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INTERNATIONAL WATER RESOURCES ALLOCATION AND CONFLICTS
The Case of the Euphrates and the Tigris[1]

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Abstract. This paper presents a linear programming model that allocates the waters of the Euphrates and Tigris rivers to agricultural and urban uses in the three riparian countries – Turkey, Syria, and Iraq – while maximizing the net aggregate benefits from these activities while accounting for water conveyance costs. Cooperative game theory concepts (core, Shapley value) are used to identify stable water allocations, under which all three countries find it beneficial to cooperate.

1. INTRODUCTION

The Mesopotamia region, within the boundaries of Turkey, Iraq, and Syria, is populated by different ethnic, national, and religious groups, which have long fought over the control of its fertile lands. Since the early 1970's, there has been an increase in tension among these countries regarding the sharing of the waters of the Euphrates and Tigris rivers. In particular, Turkey's development of Southeastern Anatolia, with water needed for agricultural and energy production projects, has been viewed as a threat to Syria and Iraq. This water problem is likely to be exacerbated in the future because of high population growth and urban development. To help analyze these issues, this paper formulates a water allocation optimization model, that represents, in network form, the system made of the two rivers and their various consumption (agriculture, urban centers, hydropower plants) and transshipment nodes, including the possibility of transferring water from the Euphrates to the Tigris. This model maximizes the aggregate net benefits of the three countries, including the gross benefits from water uses in agriculture, urban functions, and hydroelectricity, minus the costs of water conveyance. Cooperative game theory concepts (core, Shapley value) are used to identify stable water allocations, under which all three countries find it beneficial to cooperate. These analyses are carried out under different scenarios related to future energy prices, agricultural production efficiency, and total water availability.

The remainder of the paper is organized as follows. The structure of the model is described in Section 2. The results of a benchmark application are presented in Section 3. Cooperative game theory applications are analyzed in Section 4. Section 5 concludes the paper.

2. STRUCTURE OF THE EUPHRATES AND TIGRIS RIVER BASIN MODEL (ETRBM)

The existing literature on the Euphrates and the Tigris focuses on water politics, legal analyses, and water balances, but does not provide any model for the overall optimal utilization of the basin resources. In the general water resources literature, only a few studies focus on their optimum allocation at the national and international levels. Among them, four bear connections to the ETRBM: Booker & Young (1994), Dinar &

Wolf (1994a, 1994b), and Rogers (1969, 1993). With regard to the river basin system structure, the ETRBM is similar to the model developed by Booker and Young (1994) for the Colorado river (CRIM - Colorado River Institutional Model). They use a nonlinear framework and account for salinity. Their goal is to allocate scarce water resources among states by creating a water market. In contrast, the ETRBM is designed as a linear program where water is allocated to agricultural and urban demand nodes in the three countries, subject to upper and lower limits to nodal water allocations. Rogers (1969) uses linear programming to compute the optimum benefits of different coalitions in the international setting of the Ganges, and then evaluates the results in a nonzero-sum game for two countries (East Pakistan and India). Incorporating Nepal into his analysis, Rogers (1994) outlines the applicability of cooperative game theory and Pareto frontier analyses to water resources allocation problems. The ETRBM, on the other hand, involves extensive applications of core and Shapley value analyses to the ETRB. Dinar & Wolf (1994) and Wolf and Dinar (1994) illustrate the potential of water trading among Middle East countries (mainly Egypt and Israel), accounting for political constraints. They consider coalition alternatives but do not search for core solutions.

2.1. Spatial Structure of the ETRBM

The ETRBM includes 63 demand (*i*) and 45 supply (*j*) nodes (Figures 1). The supply nodes provide water for both urban and agricultural uses, and each demand node is served by only one supply node, taken as the most accessible node. Out of the 45 ETRBM *supply* nodes, 17 are in the Euphrates basin, and 28 in the Tigris basin. Turkey has 15 supply nodes: 5 in the Euphrates and 10 in the Tigris basins. Syria has 7 supply nodes, all in the Euphrates basin. Iraq has 22 supply nodes, 4 in the Euphrates and 18 in the Tigris basins. Node 45 represents the Gulf, which is assigned to Iraq, and represents the end point of all flows downstream There are three inter-basin links, all from the Tigris to the Euphrates, with one already built (from $j=31$ to $j=16$, the Tharthar Canal – see Bilen, 1994). While one link connects Turkey to Syria (from $j=21$ to $j=12$), the other two links are located within the borders of Iraq (from $j=28$ to $j=14$ and from $j=31$ to $j=16$). Of the 63 *demand* nodes, 37 are in the Euphrates basin: 16 for urban uses and 21 for agricultural uses. Of the 26 *demand* nodes in the Tigris basin, 10 are for urban uses and

16 for agriculture uses. Syria has 16 demand nodes, all of which are in the Euphrates basin, whereas Turkey and Iraq have 13 and 8 demand nodes in the Euphrates basin, and 11 and 15 demand nodes in the Tigris basin, respectively.

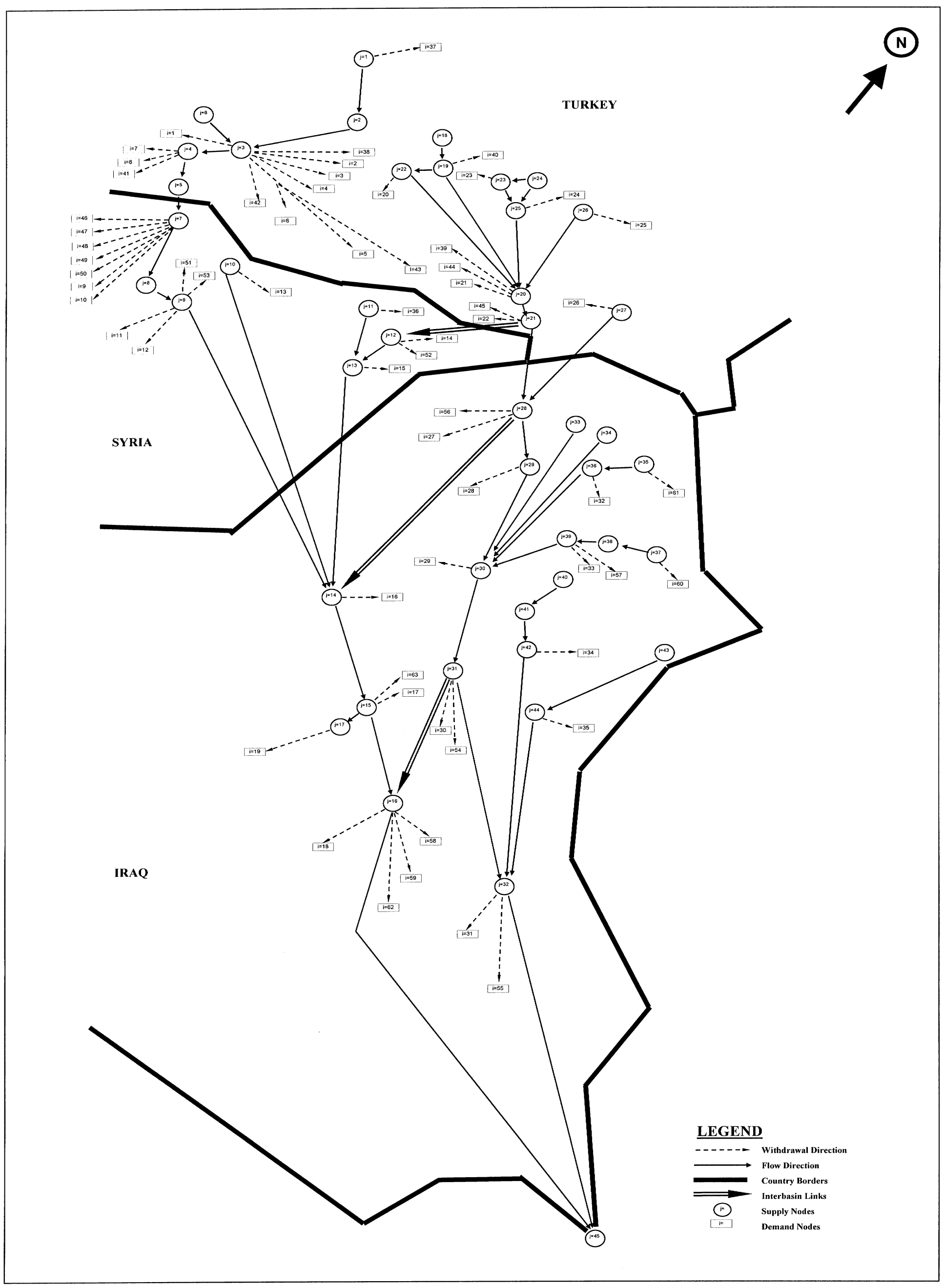

Figure 1: The Euphrates and Tigris River Basin Diagram

2.2. Mathematical Structure of the ETRBM

We first present the model equations, followed by the definitions of all the indices, variables, and parameters, and by a discussion of the objective function and constraints. The basic mode is made of Equations (1) – (10) :

Maximize

$$
\begin{aligned}
NEB = & \sum_{agr} VALAG \cdot WT_i \;\; - \sum_{j,agr} W_{j,i} \cdot DSD_{j,i} \cdot AGRTC \\
& + \sum_{urb} VALUR \cdot WT_i \;\; - \sum_{j,urb} W_{j,i} \cdot DSD_{j,i} \cdot URBTC \\
& + \sum_{j,l} EPR \cdot EG_j \cdot PQ_{j,l} \\
& - \left[(PQ_{28,14} \cdot CTSS \cdot DSS_{28,14}) + (PQ_{31,16} \cdot CTSS \cdot DSS_{31,16}) + (PQ_{21,12} \cdot CTSS \cdot DSS_{21,12}) \right]
\end{aligned} \tag{1}
$$

Subject to:

$$WT_i = \sum_j W_{j,i} \qquad i=1,\ldots,63 \tag{2}$$

$$\sum_i W_{i,j} + Q_j + REL_j = \sum_i RFR_{i,j} \cdot WT_i + TF_j + \sum_l PQ_{l,j} \qquad j=1,\ldots,45 \tag{3}$$

$$WT_i \geq SIZE_i \cdot MINAGR \qquad \forall \; i \in agr \tag{4}$$

$$WT_i \leq SIZE_i \cdot MAXAGR \qquad \forall \; i \in agr \tag{5}$$

$$WT_i \geq SIZE_i \cdot MINURB \qquad \forall \; i \in urb \tag{6}$$

$$WT_i \leq SIZE_i \cdot MAXURB \qquad \forall \; i \in urb \tag{7}$$

$$\sum_l PQ_{j,l} = Q_j \qquad \forall \; j \in inc \tag{8}$$

$$PQ_{j,l} \leq M \cdot FTRNSS_{j,l} \qquad \forall \; j \text{ and } l \tag{9}$$

$$W_{j,i} \leq M \cdot FTRNSD_{j,i} \qquad \forall \; j \text{ and } i \tag{10}$$

Indices

i:	demand nodes (1 to 63)
j & l:	supply nodes (1 to 45)
agr:	set of agricultural demand nodes
urb:	set of urban demand nodes
inc:	all supply nodes, except the Gulf

Variables

NEB:	total benefit net of transportation costs	(\$)
$PQ_{j,l}$:	internodal flow (node j to node l)	(Mm^3)
$PQ_{21,12}$:	total water transfer from Turkey to Syria through the link project 21 to 12	(Mm^3)
$PQ_{28,14}$:	total water transfer from Turkey to Iraq through the link project 28 to 14	(Mm^3)
$PQ_{31,16}$:	total water transfer from Turkey to Iraq through the link project 31 to 16	(Mm^3)
Q_j:	total water flowing out of node j towards downstream nodes	(Mm^3)
$W_{j,i}$:	water transferred from supply node j to demand node i	(Mm^3)
WT_i:	total water consumption at node i	(Mm^3)

Parameters

AGRTC:	agricultural water transport unit cost	(\$ per Mm^3-km)
URBTC:	urban water transport unit cost	(\$ per Mm^3-km)
VALAG:	agriculture water unit value	(\$ per Mm^3)
VALUR:	urban water unit value	(\$ per Mm^3)
CTSS:	internodal water transport unit cost	(\$ per Mm^3-km)
$DSD_{j,i}$:	distance from supply node j to demand node i	(km)
$DSS_{j,l}$:	distance from supply node j to supply node l	(km)
EPR:	energy price for electricity	(\$ per MWh)
EG_j:	electric generation capacities for the dam at supply node j	(MWh per Mm^3)
MINAGR:	minimum agricultural consumption rate	(Mm^3 per ha)
MAXAGR:	maximum agricultural consumption rate	(Mm^3 per ha)
MINURB:	minimum urban consumption rate	(Mm^3 per inhabitant)
MAXURB:	maximum urban consumption rate	(Mm^3 per inhabitant)
REL_j:	reservoir evaporation loss at supply node j	(Mm^3)
$RFR_{i,j}$:	return flow rates from demand node i to supply node j	
$SIZE_i$:	size of demand node i (hectare for agricultural nodes, inhabitants for urban nodes)	
TF_j:	tributary and groundwater inflows at node j	(Mm^3)
$FTRNSS_{j,l}$:	feasibility of the link from node j to l (if feasible 1, otherwise 0)	
$FTRNSD_{j,i}$:	feasibility of the link from node j to i (if feasible 1, otherwise 0)	
M:	very large number	

Let *VALAG* be the unit value of water to agriculture, and let WT_i be the water consumption at agricultural node *i*. Then the total value of the water at *i* is $VALAG \cdot WT_i$, and the total value of the water to all agricultural nodes is $\sum_{i\in agr} VALAG \cdot WT_i$. If W_{ji} is the amount of water transferred from node *j* to node *i*, DSD_{ji} the distance between the nodes, and *AGRTC* the transportation unit cost per unit distance (assumed to be spatially invariant), then the total water transport cost of getting water to node *i* is $\sum_j W_{ji} \cdot DSD_{ji} \cdot AGRTC$, and the total water transportation cost to all agricultural nodes is $\sum_{i\in agr} \sum_j W_{ji} \cdot DSD_{ji} \cdot AGRTC$. Hence the net benefits of water usage to agriculture is

$$\sum_{agr} VALAG \cdot WT_i \; - \sum_{j,agr} W_{j,i} \cdot DSD_{j,i} \cdot AGRTC \qquad (11)$$

Similarly to water used in agriculture, let *VALUR* be the unit value of water to urban uses, and let WT_i be the water consumption at urban node *i*. Then the total value of the water at *i* is $VALUR \cdot WT_i$, and the total value of the water to all urban nodes is $\sum_{i\in urb} VALAG \cdot WT_i$. If W_{ji} is the amount of water transferred from node *j* to node *i*, DSD_{ji} the distance between the nodes, and *URBTC* the transportation unit cost per unit distance (assumed to be spatially invariant), then the total water transport cost of getting water to node *i* is $\sum_j W_{ji} \cdot DSD_{ji} \cdot AGRTC$, and the total water transportation cost to all urban nodes is $\sum_{i\in urb} \sum_j W_{ji} \cdot DSD_{ji} \cdot AGRTC$. Hence the net benefits of water usage to urban centers is

$$\sum_{urb} VALUR \cdot WT_i \; - \sum_{j,urb} W_{j,i} \cdot DSD_{j,i} \cdot URBTC \qquad (12)$$

Energy benefits are measured by the market value of the energy generated by the downstream flow of water. Let *EPR* be the unit market price of water-generated energy, EG_j the quantity of energy generated at node *j* per unit of water flow, and PQ_{jl} the flow of water into downstream node *l* from node *j*. Then the value of the energy generated at *j* by releasing water to downstream node *l* is $EPR \cdot EG_j \cdot PQ_{jl}$. The total value of energy generated in the basin is then

$$\sum_{j,l} EPR \cdot EG_j \cdot PQ_{j,l} \qquad (13)$$

In the cases of interbasin water transfer links, let PQ_{jl} be the flow of water from node *j* into downstream node *l*, DSS_{jl} the distance between the supply nodes, and *CTSS* the transportation unit cost per unit distance (assumed to be spatially invariant) between the two river basins for those links. Because there are only three links, they are explicitly represented by their indices. The costs are assumed born by the country receiving the water. Let $PQ_{21,12}$ be the water flowing from Turkey to Syria, and $PQ_{28,14}$ and $PQ_{31,16}$ the water flows within Iraq. The transportation cost for link *j-l* is then $PQ_{jl} \cdot CTSS \cdot DSS_{jl}$. The total interbasin link costs are then calculated as follows:

$$(PQ_{28,14} \cdot CTSS \cdot DSS_{28,14}) + (PQ_{31,16} \cdot CTSS \cdot DSS_{31,16}) + (PQ_{21,12} \cdot CTSS \cdot DSS_{21,12}) \qquad (14)$$

Combining the benefits and costs in Equations (11) – (14) yields the objective function represented by Equation (1).

Equation (2) computes the total water delivery to demand node i, WT_i, as the sum of the deliveries W_{ji} from all *supply* nodes j to node i. The water inputs to supply node j are the tributary inflows TF_j, the return flows from the upstream withdrawals $TRFN_j$, taken as the sum of the products of return flow rates and withdrawals at node i, $\sum_i RFR_{ij} \cdot WT_i$, and water from upstream nodes l to j, $\sum_l PQ_{lj}$. The total input at node j is

$$\sum_i RFR_{i,j} \cdot WT_i + TF_j + \sum_l PQ_{l,j} \quad (15)$$

On the other hand, water leaving node j is allocated to reservoir evaporation REL_j, water withdrawal for agricultural and urban uses $W_{j,i}$, and water release to downstream nodes Q_j. Then the total amount of water leaving node j is

$$\sum_i W_{i,j} + Q_j + REL_j \quad (16)$$

Combining Equations (15) and (16) leads to the water balance constraint (3) at node j. The parameter $SIZE_i$ is a measure of the size of demand node i (either urban or agriculture), and *MINAGR*, *MINURB*, *MAXAGR*, *MAXURB* represent minimum usage rates – to sustain agricultural and urban activities – and maximum usage rates – to prevent excessive withdrawals. The total water consumption at node i, $\sum_j W_{ji}$, is noted WT_i, and is constrained by Equations (4) – (7). In Equation (8), Q_j is expressed as the sum of all water flows released from node j to downstream nodes l, equal to $\sum_l PQ_{jl}$. Equations (9) and (10) eliminates infeasible supply-to-supply and supply-to-demand node linkages by using the 0-1 parameters $FTRNSS_{jl\ \ a}$ and $FTRNSD_{jl}$..

The procedures for estimating the model input parameters are fully described in Kucukmehmetoglu (2002). They involve regional and general data sources. Supply data, including tributary and return flows, and evaporation rates, were drawn from Kolars (1986, 1992, 1994), Kliot (1994), Bagis (1989), and Altinbilek (1997). Demand data were drawn from Kolars (1992), Kliot (1994), Altinbilek (1997), the CIA (1998), Dinar and Wolf (1994), Wolf and Dinar (1994), Howitt, Mann, and Vaux (1982), and Howe and Easter (1971). Finally, transportation cost and energy data were drawn from Hirshleifer et al. (1969), Gibbons (1986), and Bilen (1994).

3. BENCHMARK MODEL APPLICATION

We assume that all three countries have the same agricultural efficiency (VALAG =$25,000 /$Mm^3$), the same energy price (EPR = $25/Mwh), and that total tributary flows are average (TTF = 81.9 Billion M^3). Table 1 presents the net overall system benefit (NEB), the gross benefits form water use (TECBW) and from energy generation (TECBE), the total water transportation costs for urban uses (TTCURB) and for agricultural uses (TTCAGR), and the cost of interbasin transfer (TTRSS). The table also includes the total tributary flows (TFT), the total reserve evaporation (RELT), the water released to the Gulf (GULF), the total water withdrawal (TWT), the total return flow (FRET), the total in-out balance (TOTBAL), the total agricultural water withdrawal (TWAGR), the minimum required total water withdrawal for agriculture (TWAGRMIN), the maximum total water withdrawal for agriculture (TWAGRMAX), the total urban water withdrawal (TWURB), the minimum required total water withdrawal for urban use (TWURBMIN), and the maximum total water withdrawal for urban use (TWURBMAX). We observe that (1) energy benefits constitute nearly 50% of overall returns, (2) return flows make up almost 50% of the water input from tributaries, and are available for reuse, and (3) total water withdrawal is very close to the total tributary flow input, whereas water released to the Gulf makes up to 35% of the total tributary inflow.

Table 1: General Summary of the Benchmark Solution

NEB	$	2,407,731,200	**TFT**	81,920	Mm^3	**TWAGR**	77,505	Mm^3
TECBW	$	2,091,003,000	**RELT**	17,750	Mm^3	**TWAGRMIN**	-	Mm^3
TECBE	$	1,175,087,800	**GULF**	28,225	Mm^3	**TWAGRMAX**	122,519	Mm^3
TTCURB	$	32,145,138	**TWT**	78,528	Mm^3	**TWURB**	1,022	Mm^3
TTCAGR	$	826,214,547	**FRET**	42,582	Mm^3	**TWURBMIN**	-	Mm^3
TTRSS	$	-	**TOTBAL**	-	Mm^3	**TWURBMAX**	1,881	Mm^3

Table 2 presents the benefits for the overall system and each country, and includes total economic benefits (TECB), total transportation costs (TTC), net economic benefits (NBEN), the ratios of economic benefits to transportation costs (R), the percentage of economic benefits by category (PTECBW: all withdrawals; PTECBE: energy; PTECBWU: withdrawals for urban uses; PTECBWA: withdrawals for agricultural uses), and the percentages of transportation costs by use (PTTCURB: urban; PTTCAGR:

agriculture; PTTRSS: inter-basin). Although the net benefits of Turkey and Iraq are close, Turkey derives most of her benefits (75%) from energy generation, and Iraq from agriculture (90%). The overall system optimization involves, first, the utilization of the energy generation potential at the upstream nodes, and then the utilization of the agricultural potential at the downstream nodes. The opportunity cost of withdrawing water at the upstream nodes is higher than that of withdrawing water at the downstream nodes. In Syria, the benefits are almost equally shared (56% for water withdrawals and 44% for energy generation). The ratios of benefits to costs show that Turkey has the lowest transport cost related to water withdrawal, and Iraq the highest. Urban transportation costs constitute a small share of total transportation costs in the whole system and in each county.

Table 2: Summary of the Components of Country Benefits

All Countries		Turkey		Syria		Iraq	
TECB	$ 3,266,090,800	**TECBt**	$ 1,161,095,600	**TECBs**	$ 294,048,029	**TECBi**	$ 1,810,947,300
TTC	$ 858,359,685	**TTCt**	$ 144,065,122	**TTCs**	$ 60,237,792	**TTCi**	$ 654,056,771
NBEN	$ 2,407,731,200	**NBENt**	$ 1,017,030,400	**NBENs**	$ 233,810,237	**NBENi**	$ 1,156,890,500
R	3.81	**Rt**	8.06	**Rs**	4.88	**Ri**	2.77
PTECBW	64.0%	**PTECBWt**	24.6%	**PTECBWs**	56.3%	**PTECBWi**	90.5%
PTECBE	36.0%	**PTECBEt**	75.4%	**PTECBEs**	43.7%	**PTECBEi**	9.5%
PTECBWU	4.7%	**PTECBWUt**	3.0%	**PTECBWUs**	2.9%	**PTECBWUi**	6.1%
PTECBWA	59.3%	**PTECBWAt**	21.6%	**PTECBWAs**	53.3%	**PTECBWAi**	84.5%
PTTCURB	3.7%	**PTTCURBt**	7.6%	**PTTCURBs**	4.7%	**PTTCURBi**	2.8%
PTTCAGR	96.3%	**PTTCAGRt**	92.4%	**PTTCAGRs**	95.3%	**PTTCAGRi**	97.2%
PTTRSS	0.0%	**PTTRSSt**	0.0%	**PTTRSSs**	0.0%	**PTTRSSi**	0.0%

Tables 3 and 4 present the optimum water allocations by country (t=Turkey, s=Syria, i=Iraq), basin (e=Euphrates, t=Tigris), and use (a=agriculture, u=urban). The highest withdrawal (61,934 Mm^3) is for agriculture in Iraq. Turkey, with the second largest agricultural land (nearly two thirds of Iraqi land), withdraws only one sixth of Iraqi withdrawal (10,263 Mm^3). Urban withdrawals (1,022 Mm^3) are significantly lower than agricultural withdrawal (77,505 Mm^3).

4. COOPERATION AND CONFLICT: GAME – THEORETIC ANALYSES

4.1. Individual and Coalition Strategies

Figure 2 illustrates country interactions under the different possible configurations of coalition/cooperation. Figure 2.a illustrates the case of independent, individual action

Table 3: Water Resources Allocation by Country, Basin, and Use

WTteu	45				
WTtea	3,402	**WTte**	3,447		
WTttu	190				
WTtta	6,626	**WTtt**	6,816	**WTt**	10,263
WTseu	58				
WTsea	6,273	**WTse**	6,331	**WTs**	6,331
WTieu	78				
WTiea	25,800	**WTie**	25,878		
WTitu	652				
WTita	35,405	**WTit**	36,057	**WTi**	61,934

Table 4: Water Resources Allocation by Country and Use

WTtu	235		
WTsu	58		
WTiu	730	**WTu**	1,022
WTta	10,028		
WTsa	6,273		
WTia	61,205	**WTa**	77,505

by each country. In Step 1, Turkey optimally utilizes the resources in its border. Next, in Step 2, Syria, taking the return flows and released water from Turkey as exogenously determined (in Step 1), optimally utilizes this exogenous input and the resources within its border. Finally, in Step 3, Iraq optimally utilizes its internal resources and the water inputs from Turkey and Syria (released and return flow waters), as determined in Steps 1 and 2. The step sequence clearly reflects the dominance of upstream countries over downstream countries. In Figure 4.b, the various two-country coalitions are presented. The *first diagram* displays the Turkish and Syrian coalition, with Iraq acting independently. In Step 1, Turkey and Syria utilizes the resources available within their territories jointly and optimally. In Step 2, Iraq optimizes the use of the resources available within its territory, together with the exogenous input from Turkey and Syria. The *second diagram* presents the Syrian and Iraqi coalition, with Turkey acting independently. In Step 1, Turkey optimally uses the available resources within its territory, and releases the unused water for the Syrian and Iraqi coalition, which takes this input as exogenous, and optimally uses all its available resources. The *last diagram* explains the interactions between the Turkey-Iraq coalition, and Syria acting independently. Because both the coalition and Syria are affected by each other's decisions and output, a stable solution is represented by a Nash equilibrium, which is reached when the sequential optimizations stop because there is no longer any change in their solutions. Figure 4.c illustrates the grand coalition, which is equivalent to the benchmark model.

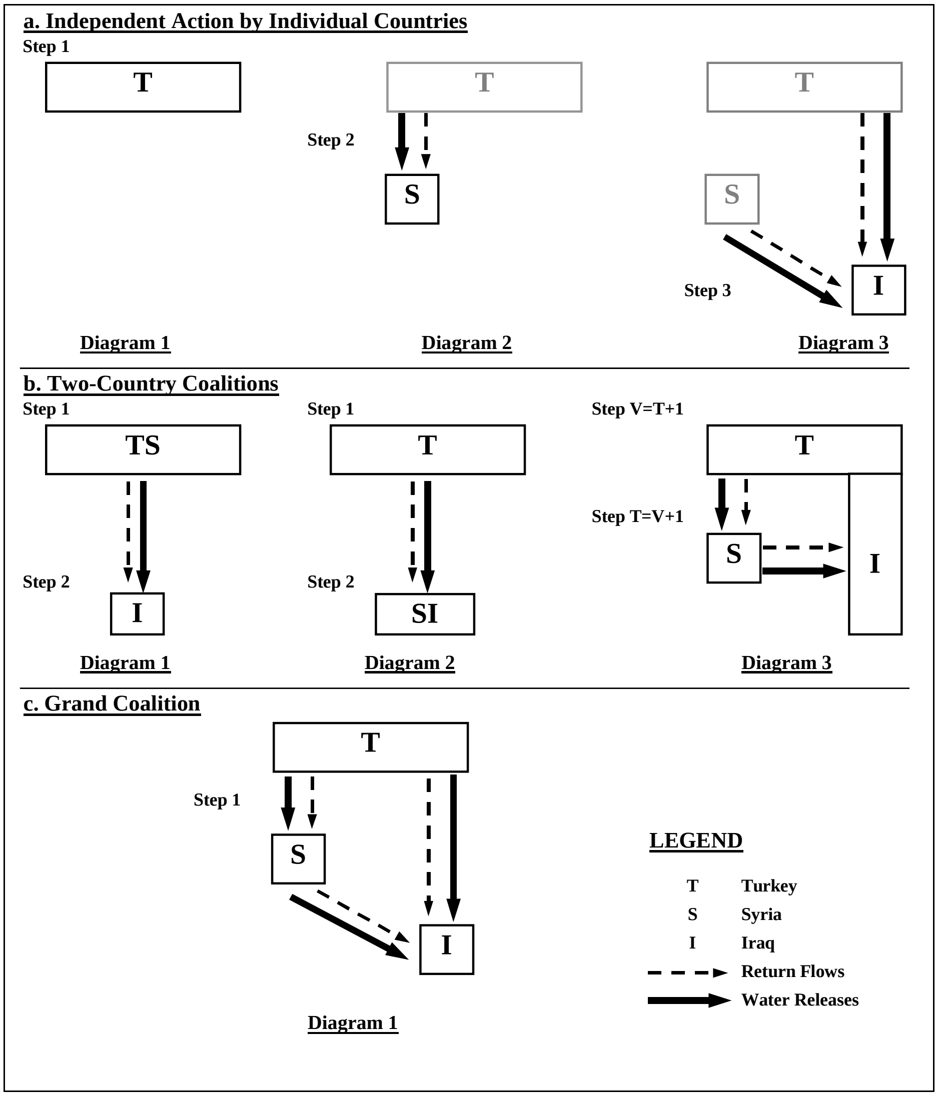

Figure 2: Country Interactions Under Different Configurations of Independence and Cooperation

The ETRBM is appropriately adjusted to reflect the optimization decisions of individual countries and coalitions of countries. The derived optimal benefits are defined below:

NEBt	net economic benefit of Turkey
NEBs	net economic benefit of Syria
NEBi	net economic benefit of Iraq
NEBts	net economic benefit of Turkey and Syria
NEBiTS	net economic benefit of Iraq given the *TS* coalition
NEBtiS	net economic benefit of Turkey and Iraq given Syria's action
NEBsTI	net economic benefit of Syria given the *TI* coalition
NEBsi	net economic benefit of Syria and Iraq
NEBtsi	net economic benefit of Turkey, Syria, and Iraq

4.2. Core, Shapley Value, and Subsidy Determination

Consider the total benefits of the grand coalition, *NEBtsi*. This is clearly the maximum aggregate benefit achievable by the three countries. The problem is to allocate this aggregate benefit among the three countries in a way that will persuade them to accept this allocation. Let X_t, X_s, and X_i be the benefits allocated to Turkey, Syria, and Iraq, respectively. This allocation should then verify that

$$X_t + X_s + X_i = NEBtsi \tag{17}$$

This allocation, to be sustainable, should verify both individual and coalition rationality constraints, so that no country acting alone or within a coalition, has an incentive to reject the allocation. The three coalition constraints are straightforwardly represented by Equations (22) – (24). The case of the individual rationality constraints is a little more complicated. Indeed, a given country c may act individually under two situations: (a) the other two countries also act individually, and (b) they act as a coalition. The benefits to country c under these two situations need not be the same. We assume that country c aims at guaranteeing to itself the minimum of these two benefits, hence the formulation of the constraints (19) – (21).

The equality (17) and inequalities (19) – (24) may or may not have a solution. In order to find out, the standard approach is to transform this system of inequalities/equality into a linear program (LP), by maximizing or minimizing any linear function of the variables (X_t, X_s, X_i). If the LP has no solution, then the system of in inequalities/equality has no solution, and the core is empty. A variation on this approach is to modify Equation (17) by introducing a new variable, *Z*, leading to Equation (25), and to use as the LP objective function *Z*. Hence, the LP is represented by Equations (18) – (25):

Maximize

$$F = Z \tag{18}$$

subject to

$$X_t \geq \min(NEBt, NEBtSI) = NEBt^{\min} \tag{19}$$

$$X_s \geq \min\left(NEBs, NEBsTI\right) = NEBs^{\min} \tag{20}$$

$$X_i \geq \min(NEBi, NEBiTS) = NEBi^{\min} \tag{21}$$

$$X_t + X_s \geq NEBts \tag{22}$$

$$X_t + X_i \geq NEBti \tag{23}$$

$$X_s + X_i \geq NEBsi \tag{24}$$

$$X_t + X_s + X_i + Z = NEBtsi \tag{25}$$

If the optimal Z^* is strictly equal to zero, then the core exists but is reduced to only one point, i.e., only one allocation is acceptable. If Z^* is positive, the core is non-empty and made of an infinite number of feasible allocations. The allocation obtained with Z^* is sustainable and allows a supra-governmental authority to extract the maximum benefits from the three countries for saving for future use. In this case, Z^* can be viewed as the maximum tax. If Z^* is negative, then the core is empty. However, if a benefit subsidy in the amount (absolute value) of Z^* were added to *NEBtsi*, then a sustainable allocation would be obtained. Hence, Z^* can be viewed as the minimum subsidy to obtain a sustainable benefit allocation.

To illustrate the application of the Shapley method, consider the case of Iraq as the player joining other coalitions. The first case is that of Iraq joining the "empty" coalitions, with the incremental benefit

$$IB_{i/\phi} = NEBi^{\min} \tag{26}$$

Next, Iraq can join either Turkey or Syria, with the incremental benefits:

$$IB_{i/t} = NEBti - NEBt^{\min} \tag{27}$$

$$IB_{i/s} = NEBsi - NEBs^{\min} \tag{28}$$

Finally, Iraq can join the Turkey-Syria coalition, with the incremental benefits:

$$IB_{i/ts} = NEBtsi - NEBts^{\min} \tag{29}$$

These incremental benefits are then weighted by the corresponding probabilities of occurrence, and the result is the Shapley allocation of benefits to Iraq.

4.3. Benefits Under Different Cooperation Scenarios

The modeling approach presented in the previous sections has been applied under each of 27 parameter scenarios, which are defined as combinations of assumptions regarding energy prices, agricultural productivities, and total water resources. These scenarios are presented in Table 5.

Table 5: Parameter Scenarios

Energy Prices (EPR)			**EPR = $0**	**EPR = $25**	**EPR = $100**
A	**Water Resources ($TTF=Bm^3$)**		**Agricultural Productivity (VALAG) Weights**		
			Turkey: 1.1	**Syria: 1.0**	**Iraq: 0.9**
	59.8	**Minimum**	A11	A12	A13
	81.9	**Average**	A21	A22	A23
	92.6	**Maximum**	A31	A32	A33
B	**Water Resources ($TTF=Bm^3$)**		**Agricultural Productivity (VALAG) Weights**		
			Turkey: 1.0	**Syria: 1.0**	**Iraq: 1.0**
	59.8	**Minimum**	B11	B12	B13
	81.9	**Average**	B21	B22	B23
	92.6	**Maximum**	B31	B32	B33
C	**Water Resources ($TTF=Bm^3$)**		**Agricultural Productivity (VALAG) Weights**		
			Turkey: 0.9	**Syria: 1.0**	**Iraq: 1.1**
	59.8	**Minimum**	C11	C12	C13
	81.9	**Average**	C21	C22	C23
	92.6	**Maximum**	C31	C32	C33

The country benefits are presented in Table 6, which is organized along the model Table 5. Table 6 presents the benefits for each country and the total benefit (column) for each cooperation scenario: all countries making individual choices (IND) and countries making choices within coalitions (TS, TI, SI, TSI - row). In the cases of two-country coalitions, Table 6 also provides the benefits for the remaining country (which are marked with an underline in the table). The cases where the benefits are the same for all cooperation scenarios (IND, TS, TI, SI, TSI) are bold-typed. Italic types are used in the total benefit column to indicate cooperation scenarios where total benefits are equal to those of the grand coalition (TSI). The cases where a country achieves less than 95% of its maximum possible benefits are highlighted, pointing to significant adverse effects. For instance, under parameter scenarios A32, Syria achieves a benefit of $ 239,928,000 under coalition TI, which represents about 93% of its maximum benefit of $ 258,236,000 under the grand coalition (TSI). As expected, Table 6 points to benefits increasing with (a) increasing energy prices (EPR=\$0 $\rightarrow$ \$25 $\rightarrow$ \$100), (b) increasing resources availability (TTF=59.8 $\rightarrow$ 81.9 $\rightarrow$ 92.6 Bm^3), and (c) a shift of agricultural productivity from Turkey (case A) to Iraq (case C). For instance, the maximum benefit under scenario A11 of \$1,139,167,000 increases to \$7,004,740,000 under scenario C33. The scenarios A31 and B31, corresponding to zero energy price and highest resources availability, lead to the same solution under all five cooperation scenarios (IND, TS, TI, SI, TSI), of course implying a core made of one point only. When EPR=\$0, the difference between the 5 cooperation scenarios (for each parametric scenario) are very small in terms of total benefits, except in the case C11 (\$1,280,585 vs. \$1,301,699,000). Larger differences take place, for individual countries (Syria and Iraq) and in total, when EPR is higher. The largest relative adverse effects (highlights) characterize Syria when EPR=\$25.

4.4. Core Analyses and Shapley Allocations

This section presents the results obtained by (1) solving the linear program, and (2) applying the Shapley formula. For each of the 27 different parameter scenarios, we first find out whether the core exists, and, if it does, whether it is reduced to a unique allocation. If it does not, we measure the minimum subsidy needed to create a core. Finally, we check whether the Shapley allocations are in the core. Tables 7-12 present the results.

In Table 7 the highlighted cells indicate the cases where there is no core. Out of the 27 cases, 6 have no core (B22, B32, C22, C32, C23, C33), 12 have a single-allocation core, and 9 have a multiple-allocation core (i.e., there is an infinite number of allocations in the core). A core always exists under (1) EPR=\$0, and (2) agricultural productivity case A (Turkey is more productive). Most of the non-core cases take place when Iraq is more productive (case C), when EPR=\$25 or \$100, and when resources are more abundant. This is not surprising, as these situations allow individual countries to achieve higher benefits on their own (agriculture for Iraq, energy for Turkey), making it more difficult to achieve a sustainable allocation.

Table 8 presents the optimal values of the *Z* variable in the linear program. Positive *Z* values characterize multiple-allocation cores, and present the maximum extractable taxes leading to a residual single-allocation core. Negative *Z* values

Table 6: Benefits Under Different Cooperation Scenarios ($1000)

Coalition	Turkey	Syria	Iraq	Total	Turkey	Syria	Iraq	Total	Turkey	Syria	Iraq	Total
IND	**254,509**	98,918	784,656	1,138,083	775,635	176,124	889,146	1,840,906	2,642,012	457,449	1,231,575	4,331,037
TS	**254,509**	98,918	784,656	1,138,083	773,714	183,244	896,653	*1,853,611*	2,640,174	469,890	1,206,183	4,316,247
TI	**254,509**	98,918	784,656	1,138,083	771,297	164,937	894,049	1,830,282	2,632,618	457,449	1,253,120	*4,343,187*
SI	**254,509**	98,721	785,937	*1,139,167*	775,635	176,124	889,146	1,840,906	2,642,012	457,449	1,231,575	4,331,037
TSI	**254,509**	98,721	785,937	*1,139,167*	773,714	183,244	896,653	*1,853,611*	2,632,618	457,449	1,253,120	*4,343,187*
IND	**255,532**	105,423	830,594	1,191,550	1,044,020	226,690	1,002,314	2,273,025	3,712,484	640,196	1,568,091	5,920,771
TS	**255,532**	105,423	830,594	1,191,550	1,042,099	233,810	1,003,879	*2,279,789*	3,710,646	652,638	1,542,133	5,905,417
TI	**255,532**	105,423	830,594	1,191,550	1,039,682	215,502	1,008,804	2,263,988	3,703,090	640,196	1,589,636	*5,932,922*
SI	**255,532**	105,226	831,490	*1,192,248*	1,044,020	226,690	1,002,314	2,273,025	3,712,484	640,196	1,568,091	5,920,771
TSI	**255,532**	105,226	831,490	*1,192,248*	1,042,099	233,810	1,003,879	*2,279,789*	3,703,090	640,196	1,589,636	*5,932,922*
IND	**256,024**	**108,570**	**834,049**	***1,198,643***	1,173,617	251,116	1,043,653	2,468,385	4,229,395	728,459	1,728,899	6,686,753
TS	**256,024**	**108,570**	**834,049**	***1,198,643***	1,171,696	258,236	1,045,218	*2,475,149*	4,227,557	740,901	1,702,942	6,671,399
TI	**256,024**	**108,570**	**834,049**	***1,198,643***	1,169,278	239,928	1,050,142	2,459,349	4,220,000	728,459	1,750,444	*6,698,904*
SI	**256,024**	**108,570**	**834,049**	***1,198,643***	1,173,617	251,116	1,043,653	2,468,385	4,229,395	728,459	1,728,899	6,686,753
TSI	**256,024**	**108,570**	**834,049**	***1,198,643***	1,171,696	258,236	1,045,218	*2,475,149*	4,220,000	728,459	1,750,444	*6,698,904*
IND	**212,941**	98,918	904,815	1,216,675	749,007	172,056	1,033,616	1,954,679	2,635,033	457,449	1,366,866	4,459,348
TS	**212,941**	98,918	904,815	1,216,675	748,895	183,244	1,030,162	1,962,301	2,628,745	469,890	1,342,690	4,441,326
TI	**212,941**	98,918	904,815	1,216,675	749,007	172,056	1,033,616	1,954,679	2,629,855	457,449	1,390,718	4,478,022
SI	**212,941**	98,721	907,023	*1,218,684*	749,007	172,056	1,033,616	1,954,679	2,635,033	453,986	1,370,392	4,459,411
TSI	**212,941**	98,721	907,023	*1,218,684*	741,320	187,752	1,038,348	*1,967,419*	2,629,855	453,986	1,394,244	*4,478,085*
IND	**213,715**	105,423	982,204	1,301,342	1,017,142	222,622	1,163,380	2,403,145	3,705,255	640,196	1,721,102	6,066,553
TS	**213,715**	105,423	982,204	1,301,342	1,017,030	233,810	1,156,891	*2,407,731*	3,698,967	652,638	1,695,145	6,046,749
TI	**213,715**	105,423	982,204	1,301,342	1,017,142	222,622	1,163,380	2,403,145	3,699,303	640,196	1,745,808	*6,085,308*
SI	**213,715**	105,226	983,746	*1,302,687*	1,017,142	222,622	1,163,380	2,403,145	3,705,255	640,196	1,721,102	6,066,553
TSI	**213,715**	105,226	983,746	*1,302,687*	1,017,030	233,810	1,156,891	*2,407,731*	3,699,303	640,196	1,745,808	*6,085,308*
IND	**214,086**	**108,570**	**987,320**	***1,309,976***	1,146,619	247,048	1,204,978	2,598,645	4,222,046	728,459	1,882,171	6,832,675
TS	**214,086**	**108,570**	**987,320**	***1,309,976***	1,146,507	258,236	1,198,489	*2,603,232*	4,215,758	740,901	1,856,213	6,812,871
TI	**214,086**	**108,570**	**987,320**	***1,309,976***	1,146,619	247,048	1,204,978	2,598,645	4,215,723	728,459	1,907,287	*6,851,469*
SI	**214,086**	**108,570**	**987,320**	***1,309,976***	1,146,619	247,048	1,204,978	2,598,645	4,222,046	728,459	1,882,171	6,832,675
TSI	**214,086**	**108,570**	**987,320**	***1,309,976***	1,146,507	258,236	1,198,489	*2,603,232*	4,215,723	728,459	1,907,287	*6,851,469*
IND	173,876	88,148	1,018,560	1,280,585	728,713	172,056	1,167,286	2,068,056	2,631,268	457,449	1,526,771	4,615,487
TS	171,373	98,918	1,024,975	1,295,266	721,211	187,752	1,176,901	*2,085,863*	2,620,530	469,890	1,504,043	4,594,463
TI	173,876	88,148	1,018,560	1,280,585	728,713	172,056	1,167,286	2,068,056	2,629,855	457,449	1,529,077	4,616,381
SI	173,876	87,951	1,023,206	1,285,033	728,713	172,056	1,167,286	2,068,056	2,631,268	453,986	1,531,775	4,617,029
TSI	153,629	98,721	1,049,350	*1,301,699*	721,211	187,752	1,176,901	*2,085,863*	2,629,855	453,986	1,534,082	*4,617,923*
IND	174,400	94,653	1,130,390	1,399,443	996,598	222,622	1,318,002	2,537,222	3,701,240	640,196	1,895,658	6,237,094
TS	171,897	105,423	1,133,814	1,411,135	989,096	238,318	1,312,503	*2,539,917*	3,690,502	652,638	1,869,701	6,212,840
TI	174,400	94,653	1,130,390	1,399,443	996,598	222,622	1,318,002	2,537,222	3,699,303	640,196	1,898,820	*6,238,319*
SI	174,400	94,456	1,132,579	1,401,434	996,598	222,622	1,318,002	2,537,222	3,701,240	640,196	1,895,658	6,237,094
TSI	171,897	105,226	1,136,003	*1,413,126*	989,096	238,318	1,312,503	*2,539,917*	3,699,303	640,196	1,898,820	*6,238,319*
IND	174,651	97,800	***1,140,591***	1,413,043	1,125,954	247,048	1,359,860	2,732,863	4,217,910	728,459	2,056,987	7,003,356
TS	172,148	108,570	***1,140,591***	*1,421,310*	1,118,452	262,744	1,354,361	*2,735,557*	4,207,172	740,901	2,031,030	6,979,102
TI	174,651	97,800	***1,140,591***	1,413,043	1,125,954	247,048	1,359,860	2,732,863	4,215,723	728,459	2,060,558	*7,004,740*
SI	174,651	97,800	***1,140,591***	1,413,043	1,125,954	247,048	1,359,860	2,732,863	4,217,910	728,459	2,056,987	7,003,356
TSI	172,148	108,570	***1,140,591***	*1,421,310*	1,118,452	262,744	1,354,361	*2,735,557*	4,215,723	728,459	2,060,558	*7,004,740*

characterize non-existing core, and represent the minimum subsidies that would have to be added to the grand coalition benefits to create a single-allocation core. Finally, zero Z values characterize single-allocation cores. Table 8 shows that positive Z values vary between 0.00% and 0.99% of the grand coalition benefits, whereas negative Z values vary between 0.00% and 0.06% of these benefits.

Table 7 also indicates whether the Shapley allocation is in the core or not. When energy is not a factor (EPR=$0), all Shapley allocations are in the core. On the other hand, in the third column (EPR=$100) none of the Shapley allocations are in core. This is so because, under high energy prices, the Shapley method assigns more power to Turkey and Syria, and less to Iraq, hence assigns more benefits to Turkey and Syria, thus putting the allocation out of the core.

Table 7: Core Analysis Summary

	Core Existence	Single or Multiple Core	Shapley in or out of the Core		Core Existence	Single or Multiple Core	Shapley in or out of the Core		Core Existence	Single or Multiple Core	Shapley in or out of the Core
A11	YES	Single	IN	**A12**	YES	Multiple	IN	**A13**	YES	Single	NOT IN
A21	YES	Single	IN	**A22**	YES	Multiple	NOT IN	**A23**	YES	Single	NOT IN
A31	YES	Single	IN	**A32**	YES	Multiple	NOT IN	**A33**	YES	Single	NOT IN
B11	YES	Single	IN	**B12**	YES	Multiple	IN	**B13**	YES	Multiple	NOT IN
B21	YES	Single	IN	**B22**	NO			**B23**	YES	Single	NOT IN
B31	YES	Single	IN	**B32**	NO			**B33**	YES	Single	NOT IN
C11	YES	Multiple	IN	**C12**	YES	Multiple	IN	**C13**	YES	Multiple	NOT IN
C21	YES	Multiple	IN	**C22**	NO			**C23**	NO		
C31	YES	Single	IN	**C32**	NO			**C33**	NO		

The highlighted areas show the cases without a core.

Table 8: Core Analyses: Taxes versus Subsidies (in Parenthesis) and their Percentages of the Grand Coalition Benefits ($1000)

Scenario	Tax/Subsidy Z	Z/B (%)	Grand Coalition Benefit (B)	Scenario	Tax/Subsidy Z	Z/B (%)	Grand Coalition Benefit (B)	Scenario	Tax/Subsidy Z	Z/B (%)	Grand Coalition Benefit (B)
A11	0	0.00	1,139,167	**A12**	7,507	0.40	1,853,611	**A13**	0	0.00	4,343,187
A21	0	0.00	1,192,248	**A22**	1,565	0.07	2,279,789	**A23**	0	0.00	5,932,922
A31	0	0.00	1,198,643	**A32**	1,565	0.06	2,475,149	**A33**	0	0.00	6,698,904
B11	0	0.00	1,218,684	**B12**	5,118	0.26	1,967,419	**B13**	63	0.00	4,478,085
B21	0	0.00	1,302,687	**B22**	(951)	-0.04	2,407,731	**B23**	0	0.00	6,085,308
B31	0	0.00	1,309,976	**B32**	(951)	-0.04	2,603,232	**B33**	0	0.00	6,851,469
C11	12,847	0.99	1,301,699	**C12**	9,614	0.46	2,085,863	**C13**	366	0.01	4,617,923
C21	5,416	0.38	1,413,126	**C22**	(1,402)	-0.06	2,539,917	**C23**	(239)	0.00	6,238,319
C31	0	0.00	1,421,310	**C32**	(1,402)	-0.05	2,735,557	**C33**	(160)	0.00	7,004,740

Table 9 presents the allocations corresponding to (1) the minimum country benefits, (2) the single core solution (possibly with subsidies), and (3) the Shapley method. Tables 10 and 11 point to the incremental benefits derived by each country joining the grand coalition or accepting the Shapley allocation, respectively, over the minimum benefits derived from individual action. It is clear that Iraq is the major beneficiary of these allocations when the energy price is highest (EPR=$100), with Turkey as a significant secondary beneficiary when Turkey's agricultural productivity is also highest (case A). However, Turkey's incremental benefits are strongly reduced under Iraq's strong agricultural productivity (case C). The incremental benefits to Syria are strong when all productivities are equal (case B) and EPR=$25.

Table 9: Minimum Benefit, Core, Shapley, and Tax Allocations ($1000)

Allocation	Turkey	Syria	Iraq	Turkey	Syria	Iraq	Turkey	Syria	Iraq
Minimum	254,509	98,918	784,656	775,635	164,937	889,146	2,642,012	457,449	1,206,183
Core	254,509	100,002	784,656	776,199	180,759	889,146	2,652,616	457,449	1,233,123
Shapley	254,509	99,460	785,198	782,695	177,309	893,607	2,654,087	463,448	1,225,652
Z	0	0	0	3,170	718	3,619	0	0	0
Minimum	255,532	105,423	830,594	1,044,020	215,502	1,002,314	3,712,484	640,196	1,542,133
Core	255,532	106,121	830,594	1,046,172	229,738	1,002,314	3,723,087	640,196	1,569,638
Shapley	255,532	105,772	830,943	1,049,365	225,365	1,005,059	3,724,653	646,290	1,561,979
Z	0	0	0	720	155	690	0	0	0
Minimum	256,024	108,570	834,049	1,173,617	239,928	1,043,653	4,229,395	728,459	1,702,942
Core	256,024	108,570	834,049	1,175,768	254,164	1,043,653	4,239,998	728,459	1,730,447
Shapley	256,024	108,570	834,049	1,178,961	249,791	1,046,398	4,241,564	734,552	1,722,788
Z	0	0	0	745	158	662	0	0	0
Minimum	212,941	98,918	904,815	749,007	172,056	1,030,162	2,635,033	457,449	1,342,690
Core	212,941	100,928	904,815	752,461	179,678	1,030,162	2,641,187	457,449	1,379,386
Shapley	212,941	99,923	905,820	755,675	178,725	1,033,019	2,649,425	462,535	1,366,125
Z	0	0	0	1,966	465	2,687	37	6	19
Minimum	213,715	105,423	982,204	1,017,142	222,622	1,156,891	3,705,255	640,196	1,695,145
Core	213,715	106,768	982,204	1,022,680	228,160	1,157,842	3,711,408	640,196	1,733,703
Shapley	213,715	106,096	982,877	1,021,599	227,079	1,159,054	3,719,984	645,548	1,719,776
Z	0	0	0				0	0	0
Minimum	214,086	108,570	987,320	1,146,619	247,048	1,198,489	4,222,046	728,459	1,856,213
Core	214,086	108,570	987,320	1,152,157	252,586	1,199,440	4,228,199	728,459	1,894,810
Shapley	214,086	108,570	987,320	1,151,075	251,505	1,200,652	4,236,794	733,811	1,880,864
Z	0	0	0				0	0	0
Minimum	173,876	88,148	1,018,560	728,713	172,056	1,167,286	2,631,268	457,449	1,504,043
Core	177,695	92,596	1,018,560	728,713	180,250	1,167,286	2,631,796	458,625	1,527,137
Shapley	180,810	97,305	1,023,584	736,014	179,358	1,170,491	2,635,787	462,291	1,519,845
Z	1,785	960	10,103	3,392	827	5,395	209	37	120
Minimum	174,400	94,653	1,130,390	996,598	222,622	1,312,503	3,701,240	640,196	1,869,701
Core	180,675	96,645	1,130,390	1,000,695	226,719	1,313,905	3,702,704	640,436	1,895,419
Shapley	179,675	100,924	1,132,527	999,778	225,802	1,314,336	3,706,462	644,807	1,887,050
Z	689	387	4,341						
Minimum	174,651	97,800	1,140,591	1,125,954	247,048	1,354,361	4,217,910	728,459	2,031,030
Core	174,651	106,067	1,140,591	1,130,051	251,145	1,355,764	4,219,454	728,619	2,056,827
Shapley	178,785	101,934	1,140,591	1,129,135	250,228	1,356,194	4,223,212	733,069	2,048,458
Z	0	0	0						

Z shows the allocation of the tax, using as weights the Shapley values, and provides additional country benefits, which may be added to the core allocations.

Table 10: Core Allocations Minus Minimum Country Benefits ($1000)

Scenario	Turkey	Syria	Iraq	Scenario	Turkey	Syria	Iraq	Scenario	Turkey	Syria	Iraq
A11	0	1,084	0	**A12**	565	15,822	0	**A13**	10,604	0	26,940
A21	0	698	0	**A22**	2,151	14,236	0	**A23**	10,603	0	27,505
A31	0	0	0	**A32**	2,151	14,236	0	**A33**	10,603	0	27,505
B11	0	2,010	0	**B12**	3,454	7,622	0	**B13**	6,154	0	36,696
B21	0	1,345	0	**B22**	5,538	5,538	951	**B23**	6,153	0	38,558
B31	0	0	0	**B32**	5,538	5,538	951	**B33**	6,153	0	38,597
C11	3,819	4,448	0	**C12**	0	8,193	0	**C13**	528	1,176	23,094
C21	6,275	1,992	0	**C22**	4,097	4,097	1,402	**C23**	1,464	239	25,718
C31	0	8,267	0	**C32**	4,097	4,097	1,402	**C33**	1,544	160	25,798

The highlighted area shows where the side payments go.

6. CONCLUSION

The major contribution of this paper is, first, the development of the ETRBM as a backbone model, and, second, its application, using the best available data, to analyses of whether it is possible to find a distribution of the total ETRBM benefits to the three riparian countries – Turkey, Syria, and Iraq – that will provide them incentives to join the

Table 11: Shapley Allocations Minus Minimum Country Benefits ($1000)

Scenario	Turkey	Syria	Iraq	Scenario	Turkey	Syria	Iraq	Scenario	Turkey	Syria	Iraq
A11	0	542	542	**A12**	7,060	12,372	4,461	**A13**	12,075	5,999	19,469
A21	0	349	349	**A22**	5,344	9,863	2,745	**A23**	12,169	6,093	19,846
A31	0	0	0	**A32**	5,344	9,863	2,745	**A33**	12,169	6,094	19,846
B11	0	1,005	1,005	**B12**	6,668	6,668	2,858	**B13**	14,392	5,086	23,434
B21	0	672	672	**B22**	4,457	4,456	2,163	**B23**	14,729	5,352	24,631
B31	0	0	0	**B32**	4,456	4,456	2,163	**B33**	14,748	5,352	24,650
C11	6,933	9,157	5,024	**C12**	7,301	7,301	3,205	**C13**	4,519	4,843	15,802
C21	5,275	6,271	2,137	**C22**	3,180	3,180	1,833	**C23**	5,223	4,610	17,350
C31	4,133	4,133	0	**C32**	3,180	3,180	1,833	**C33**	5,302	4,610	17,429

water allocation plan that provides the maximum aggregate benefits. This assessment has required an in-depth analysis of the decision-making processes of the three countries and any of their coalitions, through extensive adaptations of the ETRBM. Using concepts and methods of cooperative game theory, we find that, out of the 27 parameter scenarios considered, 21 were characterized by a non-empty core, where such cooperation can be rationally induced. The 6 empty-core cases can be transformed into core cases with a small subsidy, at most 0.06% of the total joint benefit. These cases correspond to high energy prices and high Iraqi agricultural productivity, which clearly strongly benefit Turkey and Iraq acting independently. The Shapley allocation, which is based on the incremental economic power of the participants, also reflects these energy and agricultural productivity effects.

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