generated (Million INR)	Units ramped Up (MU)	Revenue Generated (Million INR)	Units Ramped Down(MU)	Revenue Generated (Million INR)	Weighted Average Price (INR/kWh)
74.36	2,195	8,741	48.91	293.00	5.94	26.73	4.20
67.69	3,280	13,059	73.09	437.82	8.88	39.94	4.20
61.03	3,910	15,571	87.13	521.92	10.58	47.61	4.20
54.36	4,888	19,464	108.93	652.47	13.22	59.52	4.20

S.No.	Canal	Water Release (cumecs)	Increase in Annual benefit due to irrigation (Million /annum)				Total increase in benefits (Million/annum)
			Sugarcane	Wheat	Potato	Mustard	
1.	EYC	31.15	3,644	744	170	34	4,592
2.	EGC	28.31	4,620	1,020	257	91	5,988
3.	AC	31.15	11	545	330	97	983

Conclusion

- Linear Optimization using Chance Constraint Method, Tehri Multipurpose Project is fulfilling the irrigation demand for more than 70% dependability and the revenue for selling electricity is INR 8,741 million per annum.
- For the required energy generation, the ancillary services provide additional revenue of INR 319.93 million per annum.
- Tehri project providing the energy services as INR 4.20 per kWh.
- Irrigation and water distribution if combinedly taken for Eastern Yamuna, East Ganga and Agra canal the benefits comes out to be INR 11,564 million or INR 4.13 per kWh.
- Clean and green energy and by converting these benefits into monetary terms these comes out to be INR 4,065 million or INR 1.45 per kWh. Thus a total INR 5.58/kWh is additional benefits.
- The services are more important for the welfare of society as well as environment from multipurpose hydropower projects.


THANK YOU

S. No.	Reliability of meeting irrigation demand (%)	Energy generated (Million units)	CO_2 emission factor ($kgCO_2$ / MWh) for coal based power plant	Emission reduction in GHG gas (tCO_2) in hydropower	Cost of reduction in GHG (INR/ tCO_2)	Additional Saving in Cost (million INR)	Additional saving in GHG reduction (INR/kWh)
1	Base	2,797	943.8	26,39,808	1,540	4,065	1.45
2	74.36	2,195	943.8	20,71,943	1,540	3,191	1.45
3	67.69	3,280	943.8	30,95,721	1,540	4,767	1.45
4	61.03	3,911	943.8	36,90,938	1,540	5,684	1.45
5	54.36	4,889	943.8	46,13,870	1,540	7,105	1.45

The cost of emission is considered to be USD 22 per tCO_2 considering 1 USD into INR 70, then per tons of CO_2 saving comes out to be 1,540 INR per tons of carbon di oxide emission reduction.