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福島第一原発建屋内のたまり水の放射性汚染状況の解析（4）

大坪　国順

概要

本稿は、福島第一原発建屋内のたまり水の放射性汚染について2017年10月末までの状況を明らかにしようとするものである。東京電力からの原子炉建屋内のたまり水の貯蔵および処理の現状についての報告を整理した結果、この一年間で新たに判明したことは以下のようである。

（1）原子炉冷却に伴う放射性汚染水の処理は順調に進んでいる。現在、一時貯蔵タンクに貯留されている約100万m^3の汚染水の約78%は、トリチウムを除く全ての放射性物質が除去された状態にある。2018年内にはその比率は100％になる見込みである。

（2）前報では、一定値に落ち着いてきていたセシウム137とトリチウムの放射線強度が、2016年4月上旬（第250週辺り）から再び下降し始めたと報告した。しかし、2016年10月下旬（第280週辺り）以降、両者の放射線強度の上昇が続いている。特に、トリチウムにおいては初期濃度の約1/3にまで急上昇している。上昇の主な要因は、建屋に流入する地下水量を120m^3/dayまで絞りこんだためと考えられる。セシウム137については放射線強度上昇の対策が講じられつつあるが、トリチウムについては対策がない。

（3）塩素イオン濃度については、2014年11月下旬（第180週辺り）には約300ppm程度に落ち着いたものが、一時、960ppmまで上昇した。2016年1月中旬（第240週辺り）から再び低下し始め、その後現在まで200～400ppm前後で変動を続けている。これは建屋に流入する地下水の塩素イオン濃度を反映しているものと考えられる。

Analysis of time variations of radioactive substances in the water accumulated at the bottom of the main buildings of the Fukushima Daiichi Nuclear Power Plant (4)

Kuninori Otsubo

Abstract

This paper shows the latest results of weekly variations of radio-active substances in the water accumulated at the bottom of the main buildings of the Fukushima Daiichi Nuclear Power Plant. It has passed almost one year from the previous publishing of my paper on this issue. During the period, the weekly data of cesium 137, tritium, and chloride ion of the accumulated water have been kept reported by Tokyo Electric Power Co. Ltd. The weekly variations of the three parameters have shown the following new tendencies.

(1) At present, from about 78% contaminated water reserved in the temporary reserving tanks, all radioactive substances except for tritium have been removed.

(2) The strengths of radiation of cesium 137 and tritium began to increase as of October 2016 and kept increasing until now. Especially the degree of increase of tritium has been remarkable. The cause of those increases was recognized that the amount of groundwater flowing into the main buildings has been decreased to 120m³/day from 400m³/day, almost one-fourth. As for cesium137, a countermeasure was begun to be taken; however, as for tritium, there was no effective countermeasure for the increase.

(3) The concentration of chloride ion began to decrease again on Jan. 2016 and has been varying between 200ppm and 400ppm until now, although it had increased up to 960ppm at a certain time. It was found that main cause of those behaviors was the variation of chloride ion concentration of the groundwater flowing into the main buildings.

福島第一原発建屋内のたまり水の放射性汚染状況の解析（4）

1．はじめに

2011年3月11日から既に6年半が過ぎた。本稿は、福島第一原発建屋内のたまり水の放射性汚染水について2017年10月末までの状況を明らかにしようとするものである。前稿の発表から約1年経過し、放射性汚染水に関して前報までの考察をさらに裏付ける観測データや考察内容に変更を迫られる観測データも公表され、これらについて整理して考察を加えた。

本稿での検討に使われたデータについては全て東京電力から公表されているものである。原子炉建屋内の地下に存在する水（たまり水と呼ばれる）の汚染状況については、東京電力からプレス・リリース資料として毎週公表されている。その資料には、毎週の冷却水量と処理水量（セシウム137と塩分）、地表一時貯蔵タンク内の汚染水の累積貯蔵量、併せて、たまり水のセシウム137の放射能（ここでは放射線強度と呼称）や塩素イオン濃度が公表されている[1)]。たまり水のトリチウム放射性強度については、「福島第一原子力発電所周辺の放射性物質の分析結果―水処理設備の放射能濃度測定結果―」として毎月インターネット上で更新されている[2)]。

これらのデータを整理し、2017年10月までのセシウム137とトリチウムの放射線強度や塩素イオン濃度の時間変化について、この一年間で新たに判明したことを中心に検討を加えることとする。

2．直面している問題

（1）原発事故が直接原因の地下水の汚染問題

原子炉建屋の海側（東側）においてタービン建屋（以下、T/Bと呼ぶ）と地下で連結しているトレンチは、試行錯誤の結果ようやく特殊なセメントで埋め立てられてT/Bとの水の行き来が遮蔽された。トレンチ内に満杯状態にまで貯まっていた高濃度放射能汚染水は、高温焼却炉建屋（集中廃棄物処理建屋の一つ、以下、HTIと呼ぶ）に移送され既存のルートで放射性物質の処理がなされ、除去は2015年12月に完了した[3)]。依然、T.P.+2.5m（O.P.+4.0m）地盤に存在する複数の観測井で高放射性強度のトリチウム、ストロンチウム、全βが検知されており、一部の観測井では放射線強度は告示強度を超えており、強度が必ずしも低減傾向にない観測井もある。東京電力としては海側遮水壁を構築して汚染地下水の港湾への流出を防ぐ対策を取っている。また、汲み上げられた汚染地下水はトリチウム以外の放射性物質は除去され一時貯留タンクに貯留される。

（2）原子炉冷却に伴う放射性汚染水の問題

増え続ける汚染水については、多核種放射性物質除去設備（以下、ALPS等と呼ぶ）の増設がなされ、トリチウム以外の多種の放射性物質が除去された汚染水の量は、変動はあるものの平均480m³/dayで推移している。2017年7月現在、ALPS等による処理水（トリチウム以外の大半の放射性物質が除去された汚染水）は約78万m³、ストロンチウム処理水（塩分とセシウムとストロンチウムが除去された汚染水）は約20万m³となっている[4)]。（なお、今回の公開資料によれば、2016年度7月時点でのALPS等による処理水量は約68万m³、ストロンチウム処理水は約18万m³となっている。）

除去された各種の放射性物質は消滅したわけではなく、濃縮固形化されたものに形態を変えただけで、その量は汚染水の処理量に比例して増加している。

(3) 処理水の漏洩問題

一時貯蔵タンクの構造もボルト締め式から溶接式のものへの移行が進んでおり、一時貯蔵タンクからの漏洩事故件数も減って来ている。2018年度中に全ての貯蔵タンクを溶接式にする計画である。また、原子炉建屋屋上に貯まった雨水が放射能汚染されそれが排水溝に流れ出すという問題への対策も進んでいる。

(4) 一時貯蔵タンクの増加問題

ALPS等でも汚染水からトリチウムの除去はできないので、敷地内にはトリチウム汚染水が一時貯蔵タンクに保管され、その量は合計で78万m^3に及び、今後も増え続ける。一時貯蔵タンクを設置する場所に余裕がなくなってきており、原子力規制委員会はこの問題が汚染水処理関係で唯一リスクが増大している問題と位置づけている[5)]。

(5) 凍結工法による陸側遮水壁構築工事にかかる問題

地下水の原子炉建屋（以下、R/Bと呼ぶ）やT/Bへの流入を防ぐため、凍結工法で陸側遮水壁（以下、凍土壁と呼ぶ）を作り原子炉建屋周辺を取り囲む工事が行われた。

2016年12月から西側（山側）でも凍結工事が開始され、2017年6月時点で一部区間を除いて凍結はほぼ完結したという報告がなされている[6)]。最新情報として、東京電力は「福島第1原発1～4号機の周囲約1.5kmの凍土壁について、2017年11月3日までに、8月下旬に冷却を始めた建屋西側の7mの区間を含めて地中の温度がおおむね0℃以下に下がった。」と発表した[7)]。

(6) 廃炉作業に携わる職員の放射線被爆問題

東京電力によれば、一般作業服等で作業が可能なエリアは2017年3月に構内面積の約95%に拡大した。また、給食センター・大型休憩所・協力企業棟の運用が開始され、労働環境の改善が図られている[8)]。

(7) 燃料デブリの取り出しにかかる問題

東京電力は、燃料デブリに関する情報や燃料デブリ取り出しに必要な技術開発等が未だ限定的であることから、現時点で燃料デブリ取り出しを検討するには未だ不確実性が大きいとしながらも、現時点では、アクセス性の観点から、原子炉格納容器底部には横からアクセスする工法、原子炉圧力容器内部には上からアクセスする工法を前提に検討を進めることとするとしている[9)]。

①気中工法に重点を置いた取組

原子炉格納容器上部止水の技術的難度と想定される作業時の被ばく量を踏まえると、現時点で冠水工法は技術的難度が高いため、より実現性の高い気中工法に軸足を置いて今後の取組を進めることとする。

なお、冠水工法については、放射線の遮へい効果等に利点があること等を考慮し、今後の研究開発の進展状況を踏まえ、将来改めて検討の対象とすることも視野に入れる。

②原子炉格納容器底部に横からアクセスする燃料デブリ取り出しの先行

各号機においては、原子炉格納容器底部及び原子炉圧力容器内部の両方に燃料デブリが存在するという分析結果を踏まえ、以下の理由から、まず、原子炉格納容器底部にある燃料デブリを横からのアクセスで取り出すことを先行する。

○原子炉格納容器底部へのアクセス性が最もよく、原子炉格納容器内部調査を通じて一定の知見が蓄積されていること

○より早期に燃料デブリ取り出しを開始できる可能性のあること

○使用済燃料の取り出し作業と並行し得ること

(8) 使用済み核燃料の冷却プールからの取り出し[10)]

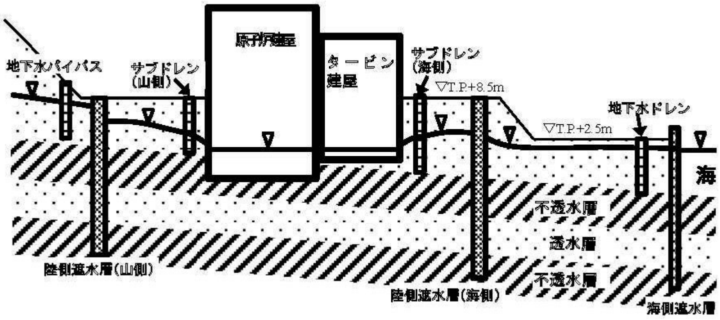
使用済燃料プール内の燃料については、4号機からの取り出しは2014 年12 月に完了した。1号機については、2017年秋から2021年秋にかけてプール内のガレキ撤去、2021年秋から2023年秋までに燃料取り出し用カバーの設置、2023年秋から使用済み核燃料の取り出しを開始し、2025年春までに完了する計画である。2号機については、水素爆発の影響を受けず建屋が健全なため建屋上部の解体が必要となり、使用済み核燃料取り出し作業の開始は最も遅く、2024年に開始し、年内完了の計画である。3号機については、既にプール内のガレキ撤去が完了し、現在燃料取り出し用カバーの設置工事中で、燃料取り出しは2018年秋に開始して、2020年内に完了の計画である。

本稿では、前報までと同様、問題（2）に関して、収集データを基にたまり水の汚染状況の時間変化特性について過去3報告書[11),12),13)]を踏まえてさらに検討を加えたものである。

3. 原子炉建屋周辺の地下水の概要

(1) 建屋周辺の断面の概略と地下水制御施設の概要

図－1は福島第一原発の建屋（1～4号機）周辺の断面（東西方向）と地下水制御施設の概要を模式的に示したものである。R/BとT/Bは不透水層の上に建造されている。2つの不透水層に挟まれた透水層は被圧地下水層となっている。R/Bの山側近傍とT/B海側近傍に数十本に及ぶサブドレンが設置されている。サブドレンを囲む形で凍土壁が複数の不透水層を突き抜ける形で設置されている。更に西の山側には地下水バイパス施設が設置されている。一方、T/B海側のT.P.+2.5m（O.P.+4m）地盤には地下水ドレンが数多く設置されており、更にその海側には海側遮水壁（鉄鋼矢板）が張り巡らされている。



図－1　福島第一原発の建屋周辺の断面と地下水制御施設の模式図

(2) T.P. +8.5m地盤における地下水の挙動

東京電力の資料[14]によれば、1、2、3、および4号機が立地するT.P. +8.5m(O.P. +10m)地盤では、西の山側斜面から約1.4kmの幅で約1,000m³/dayの地下水が流れ込むとされる。原発事故前は、原子炉主建屋を囲むサブドインにより約800m³/dayが揚水されて海に排出され、残りの約200m³/dayの地下水が海に自然流出していたものとされる。

現在は、凍土壁の西の山側に掘削された12本の地下水揚水用井戸から、約300～350m³/day程度の地下水が揚水され、放射性濃度をチェックして高い場合は目標濃度以下に浄化された上で、R/BとT/Bを迂回して海に排出されている[15](地下水バイパス)。

原発事故によりサブドレンが使えなくなったが、急ピッチで復旧工事が進められ、2015年9月までにはサブドレンは完全に復旧されて、主建屋(R/BとT/B)周辺の地下水位を調整するために常時稼働している。山側には多くの放射性汚染水の一次貯蔵タンクがあるので、サブドレンで汲み上げられた地下水は、浄化されて水質が運用目標未満であることを東京電力及び第三者機関にて確認された後、海に排水される。

地下水位データ、雨量データ、及び、サブドレン揚水量の実測値などから、凍土壁がほぼ完成した2017年9月における平均的な地下水の水収支は、以下のように見積もられている[16]。山側からの凍土壁を通過する地下水流入量は約630m³/day(推定値)、降雨による地下水涵養量は170m³/day(雨量データをもとに推定)で、サブドレン汲み上げ量は約510m³/day(実測値)、不透水層を通じた閉合範囲外への鉛直移動量は0m³/day(仮定値)、主建屋への地下水流入量は約120m³/day(実測値をもとに推定)、及び、陸側遮水壁から海側への地下水移動量は約110m³/day(実測値をもとに推定)、である。なお、地下水位変動への寄与量は50m³/dayとされる(実測値をもとに推定)。

東京電力によれば、主建屋への地下水流入量の低下は、凍土壁による地下水の堰き止めと地下水バイパスやサブドレンによる地下水揚水に起因する主建屋周辺の地下水位の低下により実現された、とされる。主建屋への地下水流入量は、主建屋周辺の地下水位と建屋内のたまり水の水位との差に左右される。実際、2017年9月のサブドレンピット内水位の全平均値はT.P. +2.0mで、2016年1月に比して約2m程低下している。主建屋内たまり水との水位差も2016年1月時の約1.5mから約0.8mに減少している[16]。この水位差の減少が地下水流入量の大幅減少の大きな要因と考えられる。

(2) T.P. +2.5m地盤層における地下水の挙動

T/B東側のT.P. +2.5m地盤層(原子炉建屋の海側地盤)には、原発事故時の放射性物質で汚染された地下水(自由地下水)や原子炉冷却に用いられた海水がいまでも相当量残存している。東側地域には数多くの自由地下水観測井が設置され、一部の観測井からは高濃度の放射性物質が観測されている。セシウム137は地層を移動中に土壌粒子に吸着されるのでそれほど高い濃度は検出されないが、トリチウム、全β及びストロンチウムが無視できない濃度で検出される観測井が点在する。

2103年12月からH25J⑦やFz-5と名付けられた観測井の下部透水層(被圧地下水層)から採取された地下水でトリチウムが検出された。さらに、2014年6月の観測では、トリチウムの放射線強度はそれぞれの観測井で140Bq/L、4,700Bq/Lを示した[17]。告示濃度60,000Bq/Lよりは低いものの、地下水汚染が下部透水層まで及んでいる可能性を示すものとして新たな問題となった。

東電は下部透水層で観測された上記のトリチウム強度の原因を明言していない。2018年度も1～4号機T/B海側下部透水層地下水の不定期の水質モニタリングが計画され、結果は資源エネルギー庁にメール

連絡することになっているが、水質分析を実施したのか否かを含めて結果は公表されていない[18]。下部透水層の水質結果については、2014年7月の公表資料[19] 以後は見当たらない。

地下水位データ、雨量データ、及び、各種揚水量の実測値などから、T.P. +2.5m地盤層での2017年9月の平均的な地下水の水収支は、以下のように見積られている[16]。凍土壁（海側）からT.P. +2.5m地盤層への地下水移動量は約110m³/day（算定値）、降雨による地下水涵養量は約80m³/day（雨量データをもとに推測）、地下水ドレンによる汲み上げ量は約150m³/day（実測値）、ウェルポイントによる汲み上げ量は約20m³/day（実測値）、不透水層を通じた閉合範囲外への鉛直移動量は0m³/day（仮定）、及び、海側遮水壁から海への移動量は30m³/day（仮定値）である。なお、地下水位変動への寄与量は0m³/dayとされる（実測値をもとに推定）。

(3) 原子炉内での放射性汚染水の発生

燃料デブリからは、今でもわずかながら各種放射性物質がたまり水中に放出されつづけていると考えられている。

現在は、原子炉は冷却水により低温安定状態に保たれているとされるので、あらたな各種放射性物質の生成はないことになる。現在でも、これまでと同様、当初生成したもののうち、初期に溶け出さなかった残留分がゆっくりと冷却水中に放出されていると考えられている（長期FPソースタームと呼ばれる[20]）。

(4) 原子炉冷却システム正式稼働後の冷却水と処理水の推移

2011年6月以降、循環式冷却システムが正式稼働に入った。主建屋（R/BとT/B）内の汚染水が周辺の地層に漏れ出さないように、周辺地下水位はT.P.+2.5m（O.P. +4.0m）以下にならないように、主建屋内の滞留槽の水位はT.P.+1.5m（O.P. +3m）前後に保持するようにポンプにより操作がなされてきた。

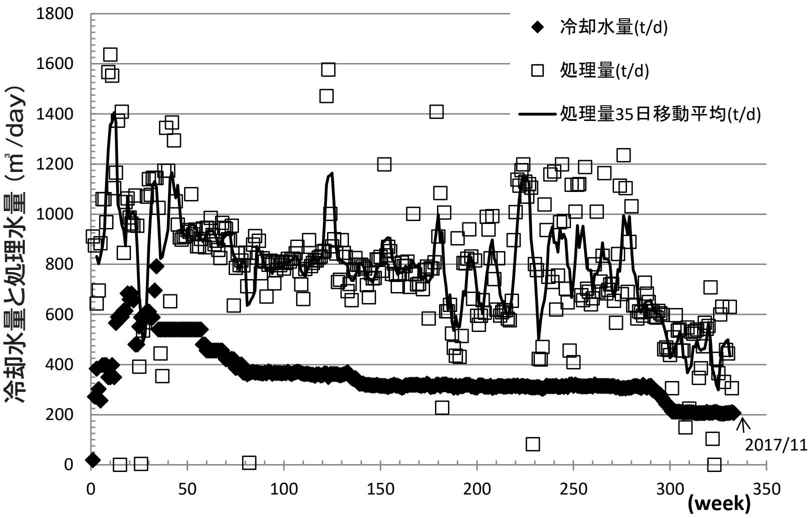
循環冷却システムのコンパクト化のパイロット事業として、2016年3月から1号機R/Bの水位をT.P. +1.7m（1号機R/BとT/Bとの間の連通箇所のレベル）以下まで常時低下させ、汚染水が1号機R/BとT/B間で流出入しない状況（R/Bのたまり水とT/Bのたまり水とが切り離された状況）とし、循環冷却システムの正常稼働に問題がないことが確認された。

図－2は、2017年10月までの日冷却水量と日セシウム除去処理水量の週変化[1] を示したものである。図中の実線は処理水量の35日移動平均値である。

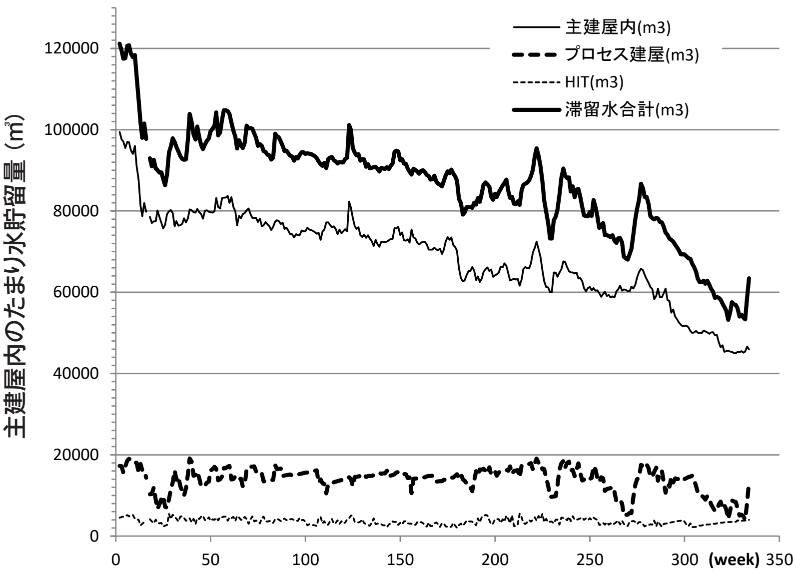
冷却水量は、第30週以降週変動をほとんど見せず、4回の段階を経て現在は約210m³/dayで落ち着いている。一方、セシウム除去処理水量の方は週変動が大きい。その原因として、メンテナンスで装置停止があること、二つの除去装置を用いることなどが考えられる。2017年3月以降の処理量の平均値は約480m³/dayとなっている。

主建屋内のたまり水総量に変化がなければ、おおまかには両者の差の約270m³/dayが主建屋流入量と言えるが、主建屋以外の汚染水も処理されているので、その分を差し引いて考える必要がある[1]。東京電力による推定によれば2017年9月の主建屋流入量の平均値は120m³/dayとされ[16]、冷却水量と処理量による地下水流入量の推定値とは150m³/dayも小さい。そこで、各建屋内のたまり水の水量の変化を調べてみた。

図－3は、主建屋内のたまり水量、プロセス建屋内のたまり水量、HTI内のたまり水量、およびそれらの合計水量の週変化を示したものである[1]。プロセス建屋とHTIのたまり水量は多少の変動はあるものの、特



図－2　原子炉への冷却水供給量とセシウム137汚染水の処理量の週変化



図－3　主建屋内のたまり水の貯留量の週変化

段の増加傾向も減少傾向もないといえる。一方、主建屋内のたまり水量には明らかな減少傾向が認められる。特に、第275週あたり（2016年10月）からの減少率が大きい。それを反映してたまり水総量もほぼ同様な傾向を示している、図－3から、たまり水総量の第275週以降の減少率を大まかに見積もると約80m³/dayとなった。

たまり水量の減少分は処理水量の増加分に相当するので、この量と主建屋以外からの汚染水の処理量分を考慮すれば、上記の地下水流入量に関する東京電力の推定値（120m³/day）と冷却水量と処理量による地下水流入量の推定値（約270m³/day）の違いが或る程度まで説明できる。

中長期計画では、凍土壁効果、地下水バイパスの定常稼働、サブドレンの強化などで2018年内には地下水流入量を100m³/dayに抑制することになっている。さらに、冷却水の注入量を210m³/day前後に抑制し、余裕の出るセシウム吸着装置能力を利用して、主建屋以外の建屋や諸設備に滞留する放射性汚染水の浄化をさらに推進するとしている[21)]。

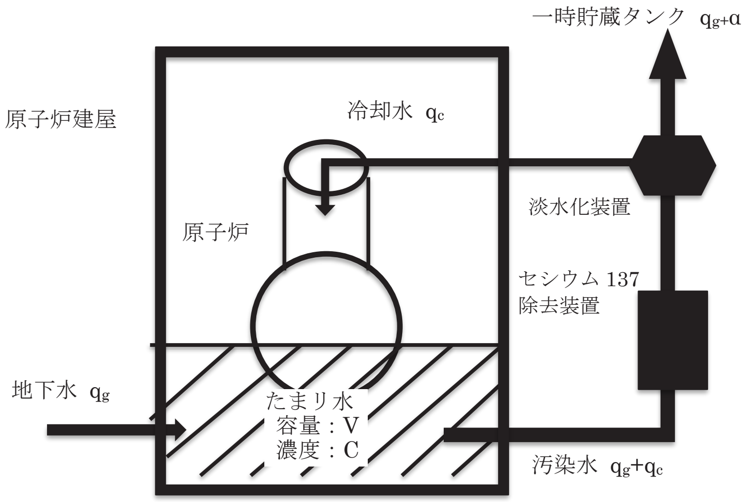
4. 原子炉建屋内の汚染水の濃度変化の解析

原発事故当初からこれまでの、冷却水の塩分濃度、セシウム137放射線強度、およびトリチウム放射線強度の時間変化を比較解析すれば、燃料デブリからどの程度の放射性物質が出ているのかなど、燃料デブリについてある程度の議論が可能と思われる。

(1) 循環式冷却システムの概要

原子炉は、現在は毎日210m³程の水で冷却されている。冷却に使われた水は、一旦、各R/BおよびT/Bの地下室に貯留される。両建屋内のたまり水は、水位に留意しながら約330m³/day（地下水流入分と冷却水分）のペースでプロセス建屋もしくはHTIに移送される。プロセス建屋とHTIには状況に応じて主建屋以外の建屋からも汚染水が移送される。プロセス建屋とHTIから合わせて約480m³/dayのペースで汚染水がポンプアップされ、セシウム137とストロンチウムが除去された後、塩分が除去される。循環式冷却システムを維持するために処理水の約210m³/dayが冷却水として循環され、残りの約270m³/dayは系外の貯蔵タンクに貯えられることになる。（図－4）

系外に貯えられる水は、セシウム137とストロンチウム以外の各種放射性物質により汚染されているので、ALPS等でトリチウム以外は除去され、一時貯蔵タンクに保存されている。放射性汚染水の処理は進んでいるが、その一方で、汚染水から除去された放射性物質はフィルターなどにトラップされた訳であるので、高濃度の固形放射性廃棄物が蓄積し続け新たな放射性汚染物質処理の問題がある。



図－4　循環式冷却システムの概要説明図

(2) 原子炉たまり水中の汚染物質の濃度変化

1) 放射線物質量の変化式

放射線物質もしくは汚染物質の濃度をCとすると、各種除去装置の除去率を100%と仮定すると、その時間変化は以下のように表される[11]。

$$d(VC)/dt = q_g C_g + \gamma - (q_c + q_g)C - \lambda VC - \theta VC \quad \cdots\cdots (1)$$

で記述できる。ここで、V：R/B、T/B、プロセス建屋、及び、HTIに滞留している汚染水全体の容積、C_g：流入地下水の放射線物質濃度（もしくは汚染物質の濃度）、q_g：地下水流入量、q_c：循環冷却水量、γ: 放射性物質の溶出量、λ: 放射性物質の自然崩壊率、および、θ: 放射性物質の沈降・吸着率である。式（1）は、Cl^-濃度、セシウム137の質量濃度、およびトリチウムの物質濃度の時間変化を記述する基本式である。

なお、放射線強度R_A（単位：Bq/L）は、放射性物質の質量濃度Cを用いて（$\lambda N_A/M$）Cで表現できる。ここで、N_Aはアボガドロ数、Mは放射性物質のモル質量である。

2) 塩素イオンの濃度変化

塩素イオン（Cl^-）のt = 0における初期濃度をC_0とすると、Cl^-濃度の変化は以下となる[11]。

$$C(t) = q_g C_g / (q_c + q_g) + (C_0 - q_g C_g / (q_c + q_g)) \exp(-(q_c + q_g)\, t/V) \quad \cdots\cdots (2)$$

Cl^-については、長期FPソースタームを想定する研究報告[20]もあるが、原子炉溶融時に塩化物が生成されるメカニズムが不明なので、ここでは塩化物が燃料デブリから溶出することはなく、たまり水のCl^-濃度を増加させる要因は外部から流入する地下水経由のみと仮定した。

前報で、ある時期（$t = t_1$）からバイパスを通じて濃度C_bの汚染水が流量q_bで建屋内に導水されていることを報告した[13]。この場合、汚染水は淡水化処理を受けCl^-が除去されるので、主建屋のたまり水のCl^-濃度の変化は式（2）で評価できるが、淡水化処理装置入口の汚染水はバイパスからの汚染水の影響を受ける。プロセス建屋のたまり水とHTIのたまり水の合計量をV_{PH}とすると、淡水化処理装置入り口でのCl^-イオンの物質収支式は次式となる。

$$d(V_{PH}C)/dt = q_g C_g + q_b C_b - (q_c + q_g + q_b)\, C \quad \cdots\cdots (3)$$

期間中V_{PH}は一定と仮定し、$t = t_1$における濃度をC_e、さらに、$q_t = q_c + q_g + q_b$とすると、$t = t_1$以降のCl^-イオン濃度の時間変化は、次式で表される。

$$C(t) = (q_g C_g + q_b C_b) / q_t + (C_e - (q_g C_g + q_b C_b) / q_t) \exp(-q_t (t - t_1) / V_{PH}) \quad \cdots\cdots (4)$$

3）セシウム137の質量濃度の変化

セシウム137（Cs_{137}）の半減期は約30年なので、$\lambda = 0.00044$（1/week）であり$\lambda = 0$と近似できる。また、前々報[12)]の考察で$\theta V = 0$である。流入地下水にはセシウム137は含まれていないと仮定できるので、期間中Vは一定と仮定すれば、$t = 0$での初期強度をC_0とすると、Cs_{137}の質量濃度の変化は以下となる。

$$C(t) = \gamma / (q_c + q_g) + (C_0 - \gamma / (q_c + q_g)) \exp(-(q_c + q_g) t/V) \quad (5)$$

時刻$t = t_1$以降に、バイパスを通じて濃度C_bの汚染水が流量q_bでプロセス建屋もしくはHTIに移送されている場合、汚染水はセシウム137除去処理装置（SARRYなど）でCs_{137}やストロンチウムが除去されるので、主建屋のたまり水のCs_{137}濃度の変化は式（5）で評価できるが、SARRY入口での汚染水は式（5）では評価できない。そこでのCs_{137}の物質収支式は次式となる。

$$d(V_{PH}C)/dt = q_b C_b + \gamma - q_t C \quad (6)$$

ここで、$q_t = q_c + q_g + q_b$である。期間中V_{PH}は一定と仮定すれば、$t = t_1$における濃度をC_eとすると、$t = t_1$以降のCs_{137}濃度の時間変化は、次式で表される。

$$C(t) = (q_b C_b + \gamma)/q_t + (C_e - (q_b C_b + \gamma)/q_t) \exp(-q_t (t - t_1)/V_{PH}) \quad (7)$$

4）トリチウムの質量濃度の変化

トリチウム（T）の半減期は約12年なので、$\lambda = 0.0011$（1/week）となり$\lambda = 0$と近似できる。トリチウムの場合、$\theta V = 0$は自明である。流入地下水中のTは無視できるとし、Vを一定と仮定すれば、$t = 0$での濃度をC_0とするとTの質量濃度の変化は以下となる。

$$C(t) = \gamma/q_g + (C_0 - \gamma/q_g) \exp(-q_g t/V) \quad (8)$$

ある時期$t = t_1$以降、バイパスを通じて濃度C_bの汚染水が流量q_bでプロセス建屋もしくはHTIに移送されている場合、TはSARRYやALPSなどを用いても除去できないので、主建屋内のたまり水もプロセス建屋等のたまり水もバイパス経由の汚染水の影響を受ける。その場合のTの物質収支式は、

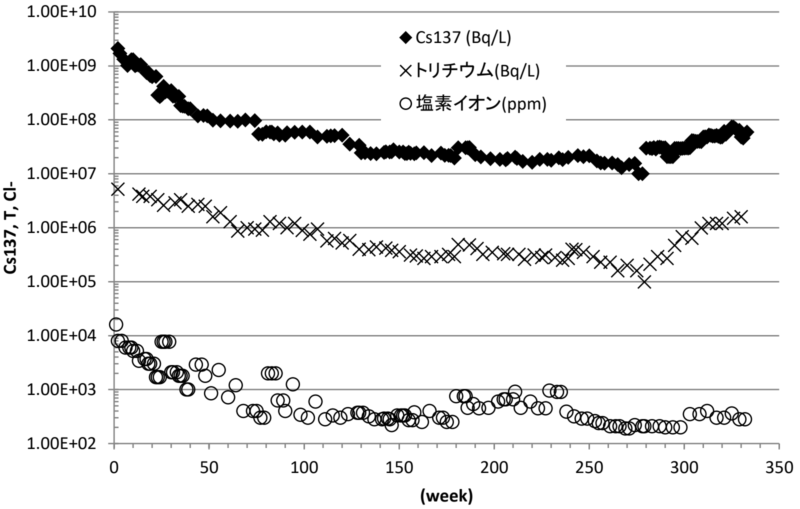
$$d(VC)/dt = q_b C_b + \gamma - q_g C \quad (9)$$

となる。Vを一定と仮定すれば、$t = t_1$における濃度をC_eとすると、$t = t_1$以降のT濃度の時間変化は、次式で表される。

$$C(t) = (q_b C_b + \gamma)/q_g + (C_e - (q_b C_b + \gamma)/q_g) \exp(-q_g (t - t_1)/V) \quad (10)$$

（2）原子炉たまり水中の汚染物質の濃度（強度）変化データ解析

滞留タンク中のCl^-濃度とCs_{137}の放射線強度については、プレス・リリース用資料として毎週公表されている。ここでは、2011年6月15日から毎週公表されている333週分のデータを整理した結果を示す[1)]。汚染水のサンプリングと分析は、毎週ではなく、およそ1ヶ月間隔でなされている。Tの放射線強度の時間変化については、2011年9月から東京電力のWebサイトに約1ヶ月間隔で公表されるデータを用いる[2)]。図－5は、Cl^-、およびCs_{137}とトリチウムTの放射線強度の週変化を半対数紙表示（濃度値を対数で表示）で示したものである。Cl^-濃度、およびCs_{137}放射線強度は2011年7月5日から2017年11月2日まで、T放射線強度は2011年9月20日から2017年10月10日までとなっている。



図－5　セシウム137強度、トリチウム強度および塩素イオン濃度の週変化

1）塩素イオン濃度

Cl^-濃度は、2011年7月5日に16,000ppmあったものが、半対数紙表示で直線的に低減し、第80週（2013年1月1日）あたりから約300ppmに漸近していく傾向があったが、第180週（2014年12月9日）あたりから徐々に上昇に転じて、第230週辺り（2015年12月）には960ppmを記録した。しかし、約10週間後（2016年1月14日）には390ppmに急落し、それ以後は徐々に低下し続け、第280週辺り（2016年11月）では約200ppmまで下がってきている。第300週当たりからは約350ppm前後で変動している。

図－5で示されているCl^-の濃度は、淡水化処理装置入り口で採水された汚染水の濃度である。第278週以前は、プロセス建屋とHTIに移送される汚染水は主建屋内のたまり水だけだったので、図－5のCl^-濃度は主建屋内たまり水のCl^-濃度と考えてよい。しかし、第279週以降は主建屋以外からの汚染水がプロセス建屋もしくはHTIに移送されてくるので、図－5のCl^-濃度は主建屋内のたまり水のCl^-濃度より高めになっていると考えられる。

2）セシウム137の放射線強度

図－5によれば、Cs_{137}の放射線強度は2011年7月5日には2.1×10^9 Bq/Lあったものが半対数紙表示で直線的に低減し、第80週あたりから低減率が小さくなり、第125週辺りからは一定値（約1.9×10^7 Bq/L）に漸近していく様態を示した。その後、第250週辺り（2016年4月上旬）から、再び、低減が始まり、第278週辺り（2016年10月中旬）には1.0×10^7 Bq/Lまで下がった。

しかし、第279週には、3.0×10^7 Bq/Lに跳ね上がった。これについて東電は、「第1号機T/Bの復水器内に滞留していた高濃度汚染水をプロセス建屋に移送したもので、2016年11月中は高い濃度が観測される」と、事前報告している[22]。東電の報告通り、その後濃度上昇が続き2017年9月には7.4×10^7 Bq/Lまで達した。2017年10月のサンプリング結果は5.0×10^7 Bq/Lである。

図－5に示されるCs_{137}の放射線強度は、プロセス建屋とHTIの両方のたまり水の放射線強度と水量から求めた平均値である。第278週以前は、両建屋に移送される汚染水は主建屋内のたまり水だけだったので、この平均値は主建屋内のたまり水の放射線強度と考えてよいが、第279週以降は主建屋以外からの汚染水が移送されて来ているので、平均値は主建屋たまり水のCs_{137}濃度を正しくは反映していない。

3）トリチウムの放射線強度

図－5にはたまり水に含まれるTの放射線強度の変化も示されている。分析に用いられたたまり水は、図－4のシステム図において淡水化装置の入口で採取されたものである。T放射線強度は、2011年9月20日には4.2×10^6 Bq/Lあったものが半対数紙表示で直線的に低減し、第160週（2014年7月上旬）あたりから約3.0×10^5 Bq/Lに漸近しつつあった。第250週辺りから低減が続き、第278週目採取サンプルでは1.0×10^5 Bq/L迄下がった。その後上昇に転じ第330週（2017年10月）には1.6×10^6 Bq/Lまで上昇した。Tについては、第279週以降であっても、図－5の放射線強度は主建屋内たまり水の放射線強度を正しく反映している。

4）たまり水の汚染物質濃度変化の無次元表示

図－6は、Cl^-濃度、および、Cs_{137}とTの放射線強度の週変化をそれぞれの初期濃度値で無次元化して示したものである。T放射線強度の場合、第150週までの減水率を用いて2011年7月5日の値を逆算しその値を初期値とした。

第160週以降のTの放射性強度の変動パターンはCs_{137}のそれによく対応している。図中の直線は、東京電力が予測したTの放射線強度の週変化[12]を無次元表示したものである。第160週以降は実測値との乖離が大きくなる。この予測式は、式（8）においてTの増加要因を無視した場合に対応するが、実測値は無視できない事を示している。

5）三者の週変化特性に関する考察

Cl^-濃度、Cs_{137}、およびT放射線強度の第270週までの週変化特性については、過去3報（福島第一原発建屋内のたまり水の放射性汚染状況の解析（1）、（2）、（3））[11),12),13)] を参照されたい。ここでは、第270週（2016年9月）以降の動向について考察する。

i）塩素イオン濃度の週変化

以下の考察により、第180週以後のCl^-濃度の上下動の原因は、建屋に流入する地下水のCl−の濃度の変動にあると推定できる。

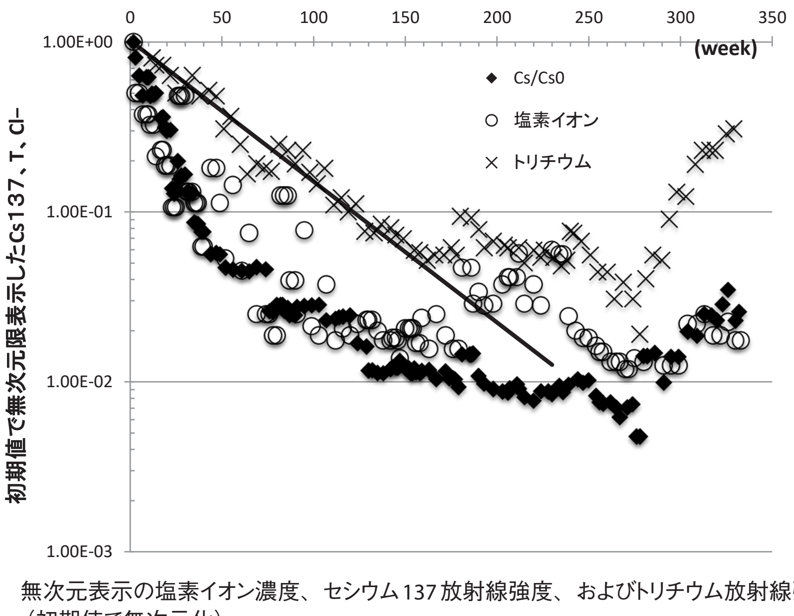
建屋近傍のサブドレンから揚水された地下水のCl^-濃度は、この一年は150～400ppmで変動している[23)]。このCl^-濃度は、T.P. +8.5m地盤層における地下水のCl^-濃度を反映していると考えられる。ちなみに、さらに西の山側に設置されている地下水バイパスでの地下水のCl^-濃度は60ppm前後である[24)]。前者のCl^-濃度が後者のそれより300ppm程高い原因は、原発事故当初に原子炉を冷却するために注水された海水と考えられる。海水はT.P. +8.5m地盤層に浸透し自由地下水層に到達し、地下水の流下とともに原子炉主建屋内の水槽に流入しているものと考えられる。図−5におけるCl^-濃度は、$(q_gC_g + q_bC_b)/q_t$、即ち、主建屋への流入地下水の濃度と量、主建屋以外から移送される汚染水のCl^-の濃度と流入量、さらに原子炉冷却水量により決まると考えられる。

ii）セシウム137とトリチウムの溶出率と放射線強度の週変化

図−6では、Cs_{137}とTの放射線強度が第250週辺りから第278週まで急減しているが、これらの減少の原因はよくわからない。放射性物質の溶出率γが変化したとは考えにくいし、かなりの量の汚染のない水が継続的に移送された形跡は見当たらない。

第279週に入るとCs_{137}の強度が跳ね上がり、その後、強度上昇が続いている。これについては、東京電力より事前に公表された、第1号機T/B復水器内の高濃度滞留汚染水をHTIに移送したために生じるCs_{137}の放射線強度の上昇予測に合致している[25)]。Tの放射線強度についても前報で予測した通り、第279週目に強度が跳ねあがり、その後強度の上昇が続いている。

前報では、Cs_{137}は4.0×10^7～5.0×10^6 Bq/Lの間で、Tは4.0×10^5～5.0×10^4 Bq/Lの間で変動を繰返し



図−6　無次元表示の塩素イオン濃度、セシウム137放射線強度、およびトリチウム放射線強度の週変化（初期値で無次元化）

ながら徐々に低下していくものと予測した。しかし、予測ははずれ、両者とも逆に増加し続けている。増加の理由は、それぞれ式（7）、式（10）で考察できる。

第250週当たりの放射線強度値は、主建屋以外からの汚染水の移送がない場合の漸近値C_eと近似できる。ここで、q_{c0}、q_{g0}は、それぞれ第250週までのq_c、q_gの値とし、q_{c1}、q_{g1}は、それぞれ第279週以降のq_c、q_gの値とする。

Cs_{137}の場合、C_eの値は$\gamma/(q_{c0}+q_{g0})$で表される。また、式（7）より、$t\rightarrow\infty$で$C\rightarrow C_{e1}=(q_bC_b+\gamma)/q_{t1}$となる。ここで、$q_{t1}=(q_{c1}+q_{g1}+q_b)$である。東京電力の実測データ[1)]によれば、第250週当たりでは$q_{c0}+q_{g0}=750m^3/day$であり、第279週以降は$q_{t1}=480m^3/day$であるので、

$$(q_bC_b+\gamma)/q_{t1}>\gamma/(q_{c0}+q_{g0}) \quad \cdots\cdots (11)$$

が成立する。式（7）と式（11）より、Cs_{137}の放射線強度は、第281週以降増加し続け、$(q_bC_b+\gamma)/q_{t1}$に漸近してゆくことになる。

Tの場合、C_eの値は、γ/q_{g0}で表される。また、式（10）より、$t\rightarrow\infty$で$C\rightarrow C_{e1}=(q_bC_b+\gamma)/q_{g1}$となる。実測データ[1)]によれば、第250週以前は$q_{g0}=450m^3/day$であり、第279週以降は$q_{g1}=120m^3/day$であるので、

$$(q_bC_b+\gamma)/q_{g1}>>\gamma/q_{g0} \quad \cdots\cdots (12)$$

が成立する。式（10）と式（12）より、Tの放射線強度は、第279週以降、著しく増加しγ/q_{g0}の数倍以上の$(q_bC_b+\gamma)/q_{g1}$に漸近してゆくことになる。残念ながら、著者は現時点ではCs_{137}、TともにC_bとq_bの実測値を把握していない。

東京電力は、201年10月に冷却水循環システムの稼働条件を変更し、主建屋流入地下水量q_gを$120m^3/day$程度に、冷却用淡水注入量q_cを$210m^3/day$程度に低減させた[21)]。これにより、一時貯蔵タンクに移送される汚染水量は$270m^3/day$程度に減ることになった。しかし、q_gとq_cの減少により、主建屋内のたまり水のCs_{137}とTの放射線強度は増大し続け、C_eの数倍高い新たな漸近値C_{e1}に近づくことになってしまったわけである。

5. 汚染水対策にかかる考察

(1) 循環式冷却システムの今後

1）1～4号機たまり水をセシウム除去装置へ直送する配管システム

東京電力は、主建屋以外の施設に滞留する汚染水をHTI、プロセス建屋に移送して貯留した後、SARRYなどでCs_{137}とストロンチウムの除去を推進している。HTIやプロセス建屋に貯留される高濃度汚染水を冷却水の循環系統から除外するため、1～4号機たまり水を移送ポンプによりSARRYなどへ直送する移送配管設置工事を実施している[25)]。この新移送システムが稼働し始めれば、HTIとプロセス建屋には、1～4号機内のたまり水だけでなく、他の建屋や設備の高濃度汚染水が移送されてくることになり、HTIとプロセス建屋内の貯留水の放射性物質の強度は1～4号機内のたまり水の放射性物質の強度を反映するもので

はなくなる。東京電力からは新移送システムの稼働時期が明示されていないが、稼働後は、1～4号機たまり水を直接サンプリングしたデータの公示が求められる。

ちなみに、現時点までのプレス・リリース資料には、プロセス建屋とHTIのCs_{137}の放射線強度しか見当たらないが、これに関連して一つ気になる点がある。それは、HTIからのCs_{137}のサンプリング・データが2017年3月9日以降全く更新されていないことである。プロセス建屋についてはほぼ毎月の頻度でサンプリング・データが更新されているのとは対照的である。サンプリングが継続されているとすれば何故データが公示されないのか、継続されていないのであれば何故されないかの説明が必要である。

なお、図－5、図－6の作成にあたり、2017年3月9日以降のHTIのCs_{137}濃度については、東電のWeb上での資料[2)]に記載されている強度で代用した。

2）1～4号機滞留水浄化設備の設置

SARRYなどによる除去や地下水流入により、主建屋滞留水中の放射能強度は低下してきていたが、原子炉注水量（冷却水量）と地下水流入量が減少していることもあり、第279週以降、主建屋内のたまり水の放射線強度は上昇に転じている。このため、滞留水中の放射能濃度を低減させることを目的に、SARRYなどによる処理水の余剰分を直接主建屋に注水するライン（滞留水浄化設備）を設置し、循環浄化量を増加させる工事が進んでいる。滞留水浄化設備は、建屋内ROのSr処理水移送ラインから分岐し3,4号機のT/Bへ、またRO処理水ラインから分岐し1号機原子炉建屋R/Bおよび2号機T/Bへ、それぞれ処理装置の処理水を直接注水できる設備構成となっている。3・4号機滞留水浄化設備は2017年12月から、1・2号機滞留水浄化設備は2018年2月からの稼働が予定されている[26)]。

これらの設備による直接注水量をq_dとすれば、Cs_{137}については新たな漸近値C_{e2}に漸近していくものと思われ、直接注水の効果は期待できる。

$$C_{e2} = (q_b C_b + \gamma)/(q_{t1} + q_d) < (q_b C_b + \gamma)/q_{t1} \quad \cdots\cdots（13）$$

同様に、Cl－についても新たな漸近値C_{e2}に漸近していくものと思われ、直接注水の効果が期待できる。

$$C_{e2} = (q_g C_g + q_b C_b)/(q_{t1} + q_d) < (q_g C_g + q_b C_b)/ q_{t1} \quad \cdots\cdots（14）$$

しかし、Tに関しては、漸近値は$(q_b C_b + \gamma)/q_{g1}$のままであるので、直接注入による漸近値の低減効果は期待できない。漸近値を下げるためには地下水流入量を増やさないかぎり実現できない。

（2）トリチウム汚染水対策

周知のようにALPS等をもってしても汚染水からTは除去できない。T汚染水を貯蔵する一時貯蔵タンクは敷地内で増え続けている。

経済産業省資源エネルギー庁内に設置されている汚染水処理対策委員会のもとにトリチウム対策に関するタスクフォース（トリチウム水タスクフォース）が設置された。2013年12月25日に第1回が開催され、2016年5月27日までに計15回の会合が開かれ、2016年6月3日に「トリチウム水タスクフォース報告書」が上申された。報告書には、トリチウム汚染水の地中注入、海洋投棄、水蒸気方式などについて、必要期間と必

要経費の試算結果が示されている[27]。

それを受けて、「多核種除去設備等処理水の取扱いに関する小委員会」が設置され、2016年11月11日には第1回会合が開催された。この小委員会の目的は、トリチウム汚染水の処理方策について風評被害など社会的な観点等も含めて、総合的な検討を行うとされている[28]。2017年10月23日までに6回の小委員会が開催されて、主に風評被害の社会的な観点を中心に議論が進められており、トリチウム汚染水処理方法のベストチョイスについての議論はほとんどなされていない[29]。

(3) 凍土壁

地下水のR/BやT/Bへの流入を防ぐため、凍結工法で凍土壁を作り原子炉周辺を取り囲む工事が行われ、2017年11月3日までに全域凍結した[7]。今後数ヶ月は凍土壁の遮水効果が検証されることになろう。

東京電力は、「凍土壁により地下水の流れが完全に遮断されなくても、サブドレンとの併用により、主建屋周辺の地下水の水位を目的値に十分制御が可能。」としている。この考え方は妥当と思われる。凍土壁を通じて地下水の流入があろうがなかろうが、凍土壁で囲まれた敷地内には降水による地下水涵養が避けられない。涵養量は平均170m³/day程と推定されている[16]。大雨の際には日涵養量はさらに大きくなるので、この敷地内の地下水位を目的値に制御するためには、サブドレンの稼働が不可欠となる。もし凍土壁により地下水流入が完全に遮断できないとしても、サブドレンの稼働率を上げれば済むことになる。

凍土壁の最大の役割は、大雨の際に山側から押し寄せる大量の地下水を一時的に堰き止めることと、凍土壁外側の地下水位を水平方向に平滑化することと考えられる。これらの役割は、凍土壁でなくても、地下コンクリート壁や濠を張り巡らすことでも可能とは思われるが、高放射能下での施工上の安全性、モンテナンスの容易性などを総合的に判断して、凍土壁が選択されてものと推察される。

(4) 燃料デブリの所在にかかる事柄

これまでのプレス・リリース資料など[1),2)]を総合的に判断すれば、原子炉内の燃料デブリの物理化学的状態は安定していると考えられる。

しかし、様々な試みがなされてはいるが、依然として全ての燃料デブリが格納容器内に収まっているということの確たる論証は得られていない。著者としては、本報でも「燃料デブリの所在によっては、現在の廃炉計画自体が無意味になることもあるので、早急に燃料デブリの所在の確認作業への注力を再度訴えたい。」という主張を繰り返さざるを得ない。

下部透水層の地下水質の調査実施とデータの公表は、その確認作業の有力な方法の一つと考えるが、下部透水層の地下水質については、前々報[12]で報告した以外の新しい情報はほとんど見つけ出すことは出来なかった。

凍土壁を設置するに当たって、凍土壁に沿って内側・外側とも近傍に下部透水層を貫いた観測井を何十本も掘削しており、水位や被圧地下水位についてはデータが公表されているので、併せて下部透水層の地下水の水質調査も実施してわかりやすい形で公表すべきと考える。2018年度も1～4号機T/B海側下部透水層地下水の不定期の水質モニタリングが計画されているはずであり[18]、これについても観測結果の速やかな公示を求めたい。下部透水層の地下水質は放射能汚染されていないという実測データが示されれば、「燃料デブリが原子炉建屋底部のコンクリート層を突き破って地層に溶け出した」という一部の人々の懸念を払拭する有力なデータとなる。

6. おわりに

福島第一原発建屋内のたまり水の放射性汚染状況の解析を通じて、前報で述べた内容に加えて以下のことが明らかになった。

(1) 原子炉冷却に伴う放射性汚染水の処理は順調に進んでいる。現在は、一時貯蔵タンクに貯留される約100万 m^3 の汚染水の約78%はトリチウムを除く全ての放射性物質が除去されている。2018年内にはその比率は100%になる見込みである。

(2) 第160週(2014年7月)以降のセシウム137とトリチウムの放射性強度の無次元表示による変動パターンはよく対応している。両者とも、第250週辺り(2016年4月)から第280週(2016年10月下旬)までは下降し続けたが、それ以降は上昇に転じ現在(2017年11月)まで上昇し続けている。下降の原因は説明がつかないが、第281週以降の上昇については、セシウム137については式(7)と式(11)で、トリチウムについては式(10)と式(12)で説明がついた。

(3) 原子炉注水量(冷却水)と地下水流入量が減少していることもあり、第279週以降、原子炉建屋内のたまり水の放射線強度は上昇に転じている。このため, たまり水中の放射能濃度を低減させることを目的に, 処理装置の処理水の余剰分を直接主建屋に注水するライン(滞留水浄化設備)を設置し, 循環浄化量を増加させる工事が進んでいる。しかし、これらの設備が正式稼働しても、セシウム137についてはたまり水の放射線強度の低減は期待できるが、トリチウムに対しては放射線強度の低減は期待できない。

(4) たまり水の塩素イオン濃度は、第250週辺り(2016年4月)以降は約200ppmから400ppmの範囲でゆっくりと変動している。建屋近傍のサブドレンから揚水された地下水の塩素イオン濃度が、この一年は150～400ppmで変動しており[23)]、たまり水の塩素イオン濃度は建屋に流入する地下水の塩素イオンの濃度に支配されていると推測される。

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Experiences and Challenges of Environmental Cooperation in Northeast Asia

Yuta Okazaki

Abstract

In Northeast Asian region, various bilateral and multilateral environmental cooperation has been implemented particularly among Japan, China and Korea among other countries for about the past thirty years. As under the discussion of community building in the region, environmental cooperation is one of the most promising areas for further cooperation.

On the other hand, recent rapid economic development in China and Korea changed the original standing position of the countries as donor county and recipient countries. Advanced environment policy in China has enlarged environmental industry market of the country while companies including Japanese and Korean companies in China are facing strict regulations.

New cooperation mode is necessary as the region is facing new problems such as radioactive pollution originated from the nuclear accident in the Fukushima Daiichi Nuclear Power Plant, and global environmental problems such as climate change and biological diversity, in addition to transboundary pollution issues such as acid rain, and dust and sand storm, and the region is deepening mutual economic reliance among the countries.

Also, recent political tension due to security, territorial and historical issues in the region has given negative impact not only on economy, cultural as well as environmental cooperation. On the other hand, it is highly expected that environmental cooperation could play a role to improve the regional tension.

In this paper, the author will review history of environmental cooperation in Northeast Asia and analyze facing issues and discuss future prospect by responding to the challenges.

北東アジアにおける環境協力の経験と課題

岡﨑　雄太

概要

北東アジア地域では、日中韓の3か国を中心としてこれまで約30年あまりにわたり、様々な二国間、多国間の環境協力が行われてきた。北東アジア地域における共同体形成の議論が行われる中、環境分野は、今後さらなる協力が期待される有望な分野の一つである。

他方、近年の中国の急速な経済成長は、旧来の援助国-被援助国という関係国の立ち位置に変化をもたらしたほか、環境対策が急速に進展し、環境産業の市場が拡大する一方、外国企業を含めて規制への対応を迫られている。また、当該地域においてこれまで課題となっていた酸性雨、黄砂などの越境大気汚染問題に加え、福島原発事故、さらには地球温暖化、生物多様性などグローバルな問題の顕在化、双方向の経済依存拡大により、従来とは異なる協力の在り方が模索されている。さらには、近年、当該地域における安全保障、領土問題、歴史問題に端を発する政治的な緊張は、経済、文化交流のみならず、環境協力にも障害をもたらしている。同時に、地域の緊張を改善する手段として、環境分野における協力への期待が高まっている

本稿では、北東アジア地域におけるこれまでの環境協力の経緯を振り返り、直面する課題を分析するとともに、こうした課題に対応した今後の協力の発展を展望する。

Experiences and Challenges of Environmental Cooperation in Northeast Asia

I. Introduction

In Northeast Asian region, various environmental cooperation has been conducted for about 30 years, mainly by Japan, China, and Korea. As discussions on community building in the region has being held, the environmental field is one of the promising fields where further cooperation is expected in the future.

At the ASEAN + 3 Summit in 1998, under the President Kim Dae Jung's initiative of Korea, an expert conference "East Asia Vision Group" aimed at materializing East Asian regional cooperation was established. The group submitted the report "Toward the East Asia Community" in 2001, which led to the holding of the East Asia Summit (Lee, 2015).

On the other hand, the rapid economic growth of China in recent years has led to changes in the standing position of the traditional donor country and recipient countries. In addition to the transboundary air pollution such as acid rain and yellow sand which had been the problem until now, the region faces new problems such as the Fukushima Nuclear Power Plant accident and global issues including climate change and biodiversity. Expanded mutual economic dependence also made the countries explore ways of cooperation that ore different from conventional ones. Furthermore, in recent years, the political tension triggered by the security, territorial, and historical issues in the region also brought obstacles not only to economic and cultural exchanges but also to environmental cooperation. At the same time, expectations for cooperation in the environmental field are increasing as a means of improving regional tension.

In this paper, the author will review the history of the past environmental cooperation in Northeast Asia region, analyze the challenges faced, and look for future developments.

II. History of environmental cooperation in Northeast Asia

In Northeast Asia, there are several frameworks for bilateral and multilateral environmental cooperation. In this section, the author will review the history of environmental cooperation in Northeast Asia region for about 30 years.

As a major environmental cooperation partnership in the region, environmental cooperation between Japan and China must be highlighted first. Normalization of diplomacy was realized by the Japan-China Joint Statement in 1972 and the Japan-China Friendship Peace Treaty was concluded in 1978. From the next year, the Japanese Government's assistance to the development of China was started. Official development assistance consists of ODA loans, technical cooperation and grant aid, of which ODA loan had dominated the whole cooperation in terms of monetary values (Otsuka, 2015). Environmental projects had started around 1988 as ODA projects such as sewage treatment plants, natural gas thermal power plants, railways, forestation and so forth. The share of environmental projects of the whole ODA projects had increased to around 70% after 2001. In total, approximately one trillion yen out of about three trillion yen was allocated for environmental cooperation projects (Someno, 2009). In 1998, City of Dalian, Chongqing and Guiyang were selected as environmental model city, and intensive support such as air pollution control technology was installed. Environmental information monitoring equipment were also installed in 100 cities all over China since 2000. Through such large-scale funding, pollution control facilities and their management know-how have been shared, and abundant human connections have been formed between the two countries. In 1996, the Japan-China Friendship Center for Environmental Protection was established in Beijing with the grant aid from the Japanese Government. In the center, Japanese experts have been stationed since 1992 in preparation for the establishment, and the center has served as a platform for Japan-China environmental cooperation, including being a base for technical cooperation projects such as human resources capacity building, environmental monitoring, dust and sand storm and acid rain countermeasures, corporate environmental supervision system, dioxin and POPs analysis, recycling economy promotion, and environmentally friendly society building. The center has grown into a core research institute with about 700 staff, and it functions as a comprehensive research base from policy planning, monitoring and analysis, capacity building and so on. To date, 377 Japanese experts have been dispatched to the center, 274 persons and more than 3,000 persons participated in training programs respectively in Japan and China (Sino-Japan Center Friendship Center for Environmental Protection, 2016).

Regarding cooperation including other countries in Northeast Asia in addition to Japan and China, the Japan - Korea Environmental Science Symposium held in 1988 served as a catalyst for the progress of cooperation in the region. China, Mongolia and the Soviet Union participated as observers. Rather than deciding specific matters, it aimed for sharing environmental information of each country, deepening mutual understanding among participants, thereby contributing to promotion of environmental policies of their own country and promotion of bilateral and multilateral cooperation.

In 1992, Northeast Asia Conference on Environmental Cooperation (NEAC), which made up of Japan, China, Korea, Mongolia and Russia was launched, and environmental experts from environmental agencies, local governments and research institutes of the five countries had participated in the discussion together with the United Nations Environment Program (UNEP), the United Nations Development Program (UNDP), the United Nations Economic and Social Commission for Asia and the Pacific (ESCAP) as observers (MOE, n.d.).

In 1993, the Japan-Korea Environmental Protection Cooperation Agreement and the China-Korea Environmental Protection Cooperation Agreement were concluded, and official cooperation between the governments began. Between Japan and Korea, Joint Committees on Environmental Protection and Cooperation were held nineteen times until 2017, and discussions on air pollution, climate change, marine pollution, and so forth have been discussed. For individual tasks such as waste recycling and climate change, individual policy dialogues have been conducted between the Ministry of the Environment of the two countries (MOE, n.d.; Nitta, 2011). Between China and Korea, environmental cooperation is the second most active field after economic cooperation, and they set up various levels of dialogue framework including summit meeting, ministerial meeting, and director general meeting. Cooperation includes environmental data erchange, environmental industry, Beijing City - Seoul City Cooperation (Qiu, 2017).

Also from that same year, the North-East Asian Subregional Program for Environmental Cooperation (NEASPEC), consisting of Japan, China, Korea, Mongolia, Russia and North Korea, started under UNESCAP, and has been working on transboundary air pollution, desertification, nature conservation, marine conservation and low carbon urbanization (MOE, n.d.). Jung (2016) notes the importance of technical support projects for countermeasures against transboundary air pollution from coal-fired power plants, while he points out inefficient communication among different focal point between the countries (Ministry of Environment and Ministry of Foreign Affairs) and overlapping of NEASPEC which covers comprehensive cooperation and the other individual cooperation bodies.

In 1994, Japan-China Environmental Protection Cooperation Agreement was concluded, and information exchange, expert exchange, seminar, collaborative research, etc. in the nine fields such as air pollution prevention, water pollution prevention, treatment of hazardous waste started. It also promoted cooperation by various stakeholders. The Japan-China Environment Protection Joint Committee established under the agreement held ten meetings up to 2012. Other than the ODA loan projects mentioned above, various cooperation such as air, water, soil, wildlife protection, climate change, energy conservation and environmental business are being carried out today.

Also in 1994, the Northwest Pacific Action Plan (NOWPAP) started by Japan, China, Korea and Russia as one of the 13 UNEP Regional Seas Program in the world to protect marine environment in the Yellow Sea and Sea of Japan (the East Sea). Cooperation includes oil spill accident emergency response plan, followed by the Nakhodka incident, and joint monitoring and countermeasures of marine drifting garbage (MOE, n.d.). Jung (2016) points out shortage of budget as the secretariat is dispersed in the two locations in Japan and Korea with limited budget of 950,000 USD for 2016–2017.

In 1999, Tripartite Environmental Ministers Meeting (TEMM), the high-level dialogue among Japan, China and Korea's environmental ministers started which will be highlighted in the next session.

In 2000, Long-range Transboundary Air Pollutants in Northeast Asia (LTP) was started by the three countries which eventually belonged to the TEMM. This project aims for collaborative research on monitoring of long-range transboundary air pollutants (ground and satellite monitoring) and modeling. Experts have been working together, but publishing the data which estimate share of contribution of transboundary contamination of PM 2.5 and ozone has always been sensitive theme. The latest research results will be reported to the TEMM 20 in 2018 (Lyu, 2017).

In 2001, Acid Deposition Monitoring Network in East Asia (EANET) was established by Japan's initiatives, which currently have 13 member states. The network designates 56 monitoring stations and monitors acid rain with a common method in each country, aiming to form common consciousness about the state of acid rain, and the scientific base under the international cooperation, which will lead to acid rain countermeasures (MOE, n.d.). While EANET is expanding activity targets from acid rain to PM 2.5 and ozone monitoring, the priorities of the participating countries are not necessarily consistent (Jung 2016).

Table1. History of Environmental Cooperation in Northeast Asia

1988: Japanese Official Development Aide for China expanded to environmental field.

1988: The first Japan-Korea Environmental Science Symposium (China as observer)

1992: The first Northeast Asia Conference on Environmental Cooperation (NEAC)
: Japan, China, Korea + Mongolia, Russia

1993: Japan-Korea Environmental Cooperation Agreement

1993: China-Korea Environmental Cooperation Agreement

1993: The North-East Asian Sub-regional Program for Environmental Cooperation (NEASPEC): Japan, China, Korea + Mongolia, Russia, DPRK

1994: Japan-China Environmental Cooperation Agreement

1994: The Northwest Pacific Action Plan (NOWPAP) for marine environment : Japan, China, Korea + Russia

1995: The Long-range Transboundary Air Pollutants (LTP) project : Japan, China, Korea

1999: The first Tripartite Environmental Ministers Meeting : Japan, China, Korea

2001: Acid Deposition Monitoring Network in East Asia (EANET): Japan, China, Korea + Mongolia, Russia, Indonesia, Malaysia, Philippines, Thailand, Viet Nam, Cambodia, Laos, Myanmar

III. TEMM

In this section, development of the TEMM will be reviewed, which is the framework of high-level environmental cooperation among Japan, China, and Korea, and at the center of cooperation in Northeast Asia. The TEMM was initiated by Korea in 1999, to promote environmental cooperation based on mutual respect, fairness, common interests, openness, and transparency. Since 1999, it has never been interrupted amid regional tensions which brought cancelations and postponements for other trilateral projects, which shows environmental cooperation has high potential to share common interests among the countries and relatively easier to proceed. The three countries cooperation that originated in the environmental field has developed into other administrative fields and summit talks. Currently there are 20 ministerial meetings, more than 50 intergovernmental meetings and more than 100 joint projects. The summit meeting started at the opportunity of ASEAN + 3 since 1999 and held independently from 2008. In 2011, the permanent Japan-China-Korea cooperation secretariat was established.

One of the top priority of the TEMM is transboundary air pollution. Dust and sand storm cooperation has promoted data sharing and joint research on modeling, monitoring and countermeasures. Air pollution policy dialogue was started after the serious smog incident in 2013. Mutual recognition of ecolabelling of the three countries has also been developed under the TEMM cooperation. It also covers marine litter, E-waste, biodiversity, chemical management and so on. Business Roundtable and Youth Forum are also held in back to back to the ministerial meeting. Recently, the TEMM 17 in 2015 decided the priority fields for the next five years (Table 2) and the TEMM 18 in 2016 launched a trilateral cooperation network for environmental pollution prevention and control technology.

Table 2. Priority Areas of the TEMM for 2015–2019

1: Air Quality Improvement
2: Biodiversity
3: Chemical Management and Environmental Emergency Response
4: Circulative Management of Resources/3R/Transboundary Movement of E-Waste
5: Climate Change Response
6: Water and Marine Environment
7: Environmental Education, Public Awareness and Corporate Social Responsibility
8: Rural Environmental Management
9: Transition to Green Economy

IV. Experience and Challenge of the TEMM

Cooperation under the TEMM has been undertaken in ways that deepen common recognition of problems, data sharing, policy dialogue, capacity building, and so on. Under the leadership of the Ministry of the Environment of the participating countries, some projects involve other stakeholders such as local governments, researchers, NGOs, etc. Cooperation has been expanded as the ministers have agreed on the new projects every year. In addition to the ministerial meeting, various activities have been held for each project.

On the other hand, the limitations of the TEMM are as follows. First of all, no permanent secretariat and common fund are established. Rather, the focal points of each country occasionally communicate and allocate funding as voluntary basis (Qiu, 2017). It does not have binding targets and deadlines as it takes the form of voluntary cooperation with mutual respect (Jung, 2016; Qiu, 2017). This is a major difference compared with mandatory international framework such as the European Convention on Transboundary Air Pollution. Type of cooperation does not include hard demonstration projects, only limited to soft cooperation such as policy dialogue, information exchange, joint research, etc. The size of the budget is very moderate. Therefore, it is difficult to ascertain the ripple effects of cooperation in short term.

There are also differences in priorities in the three countries (Jung, 2016; Qiu, 2017). It tends to be a situation that a country affected by transboundary pollution appeal to the country of the origin of the pollution reflecting domestic public opinion.

The TEMM is a high-level cooperation framework among the environmental cooperation frameworks in Northeast Asia. Annual ministerial level talks confirm common understanding and instruct cooperation at the administrative level afterwards, which will give positive effect to advance future cooperation smoothly. It is important to establish the personal trust relationship necessary for frank discussion with transboundary pollution among the ministers. It also takes a certain period to confirm the result of the agreed projects. For the last nineteen years, 15 ministers of Japan, 4 ministers of China and 8 ministers of Korea attended the TEMM. It might be difficult for short-term ministers to build strong trust relationship with their counterparts.

In order to implement environmental policy in each country, inner cooperation among different departments is indispensable. For example, air pollution policy relates to various departments such as economy, transportation and agriculture. It is also necessary to improve capacity of local governments. As recent agenda in the TEMM, control of alien species such as fire ant also needs corroboration with customs department and port management department. This point is unique challenge in the environmental field.

Finally, there are differences in the duties of the environmental ministries of each country. For example, concerning wildlife protection and climate change, the Ministry of the Environment is in charge in Japan and Korea, but not in China, therefore substantive discussion for these topics cannot be made at the TEMM.

Jung (2016) and Qiu (2017) also suggests overlap with other cooperation frameworks. Jung (2016) also points out leadership (rivalries and geopolitics) as a hurdle in the region.

V. Changes in Standing Positions

As the TEMM will commemorate 20 years anniversary in 2018, there are changing situations in recent years which will affect the condition of regional cooperation. One of the major changes is economic situation because of China' rapid economic development. Initially, Japan was a donor country and China and Korea were recipient countries, however Korea joined the OECD in 1996 and graduated from ODA in 2000. In addition, China's GDP has exceeded that of Japan around 2010, already exceeding twice the level of Japan (Jung 2016; Nitta, 2011; Otsuka, 2015).

Responding to the situation, there is growing public opinion to oppose to continue assistance for those "rich countries". While China has a population of 11 times that of Japan and 26 times the size of the country, GDP per capita is about one tenth level of Japan, and environmental pollution is still very serious (Table 3). Diplomats and media reporters staying at the site understand the situation and the needs of further cooperation, but it is hard to get understanding of political leaders and general public in Tokyo who never visit China and get to know the economic growth of China through the media. In particular, political tension in recent years has spurred these reactions.

Table 3. Comparative statistics among the three countries

	Population (mil.)	GDP (bln. 2005 USD)		GDP per capita (2005 USD)		CO_2 (Mt)		CO_2 per capita (t)		PM2.5 (μg/m³)
	2016	1990	2015	1990	2015	1990	2012	1990	2012	2010
China	1,382	537	5,762	465	4,188	3,893	12,455	3	9	41
Japan	126	3,926	5,019	32,114	39,649	1,305	1,479	11	12	10
Korea	51	364	1,271	8,477	25,280	301	669	7	14	23

Source: United Nations ESCAP Statistical Online Database.

It should also be noted that along with economic development, environmental policy in China is progressing rapidly. Until recently, in China as a developing country, the enforcement of environmental regulations had serious problems, where local governments and companies did not comply with the regulations. Foreign companies claimed that they were placed to unfair position in competition with local companies if only they paid cost for compliance to the regulations. However, in recent years, in response to the serious air pollution, the regulatory system has been strengthened. The speed of policy change is very fast. In some cases, new emission standards are so strict that even foreign companies' products are difficult to achieve the standards (K. Hara, personal communication, November 6, 2017).

Such economic development and strengthened environmental regulations are creating a new market for environmental business, and the possibility of win-win environmental cooperation is increasing among companies. In the 13th Five-Year Plan for Energy Saving and Environmental Protection Industry Development (2016–2020), the Chinese government plans to accelerate the development of the energy saving and environmental protection market by 2020 from 4.5 trillion RMB in 2015 (NDRC, 2016). Technical research and development, production and sales of environmental goods by local companies are very active in order to advance to the new market. International competition of pollution reduction technology, solar power system, electric vehicle and so on is becoming fierce. In addition, new technologies and services that have never been experienced in Japan, such as reduction of pollutants using IoT and big data, rapid spread of rental cycle due to popularization of sharing economy, are progressing. In the future, these movements will certainly accelerate.

China and Korea are now involved in international environmental cooperation in Asian region and globally. Asia Infrastructure Investment Bank, the Belt and Road Initiative also focus on environmental field as a pillar of cooperation. China-ASEAN Environment Cooperation Center was established under the Ministry of the Environmental Protection, China, and climate change training and assistance are also provided to African countries. In addition, Korea has been promoting international environmental cooperation, including establishment of Global Green Growth Institute and hosting of the United Nations Green Climate Fund.

VI. Changes in Facing Issues

Another major change is the change in environmental problems focused in the area. Traditionally, issues to be discussed in Northeast Asian region include acid rain, dust and sand storm, and PM 2.5, which are cross-border pollution flying from China to Korea and Japan, and marine litter drifting from China and Korea to Japan.

On the other hand, problems such as the electronic waste exported from Japan to China and Korea, the Access and Benefit Sharing of genetic resources under the Convention on Biodiversity, are increasing interests. The Fukushima Daiichi nuclear power plant accident in 2011 caught strong interest in radioactive contamination in China and Korea.

The issue of fire ants that became a big concern in summer 2017 was found from cargo exported to Japan from China, but problems of alien species are expected to increase in both directions in future as economic globalization progresses.

Recently, the idea of capturing the environmental impacts accompanying economic activity in the entire supply chain of products is spreading. Investors and NGOs are pushing companies to disclose information and implement countermeasures against the occurrence of environmental impacts including supply chains. As the economic globalization advances, interdependence such as raw material procurement, parts production, product production is progressing. Unlike transboundary contamination, where origin of pollution is clear and bring impact through one-way, new problems are more complicated and closer cooperation will be needed.

Also, policy competition is progressing like carbon emissions trading. In Japan, Tokyo Metropolitan Government introduced carbon emissions trading in 2010. In China, the pilot projects were introduced in 7 provinces and cities from 2013, and the national system was introduced in Korea since 2015. China announced the launch of the national system in 2017. The three countries started an annual seminar in 2016 with a view to future carbon market links. As for conventional environmental measures, Japan is still at the leading position, but in the future, in some areas of environmental policy, it can be said that the three countries will enter the era of competition.

VII. Continuing Cooperation under Regional Tensions

Cooperation has been continuously developed despite tensions between each of Japan, China and Korea. It indicates environment field would be one of the best fields to promote regional cooperation with mutual benefits among other fields. Even when high level bilateral contact is difficult, ministers still have opportunity to meet their counterparts in the occasion of the TEMM.

Having said this, regional tensions became hurdle for environmental cooperation. When tension was high, due to the pressure from diplomatic authorities, some projects were suspended, or downgraded in terms of level or scale of participants. Some seminars closed the door to observers and media. More seriously, the suspension of the cooperation projects led to the decrease in the budgets in the following years which would give negative impact in the long run.

Vulnerable regional relationships easily lead to overreaction by public opinion and political leaders against transboundary pollution which would bring vicious circle of hard line by one country and strong reaction by the other country as an international environmental problem is dealt as a domestic political issue. Under the political tension, media reporters tend to always look for negative news, and which lead public opinion toward worse direction. Faced with this situation, people in charge of cooperation projects must face strong pressure domestically. Business community also face political risk when entering environmental market in the foreign country, as they found particularly difficult to enter public procurement market under the hostile relationship of the countries.

VIII. Future Prospect

Facing with changes in economic positions and environmental issues as well as political tensions, new paradigm should be introduced to further develop environmental cooperation in the region.

First of all, political confrontation should not be extended to other areas such as economy, tourism, culture as well as the environment. As two-way trade, human exchange as well as environmental problems increase, the confrontation would not only give negative impact on the other country, but also on its own. Moreover, full range confrontation would make resume of cooperation in future very difficult.

Expectation is very high to use environmental cooperation as leverage to improve bilateral and trilateral relationship in the region, as officially mentioned by the national leaders. People working for environment cooperation also hope to somehow contribute to improving the broader "environment" in the region. However, it would be wrong and would not succeed to overly relying on environment cooperation without direct negotiation and coordination on the political issues.

Facing with two-way environmental issues in addition to traditional transboundary issues, it is important to continue discussion in an equal and open manner, and deepen mutual trust. Political trust is necessary to provide base for smooth cooperation and personal trust between leaders are important.

China and Korea's involvement in Asian and global environmental cooperation brings chances for joint collaboration where each county can take advontage of its policy experiance, technology, human and financial resources, and jointly provide assistance to other countries, and plays leading roles in the world. At the same time, it is an opportunity to further strengthen existing cooperation in the region. The countries should consider staring to work from areas which they find relatively easier to set concrete numerical targets and time table.

Chance of win-win cooperation should be explored between the countries beyond the traditional one-sided aid. Recognizing that Chinese companies are catching up at the technology level, it is important for Japanese companies to promote production and sales based on local needs with low-cost. The support that the government can provide to enterprises is to secure the political stability of the region first, and then to provide necessary assistance for specific projects. Especially for small and medium enterprises, sufficient support should be considered.

With China's economic growth, the development of new technologies, and the development of environmental policies, Japan's experience will become older in the future. Therefore, it is necessary to constantly make improvements on domestic policies without believing in one's publicity, by taking account of competition of companies' technologies and new era of inter-government policy competition.

When considering further cooperation, possibility of multi-stakeholder participation is advantage of environmental cooperation. Track 1.5 and Track 2 cooperation, especially involvement of NGOs and the youth should be further promoted. In this sense, the countries should consider more diverse participants beyond traditional manner.

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International Overview of Sacred Natural Sites and Indigenous and Community Conserved Areas (ICCAs) and the Need for Their Recognition

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Abstract

Sacred natural sites and indigenous and community conserved areas (ICCAs) are repositories of biological and cultural diversity, and represent communities' religious values, customary rules, institutional fabric, traditional knowledge and conservation culture. With changing environments, ICCAs, including sacred sites, face external and internal challenges to their survival, evolution and preservation. As such, ICCAs require recognition on par with the official protected areas managed by governments. Yet despite increasing recognition of ICCAs in international conservation policies, they still largely lack effective and appropriate recognition in national policies and practices. In addition to exploring sacred groves as ICCAs, this article examines the policy and legal instruments that recognize ICCAs at the international and national levels. This article also recommends strategies to enhance the protection of ICCAs, including by shifting the paradigm from government-controlled protected areas to community-controlled conservation areas. National policies and legislation must give more prominence to the customary laws and traditional institutions of the indigenous peoples and local communities managing these conservation areas, as well as acknowledging their rights to self-governance and self-determination.

Keywords:

Sacred groves; Sacred natural sites; ICCA; Indigenous people; Protected areas; Community conservation

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神聖な自然地と先住民・コミュニティ保全地域（ICCAs）についての国際的概観、およびこれらの認識の必要性

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概要

神聖な自然地と先住民・コミュニティ保全地域（ICCAs）は生物的文化的多様性の宝庫であり、コミュニティの宗教的価値、伝統的しきたりや知識、保全文化の現われである。しかしながら、環境変化によって、ICCAsや神聖な土地の存続が危ぶまれる事態が起こってきており、ICCAsについても公的な保全地域と同様な認識が得られるべきである。国際的な保全政策においてICCAsの認識は高まりつつあるが、国家レベルの政策実行においては未だ極めて不十分な実態がある。本論においては、ICCAsの国際的国家的レベルにおいての制度的措置について概観を行った。政府が管理する保全地域からコミュニティが管理する保全地域へのパラダイムシフトのためには、国家レベルの政策において、伝統的法制度、先住民の自治、コミュニティによる保全地域の管理などを明確に位置づけることが必要である。

International Overview of Sacred Natural Sites and Indigenous and Community Conserved Areas (ICCAs) and the Need for Their Recognition

Introduction

Indigenous peoples and local communities, both settled and nomadic, have for millennia played a critical role in conserving a variety of natural environments and species. Such conserved areas range in size from a few trees or a small tract of land to much larger landscapes. These communities practice conservation for a variety of economic, social, cultural, spiritual, and aesthetic reasons. These local conservation areas were popularly known as 'sacred groves' – culturally conserved sites with flora and fauna, religious sites with significant biota, and environmentally conserved areas protected and preserved by indigenous people and / or local communities. Once existing all over the world, particularly in ancient Europe, Japan, China, the Indian subcontinent, South-East Asia, Africa, Mexico, and parts of the Middle East, today most sacred groves are contained within government-managed protected areas such as national parks and sanctuaries, or outside formal protected areas altogether.

The ancient culture of conservation has continued into the early 21st century with the modern movement of nature conservation on the part of States. Indigenous people and local communities have also continued to conserve territories outside government-managed protected areas in the form of sacred groves or other types of commons (with communal tenurial rights). In 2003, the 5th World Parks Congress (WPC5)(1), held in Durban, recognized such areas and territories as indigenous and community conserved areas (ICCAs)– spaces governed *de facto* by indigenous peoples or local communities. This recognition has had positive outcomes for the conservation of biological and cultural diversity in ICCAs. Today there are thousands of ICCAs across the world, including sacred wetlands, village lakes, forests, landscapes, catchment forests, rivers, coastal stretches, and marine areas. Fortunately, there is also a growing recognition of ICCAs and an acknowledgement of their role in the conservation of biodiversity. Some governments have integrated them into their official Protected Area Systems, and the Programme of Work on Protected Areas (PoWPA)(2) of the Convention on Biological Diversity (CBD) has recognized them as legitimate conservation sites that deserve support and, as appropriate, inclusion in national and international systems. Indeed, the 11th, 12th and 13th Conference of the Parties (COP) to the CBD also adopted a wide range of decisions broadly relevant to ICCAs, giving distinct recognition to this concept of community conservation. In 2016, the IUCN(3) World Conservation Congress focused specifically on ICCAs. By mid-2017, over 64 countries had recognized ICCAs, while 28 countries had properly registered in the ICCA registry.(4)

(1) https://www.iucn.org/content/2003-durban-world-parks-congress
(2) https://www.cbd.int/protected/pow
(3) The World Conservation Union, https://www.iucn.org/
(4) http://www.iccaregistry.org/en/explore

Despite increasing recognition of ICCAs in international conservation policies, for the most part they still lack effective and appropriate recognition of ICCAs in national policies and practices. In cases where there is no legal recognition of ICCAs within a country, there may also be a lack of recognition of ICCAs by private entities and neighbouring communities. In such cases, ICCAs are vulnerable to appropriation or development for alternative use. To non-members of the relevant communities, many ICCAs appear as natural, 'unmanaged' and 'unutilized' ecosystems – all the more coveted for resource extraction. ICCAs may also suffer as a result of changing value systems, increased pressure on natural resources, and other internal tensions. As a result of these threats and challenges, there is now a striking urgency to revive, sustain, preserve and maintain ICCAs.

How can the protection of ICCAs be realized? Global policies and frameworks can create an environment conducive to supporting ICCAs. Changing international policies to create a more supportive legal environment is important, not only to change the attitudes of civil society, national governments, the private sector, and local communities towards the sacred sites or ICCAs, but also to pave the way for structured institutional support for ICCAs. National policies and legal instruments must also enable ICCAs to survive sustainably. Countries can promulgate policy or legislation based on model international legal instruments. This article highlights changes to international and national law and policy environments that can improve protections for ICCAs. It is recommended that ICCAs receive national treatment on par with formal protected areas governed under State laws. This will enable the protection of ecosystems and habitats, and the conservation of biological and cultural diversity in community-controlled ICCAs as they are preserved in State-controlled formal protected areas.

Sacred Natural Sites and their Philosophical Foundations

The foundations of conservation go back to the time of temple gardens in Asia and European game preserves (Borgerhoff-Mulder and Coppolillo, 2005). For example, the totemic system was an ancient practice among indigenous and traditional communities around the world, relating to the animals or plants assigned by and to particular families. Humanity's reverential relationship to plants and animals has not vanished with advances in science and technology (Sivakumar, Nair and Jaya, 2014).

Sacred groves are one example of human-nature interactions that rest on cultural, spiritual, religious and socio-economic foundations. A sacred grove is a grove of trees / vegetation or a land- or waterscape that is protected and conserved by the local community through traditional, cultural, social and religious practices. Sacred groves feature in various cultures throughout the world, and have been closely interwoven with social and cultural life. They were important features of the mythological landscape and cult practices of Celtic, Baltic, Germanic, ancient Greek, Near Eastern, Roman, and Slavic polytheism, and were also used in India, Japan, China, and Africa, although they were called by many different names. Though India has documented the sacred forests or groves thoroughly, traditional sacred areas of various types are found in all parts of the world (Ramakrishnan, Saxena and Chandrashekara, 1998). Many parts of Mexico, Ghana, Nigeria, Syria, Turkey and Japan are reported to hold a concept of sacred groves (Priyanka, Singh and Husain, 2012). In Kenya, it is 'Kaya', whereas in Japan, sacred groves are called 'Chinju-no Mori' (Madeweya, Hiroyasu and Mitsuo, 2004). As Kala (2011) states, the evidence suggests that the sacred grove concept of biodiversity conservation was adopted by various indigenous communities worldwide, including Aboriginal Australians, the communities of the Caucasus Mountains, ancient Slavic people, German tribes (Tokarev, 1989), ancient Greeks and Romans, the Kikuyu of Africa (Hughes, 1990), and the Mbeere tribe of East Africa (Gowda, 2006). In many parts of the world, local habitat taboos often provide effective protection for smaller ecosystems, for example in West Africa (Lebbie and Guries, 1995; Kokou *et al.,* 1999), East Africa (McClanahan *et al*., 1997; Mgumia and Oba, 2003), Southern Africa (Byers, Cunliffe and Hudak, 2001), India (Gadgil and Guha,1993) and China (Liu *et al*., 2002). In South Asia, religion and nature are seen as intertwined; since the 'Vedic' era, there has been a strong notion that humans should not destroy nature (Sivakumar, Nair and Jaya, 2014). For example, the sacred groves of Meghalaya, in India, are village forest lands set aside for religious purposes under the traditional land tenure system (Gurdon, 1975). It is an offense, customarily, to cut trees from a sacred grove except for cremation and religious purposes. Three types of forests under traditional forest classification system (viz. Law Lyngdoh, Law Kyntang and Law Niam) are considered sacred forests in Meghalaya (Tiwari, Barik and Tripathi, 1998).

It is believed that before the spread of Christianity and Islam, sacred groves covered much of the Middle East and Europe. Despite its decline, the concept of the sacred grove is still relevant today, especially in many parts of Asia, Africa and Mexico (Gadgil, Berkes and Folke, 1993). In India, for example, over 13,720 sacred groves have been listed (Malhotra *et al*., 2001), existing across diverse topographical and climatic conditions from north to south. Likewise, Ecuador has identified 328 sacred sites and 263 sacred sites have been identified in the Russian north (Oviedo, 2006).

Sacred groves are home to a number of plant and animal species that are not found elsewhere (Haridasan and Rao, 1985) and hence they are very rich in biodiversity. For example, a sacred grove of just 1.4 km^2 in the Indian state of Kerala has 722 species of angiosperms, whereas an area of 90 km^2 in Silent Valley National Park in the same state has 960 species. Thus, the size of a sacred grove cannot be a measure for the biodiversity resources it contains (Basha, 1998). Darlong (1995) notes that since sacred groves provide safe sites for the reproduction of a variety of plant and animal species, they also help in maintaining viable populations of pollinators and predators and in conserving germplasm (Khiewtam, 1986). Thus, sacred groves are precious resources for native utilization of plant varieties and ethnobotanical practices. Indeed, many of the plants in sacred groves have medicinal value as well as environmental importance. For example, in Pallapatty village in Tamil Nadu, India, a total of 133 plant species belonging to 113 genera of 51 families are found in sacred groves, and many have spiritual and therapeutic uses (Ganesan *et al*., 2009).Numerous studies have highlighted the role of sacred groves in the conservation of biodiversity across India, including in West Bengal (Pandit and Bhakat, 2007), Northeast India (Khumbongmayum, Khan and Tripathi, 2004), and the Eastern Ghats (Gadgil and Vartak, 1976).

Moreover, sacred groves encompass canopies that provide the necessary shade for keeping air, soil and water clean and pollution free. Due to the thick vegetation present in sacred groves, the topsoil is also protected and kept wet enough to sustain watersheds. Plant residues like dry leaves and twigs provide a natural bed, helping the soil to retain desired levels of moisture, aeration and fertility. The microclimate associated with sacred groves serves as a catalyst for nutrient recycling, and can also recharge aquifers and act as a primary source of perennial streams. Soil is usually rich in nutrients, and the canopy of vegetation helps prevent soil degradation, resulting in soil with a high accumulation of biomass and organic contents (Kala, 2011). Land surrounding sacred groves also tends to have higher moisture content, and farmers in proximity of such groves have relatively higher production of crops (Kala, 2011). As a result of these factors, sacred groves have been found to generate important ecosystem services for local communities, including non-timber forest products (e.g. medicinal plants, fruits, and firewood), firebreaks, watershed protection, and protection of freshwater sources (Lebbie and Guries, 1995; Virtanen, 2002; Ramakrishnan, 1998).

From Sacred Nature to Modern Conservation

According to Robson and Berkes (2010) the similarities between traditional and modern conservation are greater than many people appreciate. Colding and Folke (1997) found that nearly one-third of species-specific taboos held by indigenous peoples worldwide corresponded to threatened species that appeared on the IUCN Red List.[5]

Many UNESCO World Heritage Sites[6] integrate the conservation of cultural and biological diversity, sacred mountains, sacred forests, temples and shrines, sacred lakes and springs. Schaaf and Lee (2006) have reiterated the classification proposed by UNESCO of sacred sites. These are: (1) sacred mountains (e.g. sacred sites and pilgrimage routes in the Kii Mountain Range of Japan, Mount Fuji of Japan, sacred peaks of the Nepali and Indian Himalayas, Adam's Peak in Sri Lanka); (2) sacred landscapes (e.g. sacred hidden valleys of the Nepali Himalayas, sacred sites and burial sites of Kyrgyzstan, the cultural landscape of the Kalahari in Botswana, sacred islands of the Solovetsky Archipelago in the White Sea, Russia); (3) sacred forests (e.g. sacred forests in temples and shrines in Japan, Kaya forests of coastal Kenya, sacred areas with protective magic, co-managed Bolivian sacred forests and indigenous lands); and (4) sacred water (e.g. American Indian sacred springs and waters of New Mexico, Sacred Sites and Gathering Grounds Initiative of Arizona, sacred lakes and springs of the Huascarán World Heritage Site and Biosphere Reserve in Peru, rivers of the Ainu people in Japan).

Robson and Berkes (2010) also note that many national parks around the world have been established at the sites of former sacred areas. One such example is the Alto Fragua Indiwasi National Park – the first

(5) http://www.iucnredlist.org/

(6) http://whc.unesco.org/en/list

national park in Colombia created at the request of indigenous groups. Another example is the Kazdagi National Park in western Turkey, which was established in an area with centuries-old sacred sites and a high diversity of trees used by local woodworkers for crafting wood products since the time of the Ottoman Sultan Mehmed II in the 1400s (Berkes, 2008). Likewise, Namibia's ICCA, the Ehi-rovipuka Conservancy, borders Etosha National Park and is part of a national network of conservancies that devolve wildlife rights, use and benefits to local communities (Hoole, 2008). It is one of the community-based conservation areas in southern Africa that originated with the Communal Areas Management Program for Indigenous Resources (CAMPFIRE) in Zimbabwe in the 1980s and spread to other countries like Zambia and Mozambique (Fabricius *et al*., 2004). These cases exemplify mixed systems that respond to contemporary issues and livelihood needs, while retaining historic sacred relations and traditional land use practices.

Sacred natural sites are now encompassed in the concept of Indigenous and Community Conserved Areas (ICCAs). Alongside ancient ICCAs such as sacred groves, a number of new ICCAs have been established in recent years. As the IUCN (2016) describes, ICCAs are natural and / or modified ecosystems containing significant biodiversity value, ecological services and cultural value, voluntarily conserved by indigenous peoples and local communities, both sedentary and nomadic, through customary laws or other effective means. ICCAs can include ecosystems that have been minimally or substantially influenced by humans, and can also encompass cases of the continuation, revival or modification of traditional practices as well as new initiatives taken up by communities in the face of changing threats or opportunities. In terrestrial areas, ICCAs often emerge from a combination of traditional practices applied to new species, and an evolving consensus on what constitutes environmentally friendly land use practices (Robson and Berkes, 2010). In the case of waterscapes, marine ICCAs are often a legacy of traditional reef and lagoon tenure systems in which the use of closed areas, closed seasons and taboo species is common. More than 500 locally managed marine areas are found in the Philippines and more than 300 in Fiji, reflecting rapidly growing networks resulting from the efforts of leading island nations (LMMA Network, 2009).

Pathak-Broome and Dash (2012) have highlighted that the analysis of 140 case studies from India indicates that 99 community conserved areas (CCAs) have sustained the availability of natural resources; 62 CCAs have financially benefited people from the sale of resources; 67 CCAs have socially benefited by maintaining livelihoods and social equity; 52 CCAs have culturally benefited the local community through cohesiveness within the community, revival of abandoned cultural practices and so on; and 22 CCAs have provided better employment opportunities. Political or governance-related benefits are also an important aspect of CCAs (Pathak-Broome and Dash, 2012).

Barring certain exceptions, ICCAs are mostly found on common or collectively owned and managed lands, or on government lands that may have originally been the customary commons of indigenous peoples or local communities. Kothari *et al.* (2012) have identified several categories of ICCAs, including:

- Sacred natural sites or spaces, ranging from tiny forest groves and wetlands to entire landscapes and waterscapes, often (but not necessarily) left completely or largely inviolate (Kothari *et al.*, 2012).
- Indigenous peoples' territories having both sustainable use value and cultural value (e.g. Tierras Comunitarias de Origen in Bolivia[7], indigenous territories with multiple villages in Suriname, Indigenous Protected Areas in Australia[8], Indigenous Reserves in Costa Rica[9], Indigenous 'Comarcas' in Panama[10]).
- Territories (terrestrial or marine) over which nomadic communities have traditionally roamed, managing resources through customary regulations and practices (e.g. customary rangelands of tribal confederacies in Iran, pastoral landscapes in Kenya and Ethiopia (Bassi, 2006)).
- Resource catchment areas on which communities base their livelihoods or from which key ecosystem benefits are derived, managed in such a way that these benefits are sustained over time (e.g. locally managed marine areas[11] in the South Pacific and Madagascar, autonomous marine protected areas and Satoumi seascapes in Japan (Tsujimoto, 2011), marine areas for responsible fishing in Costa Rica, community forests in countries of South Asia, Tanzania and others (Bhatt *et al*., 2012; Makino, 2011; Yagi, 2011).
- Nesting or roosting sites, other critical habitats of wild plants and animals, or wildlife populations spread over large territories, conserved for ethical or other reasons connected to the protection of plants and animals (e.g. dozens of bird nesting and roosting sites in India, sacred crocodile ponds in Gambia and Mali, certain tree species like arawone (*Tabebuia serratifolia*) in Suriname, marine turtle nesting sites in Chile, Costa Rica, Suriname, and several countries of South Asia (Bhatt *et al.,* 2012).
- Landscapes with mosaics of natural and agricultural ecosystems, containing considerable cultural and biodiversity value, managed by farming and pastoral communities or mixed rural-urban communities (e.g. Parque de la Papa in Peru[12], some protected landscapes in Europe, and others (Amend *et al*., 2008; Brown and Kothari, 2011; MEQ, 2011).

There are no exact figures for ICCAs available to date, as the concept has only been consolidated recently. Some scholars estimate that about 420 million ha of forests (11% of the world's total) are under community ownership or administration (Molnar, Scherr and Khare, 2004), and that this could double in the near future (White, Khare and Molnar, 2004). UNEP-WCMC has established an ICCA Registry[13], which has begun

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(7) http://www.territorioindigenaygobernanza.com/bov_06.html
(8) http://www.environment.gov.au/land/indigenous-protected-areas
(9) E.g. Talamanca Cabecar Indigenous Reserve, Maleku Indian Reserve, Yorkin Indigenous Reserve (http://www.timetravelturtle.com/2014/01/bribri-yorkin-indigenous-costa-rica/), and so on.
(10) http://www.villagerights.com/Panama-The-Comarca-And-The-Kuna
(11) http://lmmanetwork.org/
(12) http://www.parquedelapapa.org/
(13) http://www.iccaregistry.org/

to document ICCAs[14]. ICCAs may far outnumber current officially designated protected areas (of which there are about 130,000 – mostly governed by government agencies), covering as much if not more territory (nearly 13% of the earth's land surface) (Kothari *et al.*, 2012).

Threats and Challenges to Sacred Sites and ICCAs

Currently threats and challenges faced by ICCAs are at a critical point. Over the last two centuries, formal policies and practices governing conservation and development have largely ignored ICCAs, or worse-actively threatened them. Even today, as neglect and harm give way to emerging recognition and support, the interface between state-promoted institutions and the customary institutions of indigenous peoples and local communities remains riddled with conflict.

The ICCA Registry (2016) has identified the following threats to ICCAs:

- Loss of important sacred sites, species and traditional medicines;
- Undeclared ownership or tenure of land and resources (i.e., lack of recognition);
- Inappropriate forms of recognition or national policies that weaken traditional governance;
- Conflict with other protected areas overlapping with the ICCA, leading to expropriation of community lands;
- Development (transport infrastructure, buildings and so forth);
- Extraction (e.g. hunting, mining, logging, fishing);
- Localized impacts of global climate change;
- Invasive species;
- Over-harvesting of resources;
- Biodiversity decline;
- Excessive tourism access;
- Inappropriate management;
- De-legitimization of customary rights;
- Inequities (social, economic and / or political) within the ICCA;
- Conflict with neighbouring or associated communities;
- War and movement of refugees;
- Loss of traditional or local knowledge;
- Change in cultural practices; and
- Destabilization of community due to exodus of members.

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(14) Kothari *et al.* (2012) have reported that certain ICCAs were documented until 2012 in some countries, including Australia (50), Bolivia (258), Canada (30), Costa Rica (22), Fiji (150), India (20000, with 100000–150000 sacred natural sites), Iran (several hundred), Japan (>1000), Kenya (111), Mexico (301), Namibia (89), Nepal (several hundred), Philippines (156), Russia (475), Senegal (33), China (60000), Madagascar (1016), and Tanzania (1457). The documentation is still evolving.

Gu and Chen (2011) articulate that despite progress made at the international level, challenges remain as to how to develop contextualized local strategies to maintain the cultural and ecological integrity of such sites, which are increasingly under pressure from rapid socio-economic changes. Sacred natural sites in developing countries are particularly susceptible to the negative impacts associated with infrastructure development, tourism, commercial farming and secularization. However, with proper and appropriate governance procedures in place, ICCAs could be an integral part of tourism and sustainable development.

There also remains an overall lack of effective and appropriate recognition in national policies and practices. In cases where there is no legal recognition within a country, ICCAs may also not be recognized or respected by private entities and neighbouring communities. In such cases, ICCAs are vulnerable to land and water being appropriated or "reallocated" for an alternative use. To non-members of the relevant communities, many ICCAs appear as natural, "unmanaged" and "unutilized" ecosystems, and are coveted for resource extraction. ICCAs may also suffer as a result of changing value systems, increased pressure on natural resources, and other internal tensions. In general, ICCAs are exposed to both external and internal threats that must be met with systematic institutional and policy interventions.

International Recognition of ICCAs

At the global level, conservation professionals acknowledged that indigenous peoples and local communities should be fully recognized in conservation governance for the first time at the 5th World Parks Congress (WPC 5) held in Durban in 2003. The WPC also developed specific recommendations on ICCAs and on the governance of protected areas (PAs) (IUCN, 2016). The IUCN and various civil society organizations federated under the ICCA Consortium[15] pushed the need for the recognition of ICCAs at the intergovernmental level.

The first global recognition of ICCAs occurred with the UN Convention on Biological Diversity (CBD). Shortly after WPC 5, parties to the CBD at its COP 7 meeting in Kuala Lumpur in 2004 approved the CBD Programme of Work on Protected Areas (PoWPA), which supported a "new approach" to protected areas, calling for greater attention to the type and quality of governance, to equity in conservation, and to indigenous peoples' rights. The CBD's COP 8 and COP 9 reviewed the implementation of PoWPA and stressed the need to engage more robustly with 'Governance, Participation, Equity and Benefit Sharing' (CBD, 2016). This was also reflected in the statement of recommendations that the CBD's SBSTTA[16] submitted to COP 10 in Nagoya in October 2010. Notably, SBSTTA delegates made specific recommendations

(15) https://www.iccaconsortium.org

(16) Article 25 of the Convention on Biological Diversity established an open-ended intergovernmental scientific advisory body known as the Subsidiary Body on Scientific, Technical and Technological Advice (SBSTTA) to provide the Conference of the Parties with timely advice relating to the implementation of the Convention. https://www.cbd.int/sbstta/

concerning the recognition of ICCAs, clarifying, for example, that "mechanisms for recognition should respect the customary governance systems that have maintained ICCAs over time" (IUCN, 2010). At COP 10, Decision X/31 also stressed the role of indigenous peoples and community conserved territories and areas, and invited Parties to recognize their organizations and contributions.[17] COP 10 also produced the Strategic Plan for Biodiversity 2011–2020, with 20 'Aichi Targets'.[18] Each of these targets is in some way related to ICCAs, since ICCAs cut across the entire spectrum of issues on biodiversity. However, Aichi Targets 11, 13, 14 and 15 are of particular and direct relevance to ICCAs. While COP 10 embraced the text on ICCAs, noting that national legislation should explicitly address ICCAs (and that legislation that does not address them should be improved to do so), it failed to mention the need for safeguards addressing customary governance systems.[19]

COP 11 in Hyderabad signaled a step change, with direct references to ICCAs in Decision XI/14 on Article 8 (j) and Related Provisions.[20] COP 12 in Pyeongchang further entrenched ICCAs in the CBD through a number of decisions (Decisions XII/3, XII/5, XII/12, XII/19).[21] These decisions contain provisions addressing the need for 'appropriate' recognition and support of ICCAs.[22] COP 12 also acknowledged that many poor communities have traditionally been very effective at conserving nature and biodiversity (Decision XII/5, preamble) and it encouraged Parties, other governments, international organizations and relevant stakeholders to support ICCAs (Decision XII/5, para 11). Emphasis was placed on linking ICCAs with the provisions of UNDRIP, underscoring the inclusion of indigenous peoples' rights.[23] COP 12 cautioned Parties not to interfere with customary governance systems underlying ICCAs. It also invited Parties and others to promote ecosystem conservation and restoration in ICCAs, with the full and effective participation of indigenous and local communities (Decision XII/19, para 4 (b)), and to provide support and incentives to indigenous and local communities in their efforts to conserve biodiversity in ICCAs (Decision XII/19, para 4 (f)).[24] Like COP 12, COP 13, held in Cancun, Mexico in 2016, addressed ICCAs in its decisions XIII/2, XIII/5, XIII/20, XIII/28.[25] Under decision XIII/2, para 7, the COP invited Parties, the IUCN, the ICCA Consortium and other partners to develop voluntary guidance and best practices on identifying and recognizing ICCAs, including in situations of overlap with protected areas (as emphasized in XIII/2, para 5 (b) (viii)).[26] Notably, Decision XIII/5 ("*Ecosystem restoration: short-term action plan*") stressed that

(17) CDB's COP 10 Decision X/31 –Protected areas: http://www.cbd.int/decision/cop/?id=12297
(18) https://www.cbd.int/sp/targets/
(19) http://www.iccaconsortium.org/?page_id=35
(20) https://www.cbd.int/doc/decisions/cop-11/cop-11-dec-14-en.pdf
(21) https://www.cbd.int/decisions/cop/?m=cop-12
(22) https://www.iccaconsortium.org/index.php/2014/12/14/decisions-of-cbd-cop-12-pyeongchang-2014/
(23) https://www.iccaconsortium.org/index.php/2014/12/14/decisions-of-cbd-cop-12-pyeongchang-2014/
(24) https://www.cbd.int/decision/cop/default.shtml?id=13382
(25) https://www.cbd.int/decisions/cop/?m=cop-13
(26) https://www.iccaconsortium.org/index.php/2016/12/19/decisions-of-cbd-cop-13-cancun-2016/

restoration activities must include support for ICCAs and respect for the traditional customary knowledge and practices of communities (XIII/5, Annex, Section IV/C, para 15 (1)).(27)

Subsequently, other international organizations have given paramount importance to ICCAs. In 2016, the IUCN World Conservation Congress focused specifically on ICCAs. Resolution 6.030 called for recognizing and respecting the territories and areas conserved by indigenous peoples and local communities (ICCAs) that are overlapped by protected areas.(28) UNESCO also developed guidelines incorporating ICCAs and culturally-conserved sites into its MAB(29) and World Heritage Sites programs. As a result, ICCAs have started to gain policy recognition at the global level through international agreements and guidelines. Several international human rights frameworks (see Box.1), some dealing directly with indigenous peoples, and others dealing with peoples and communities in general, also support ICCAs.

Box.1: International Frameworks Supporting ICCAs

African Charter on Human and Peoples Rights (1986);

American Convention on Human Rights (1978);

American Declaration on the Rights and Duties of Man (1948);

American Declaration on the Rights of Indigenous Peoples (2016);

Convention on the Elimination of all Forms of Racial Discrimination (CERD) (1965);

FAO Voluntary Guidelines for Securing Sustainable Small-Scale Fisheries in the Context of Food Security and Poverty Eradication (2015);

FAO Voluntary Guidelines on the Responsible Governance of Tenure of Land, Fisheries and Forests in the Context of National Food Security (2012);

Global ICCA Registry;

Globally Important Agricultural Heritage Systems (GIAHS);

International Covenant on Civil and Political Rights (1966);

International Covenant on Civil and Political Rights (1976);

International Covenant on Economic, Social and Cultural Rights (1976);

International Labour Organization (ILO) Convention No. 169 concerning Indigenous and Tribal Peoples in Independent Countries (1989);

International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGRFA);

Principles and Guidelines for the Protection of the Heritage of Indigenous Peoples (of Special Rapporteurs of the United Nations Working Group on Indigenous Populations);

UNESCO Convention for the Safeguarding of the Intangible Cultural Heritage (Convention on Cultural Heritage);

(27) https://www.cbd.int/doc/decisions/cop-13/cop-13-dec-05-en.pdf

(28) https://portals.iucn.org/library/sites/library/files/resrecfiles/WCC_2016_RES_030_EN.pdf

(29) Man and Biosphere Programme (MAB): http://www.unesco.org/new/en/natural-sciences/environment/ecological-sciences/man-and-biosphere-programme/

UNESCO Convention on the Protection and Promotion of the Diversity of Cultural Expressions (Convention on Cultural Expressions);

UNHRC's Expert Mechanism on the Rights of Indigenous Peoples (EMRIP);

United Nations Declaration of the Rights of Indigenous Peoples (UNDRIP) (2007);

United Nations Declaration on the Rights of Persons Belonging to National or Ethnic, Religious and Linguistic Minorities (1992);

United Nations Permanent Forum on Indigenous Issues (UNPFII);

Universal Declaration on Human Rights (1948)

The Vital Importance of Future National Recognition of ICCAs

Throughout the globe most sacred groves have no legal recognition or protection, resulting in the degradation of sacred sites. States have generally created formal protected areas under statutory laws.

Critical gaps exist in the recognition of sacred sites and ICCAs by States. Since ICCAs are usually based on customary law and traditional practices, not only do they often lack statutory protections in national laws, but they are also often affected by unfavourable legislation (Kothari, 2006). Nevertheless, there are a number of countries where ICCAs are under protection by national or local government policies and laws, either explicitly as conservation units or protected areas (e.g. in Australia and many South American countries), or more generally through protection given to community territories and rights. Some ICCAs have been recognized as equivalent to protected areas and are included in national systems of protected areas in countries such as Australia and Namibia (Stevens, 2014). India has also amended its Wildlife (Protection) Act, 1972 (as amended in 2002) to accommodate community conserved areas as an additional category of protected area, but again, the state has considerable authority to interfere with and control the ICCAs. Many more ICCAs meet the international criteria for protected areas, but nationally have not yet been recognized as such (Kothari *et al.*, 2012; Stevens *et al.*, 2016a).

Their conservation is made even more difficult by the fact that some forms of legal recognition are inappropriate. Kothari *et al.* (2012) note that in cases where ICCAs are not recognized, indigenous peoples and local communities are more likely to suffer a range of adverse effects, including:

- A resort to short-term land management decisions, as communities are restricted from making long-term plans in accordance with their own visions and aspirations;
- The undermining of, or disregard for, communities' customary laws, procedures and protocols if the government simultaneously issues exploitative concessions and other permits in indigenous territories or communities' lands without their involvement or free, prior and informed consent;
- The overruling of customary rules and traditions by force or by court decision;
- General legal uncertainty and marginalization causing suffering on the part of communities.

Recently, the overlap between formal protected areas and ICCAs has been brought squarely into the debate. The IUCN World Conservation Congress 2016 and the CBD COP 13 decisions of 2016 particularly highlight this overlap. In countries such as India, Nepal, the Philippines, Iran, Colombia, Bolivia, Canada, Australia, and USA, the overlaps are particularly extensive and can involve most or all of the national protected area system (Stevens *et al.*, 2016b). Stevens *et al.* (2016a) note that one of the main consequences of such overlap is the superimposition of official protected area governance and management systems upon ICCAs. This has profound consequences for both conservation and the wellbeing and cultures of the concerned peoples and communities (Tauli-Corpuz, 2016; Stevens, 2014).

Despite contentious debates, some countries have recently started to seek legal backing in order to create conducive environments for ICCAs in their territory. Moreover, either explicitly or implicitly, certain laws in a large number of countries have supported sacred sites or ICCAs. In some places, people have identified enabling legal provisions in order to enhance conservation, whereas in others, people have missed such opportunities. Going forward, it is important to closely examine the interplay between legal and policy recognition of ICCAs and sacred sites in selected case countries, as this may uncover gaps in national legal or policy instruments.

The Case of India

In India, only the state of Meghalaya has a legal framework addressing sacred groves. The United Khasi-Jaintia Hills Autonomous District (Management and Control of Forests) Act, 1958 and the Garo Hills Autonomous District (Management and Control of Forests) Act, 1961 under the Sixth Schedule of the Indian Constitution(30) govern the sacred groves of Meghalaya. The Sixth Schedule of the Constitution, under Articles 244 (2) and 275 (1), provides exclusive protection of tribal territories in the states of Assam, Mizoram, Meghalaya and Tripura. The special administration of tribal territories does not specifically mention ICCAs, although it does emphasize self-governance of natural resources by the tribes themselves through the application of their customary laws and institutions. Like Sixth Schedule areas, Indian Constitution also established and protects tribal territories through Fifth Schedule(31) areas in which the Provisions of Panchayats (Extension to Scheduled Areas) Act, 1996 applies.

The most important law relating to ICCAs is the Wildlife (Protection) Act, 1972. Interestingly, an amended version of this law, the Wildlife (Protection) Amendment Act, 2002, included two additional

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(30) http://lawmin.nic.in/olwing/coi/coi-english/Const.Pock%202Pg.Rom8Fsss(34).pdf

(31) Under Article 244 (1), the most important institution is the Tribes Advisory Council. Essentially The Fifth Schedule is a historic guarantee to indigenous people on the right over the land they live in. Such areas exist in 9 provinces of India namely Andhra Pradesh, Jharkhand, Chhattisgarh, Himachal Pradesh, Gujarat, Madhya Pradesh, Maharasthtra, Orissa and Rajasthan. http://www.constitution.org/cons/india/shed05.htm

categories of protected area: 'community reserve'[32] and 'conservation reserve'[33]. According to Pathak-Broome and Dash (2012), Community Reserves can be declared by the government on privately-owned or community lands (the definition of which is not clear). On the other hand, Conservation Reserves can be declared by the government on government-owned lands in consultation with local people. However, in both cases, the proposal for declaration and the declaration itself can only be made by the government; communities have no power to declare their own CCAs (Pathak-Broome and Dash, 2012). While the Community Reserves resemble CCAs, there are also obstacles to legally treating CCAs as Community Reserves. Almost all of the 663 national parks and sanctuaries of India overlap with and include one or more ICCAs without recognizing and devolving community ownership and control. As per the legal provisions, no protected area can be declared a Community Reserve or CCA without de-notifying the protected area first. Pathak-Broome and Dash (2012) identify the underlying problem – the Act mandates a uniform governance system for Community Reserves, which is inappropriate given the very large diversity of customary management arrangements that communities have developed in CCAs across India. This creates a situation where most communities prefer not to declare their CCAs as Community Reserves since this category of protected area does not recognize existing systems of community customary governance. The National Environment Policy 2006 also recognizes that communities have a special role in protecting common resources, but it fails to clearly define space for CCAs in the country's policy or legal domains.

Thus, the case of India demonstrates how community power is undermined and how conservation suffers because the legal apparatus and policies do not support community initiatives, people's ownership over natural resources, and the customary laws that underlie the success of conservation.

The Case of Iran

Though the Islamic Republic of Iran has not yet evolved any specific law or policy recognizing ICCAs *per se*, there are few ways in which ICCAs may be recognized. Iran is known for a tradition of community management of natural resources, particularly in the migration territories of nomadic indigenous peoples (estimated to be over 700 tribes). Article 44 of the Constitution[34] of Iran 1979 refers to the handover to nomadic tribes and other local communities collective governance rights to their territories.[35] Article 2 of the 1980 Law on Conservation and Use of Forests and Rangelands provides that the reallocation or change of

(32) Sections 18, 35, 36A and 36C of Wildlife (Protection) Amendment Act, 2002

(33) Sections 36B of Wildlife (Protection) Amendment Act, 2002

(34) https://www.constituteproject.org/constitution/Iran_1989.pdf?lang=en

(35) This article can be an opportunity as well as a threat for the rights of IPs and LCs as it can be interpreted to reducing the role of government in governing natural resources though processes of privatization. Enlightened government officials believe that the article could allow, however, the fusing of indigenous knowledge with the latest scientific findings in the field of range ecology in the territories of nomadic tribes, which would be governed/ managed by the tribes through their registered and formally recognized CBOs, with the support of both government and CSOs (Naghizadeh, Abbas and Farvar, 2012).

use of 'public lands' is 'absolutely forbidden' in areas including the common property rangelands of villages; forest parks and common property forests; and the customary migration routes and territories reserved for nomadic tribes. This law clearly confirms the absolute inviolability of migratory territories (the heart of territorial rights of indigenous people in Iran) and strictly forbids any change of use of their purpose (Naghizadeh, Abbas and Farvar, 2012). Other than these laws, there are several practical cases where the State has recognized ICCAs. For instance, the Department of the Environment (DOE) confirmed in 2005 the recognition (initially made at provincial level) of the Namdan Plain Wetland as an ICCA of the Shish Bayli tribe of the Qashqai nomadic people. Another such example is the ICCA of the Farrokhvand tribe of the Bakhtiari nomadic tribal confederacy, which is not only valuable for grazing, but also for its economically valuable wild plants. As partners of UNDP-GEF projects, the Ministries of Foreign Affairs, Agriculture, Energy, Forest, Rangeland and Watershed Organization officially recognize numerous areas resembling ICCAs with tribes having managerial control.

As for *de jure* government recognition of ICCAs, the situation is still very fluid. The active engagement of CSOs by the Habitats and Protected Areas office of the Iranian Department of Environment will likely yield satisfactory results in the near future. Non-legal policy recognition of ICCAs includes action plans jointly prepared by CSOs, indigenous people and government functionaries. This eventually led to the inclusion of territory-based ICCAs in the Law of the Fifth Five-Year Development Plan (Naghizadeh, Abbas and Farvar, 2012). Recognition of the boundaries of the ancestral territory of the Abolhassani indigenous nomadic tribe in the Touran UNESCO Biosphere may also be considered a positive step in this regard.

This particular case study speaks to gaps in the recognition of the conservation efforts of local communities. Yet negotiation with government agencies in Iran shows that government agencies and programmes can recognize ICCAs in a *de facto* manner, despite a lack of formal legal recognition, demonstrating a way forward towards the creation of favourable policy environments in support of ICCAs.

The Case of Canada

Canada and Australia are known aboriginal lands. Australian laws enable State recognition and support of Indigenous Protected Areas (IPAs) where communities enjoy full rights to sustainably use, control, and manage their lands and resources. However, compared to Australia, Canada does not have legislation that would support ICCAs. Nevertheless, since 2001, 10 coastal 'conservancies' covering 28% of the coastal area of 6.4 million hectares have been created by provincial and territorial governments, recognizing the cultural, social and ceremonial uses by 31 First Nations (Herrmann *et al*., 2012; Rozwadowska, 2011). These conservancies are under the *de facto* control of indigenous people, so they can be considered ICCAs. A number of tribal parks created by indigenous people in Canada have also been recognized by the Canadian government. Some examples are the Tla-o-qui-aht Tribal Parks, the Haa'uukmin Tribal Park, and the K'ih Tsaa dze Tribal Park. Another category of ICCAs is the protected areas established by some First Nations on their own. For example, the Haida Protected Areas cover 250,000 hectares of land (CHA, undated, cited in Herrmann *et al*., 2012), and were established by administrative decisions of the Council of the Haida Nation. The Saoyú-Æehdacho National Historic Site of Canada is also a form of ICCA cooperatively planned and managed by the community of Déline in Northwest Territories and by Parks Canada. Five Aboriginal Protected Areas (two in the Yukon and three in the Northwest Territories) also represent 1.2% of the total PAs in Canada (Environment Canada, 2006). These Aboriginal PAs are set aside for conservation by an indigenous community through a land claim agreement or other legal instrument. They have no federal, provincial or territorial protected area designation, but are recognized as protected areas by Parks Canada (Herrmann *et al*., 2012). The sacred natural sites have also been designated as a zone of extreme protection. Some initiatives, such as Caribou Heaven, *Waabushukamikw* or Rabbit's House, and the Muskuuchii hills are among the first efforts by the Government of Québec to recognize the sacred sites or ICCAs of First Nations. These sacred sites are administered in accordance with the IUCN-UNESCO *Sacred Natural Sites Guidelines* (Wild and McLeod, 2008).

Even in absence of a specific law or policy on ICCAs, Canada provides an example of how indigenous communities' initiatives may be given formal recognition with rights of self-determination and rights to land, in accordance with UNDRIP's obligations for States. Developing countries should follow such examples.

The Case of Japan

Since ancient times, Japanese people have believed that the God lives in transcendental things like high mountains and huge trees. For example, the *Oomiya* Shinto Shrine in Nara Prefecture, the oldest Shinto shrine in Japan,(36) has no main shrine building because a God is believed to live in Mt. *Miwa* – a mountain beyond the gateway. Mt. *Miwa*'s altitude is 467 meters high, and its area of 350 ha includes large pines and cedars; it is believed that the God lives in every tree and plant.(37) It is also believed that the God occasionally comes down to visit villages from the mountains. Accordingly, in order to welcome the God, it was considered necessary to establish a place where large trees grew, and villagers started to grow trees on a small hillside. The place is a sacred site to welcome the God, and is managed cooperatively by villagers. It is *Chinjyu-No-Mori* (Shrine and Temple Forests), a typical case in which a sacred grove has traditionally been conserved and managed through community-based efforts in Japan. Such a strong relationship between people and forests fostered a unique "local system to protect and utilize forests" (Hayashi, 2007).

Today, the situation has changed drastically due to rapid urbanization and lifestyle changes. According to Hayashi (2007), people no longer interact with *Chinjyu-No-Mori* as they did before. The ICCA is no longer collectively managed by the local community, but only by a few people related to the shrine. Furthermore, *Chinjyu-No-Mori* is rarely visited except on special occasions such as festivity time. Traditional local system

(36) http://oomiwa.or.jp/jinja/miwayama/#linktop

(37) http://oomiwa.or.jp/jinja/miwayama/#linktop

to protect and utilize forests no longer exist. As a result, although there are some exceptions, it is reported that many *Chinjyu-No-Mori* are facing threats from development and fragmentation.

There is no specific law to comprehensively protect *Chinjyu-No-Mori,* but some temples and shrines have large areas of ancillary forests for which the Forest Act can apply, and some *Chinjyu-No-Mori* are to be protected by municipal-level landscape / town plans and / or cultural heritage / historical site protection plans.

The Case of Bolivia

Tierra Comunitaria de Orígen (TCO)[38] is a Bolivian name given to autonomous and communally owned indigenous lands, which are a classic example of Bolivian ICCAs. The original basis for TCOs was enshrined in the Bolivian 1994 Constitution[39], but the term TCO itself was first codified into Law 1715[40] in 1996. Bolivia's 2009 Constitution[41] further guarantees to indigenous people the rights to the natural resources found on their lands:

The Constitution of 2009 recognizes the comprehensive nature of peasant indigenous territory, which includes the right to land use and exclusive benefit of renewable natural resources to the prior and informed consultation and participation in profits from the exploitation of non-renewable natural resources, and the ability to apply their own rules, its structures of representation and definition of their development in accordance with their cultural criteria and principles of harmonious coexistence with nature.

Other than TCOs, Article 30 of the Constitution of Bolivia recognizes indigenous territories (ICCAs) by declaring "self-determination and territoriality" (inc.4) and "collective title to lands and territories" (inc.6). The right to self-determination and territoriality has been given prominent place in Part III of the Constitution, in the 7th Chapter on "Rural indigenous autonomy". Indigenous peoples have full authority under Part IV of the Constitution, in the chapter on "Land and Territory", wherein specific treatment is given to indigenous people for their right to collective ownership of their lands and territories (Miranda and Alcides, 2012). Since the enactment of Law No. 171522 in 1996, indigenous people have achieved the recognition and certification of 190 indigenous territories as communal lands (TCOs) covering an area of 20.7 million hectares (Miranda and Alcides, 2012).

Bolivia is a perfect example of protecting the rights and interests of indigenous people and of recognizing their territories under law. This is the right path to conserve and maintain biological treasures once ICCAs are designated and formally protected.

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(38) http://www.territorioindigenaygobernanza.com/bov_06.html

(39) http://www.constitution.org/cons/bolivi94.htm

(40) http://www.bolivianland.net/UserFiles/File/0ParaDescripciones/1Inversiones_Bolivia/Ley_Agraria_Bolivia_Ing.pdf

(41) http://www.parliament.am/library/sahmanadrutyunner/Bolivia.pdf

The Case of Kenya

Kenya has a poor record of recognizing ICCAs. In territorial forests, community conservancies have been used as an innovative mechanism since the 1990s to strengthen local conservation efforts. The first local conservancies were formed with the support of the Kenya Wildlife Service (Honey, 2008). But this initiative has failed due to inconsistent follow up by the Kenya Wildlife Service (Kabiri, 2010). The sacred Kaya forest groves of the coastal zone are the only ones recognized as traditional ICCAs in Kenya. The Department of Fisheries has played a key role in the support and recognition of ICCAs in the coastal zone, in the form of locally managed marine areas (LMMAs) based on local Beach Management Units. The Kenya Fisheries (Beach Management Units) Regulations(42) 2007 and the Fisheries Act, 1989 provide the legal framework for establishing LMMAs and enforcing territorial rights over marine resources and reef fisheries (Nelson, 2012).

Several lessons can be learned from the foregoing case studies. Bolivia demonstrates the most advanced recognition of ICCAs. It is estimated that over the last 15 years, the recognition of indigenous rights has been at its highest in terms of land ownership in the 175-year history of the Republic of Bolivia. This form of legal recognition is innovative, and has evolved in a dynamic fashion, seeking to further expand autonomy for indigenous peoples (Miranda and Alcides, 2012). In terms of other countries, developed nations like Australia, Canada, Japan, etc. have recognized indigenous rights and ICCAs relatively more than many developing countries such as India, Iran and Kenya. Finally, the majority of countries need to recognize and support ICCAs and sacred sites through the creation or amendment of legislation and policy, with appropriate administrative measures.

Conclusion and Recommendations

Considering the fact that sacred natural sites and ICCAs have gained recognition worldwide (which will take a decade or two to trickle down), and the fact that national governments have either inadequately recognized or ignored the conservation initiatives of their own indigenous peoples and local communities, policy and legal interventions to assist the majority of countries are urgent and essential. In the absence of national frameworks supporting ICCAs, 13% of the vegetation of the globe thus conserved may eventually vanish. Therefore, in addition to international policies (e.g. the CBD's adoption of ICCAs as satellite areas within or adjacent to protected areas), pressure should be on countries to promulgate or amend national policy or to create domestic legislation in order to adequately integrate ICCAs.

Since modern conservationists mainly advocate for state-controlled official protected areas, the argument of this article is that linking traditionally conserved areas with modern conservation initiatives is a crucial step towards successful modern conservation. Conservationists must understand that sacred sites not only strengthen the existing protected area system but also have the potential to conserve additional territories.

(42) http://www.cisdl.org/aichilex/Target6-Kenya2007

Yet serious revision of conservation philosophy is also required to enable the creation of these linkages. According to Robson and Berkes (2010), the rise of ICCAs has been paralleled by recent dramatic shifts in international conservation paradigms and thinking. As Kothari (2009) notes, "while the formal conservation movement has long attempted to separate people from so-called pristine ecosystems, and focus its efforts on islands of biological diversity, recently a remarkable turnaround is observed towards linking protected areas (or conservation more generally) with the traditions and practices, livelihoods and aspirations of indigenous peoples and other local communities." Nevertheless, some caution is needed, especially given that the successful integration of ICCAs into national and international conservation systems would first require a range of conditions to be in place (Kothari, 2009). Indeed, several indigenous peoples have raised a legitimate concern that formal conservation frameworks value ICCAs only for species and ecosystem conservation. Policy analysts should articulate the voices of indigenous people by advocating that ICCAs first and foremost be seen as holistic bio-cultural or eco-cultural landscapes and seascapes, inseparably connected to the socio-cultural, economic, political, and spiritual lives, identities and survival of the peoples or communities governing them (Kothari *et al*., 2012). It is important to anticipate the implications of the integration of ICCAs, keeping in mind the apprehensions of indigenous communities.

Within the progressive international debate on the overlap between protected areas and ICCAs, the formation of a new IUCN category of protected areas for ICCAs should proceed with due consideration of States' tendency towards weakening community initiatives and institutional fabric. The customary laws, traditional institutions, self-governance and right to self-determination of the indigenous peoples or local communities managing ICCAs should be given priority in national policies and legislations.

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Reviewing theoretical frameworks, factors, and drivers for the introduction of renewable energy technologies among developing countries

Nwabialu Biola Onyeanusi and Masachika Suzuki

Abstract

The introduction of renewable energy technologies (RETs) is an important component to tackle against climate change. However, the diffusion rate of the renewables is quite slow, especially among developing countries. This article illustrates key factors, drivers, roles of each actor that affect the diffusion of RETs with reference to four theoretical frameworks. The first one is the social acceptance framework proposed by Wustenhagen et al. The second framework is the transition management framework focusing upon transition pathways and different stages of diffusion occurring among niche innovation, socio-technical landscapes and regimes. The Technology Innovation System (TIS) is the third framework illustrated in this article and it focuses on the dynamics of a TIS which is a network of actors, institutions and technologies for emerging energy technology by mapping the development of seven key activities called system functions. The fourth framework is the collaborative governance framework being elaborated by Ansell & Gash. The last part of this article checks the highlighted roles of actors under the four frameworks that are involved in the development of RETs.

途上国における再生可能エネルギー導入に向けた理論的フレームワーク及び促進・阻害要因のレビュー

オニアヌシ ンワビアル ビオラ・鈴木　政史

概要

再生可能エネルギー技術の導入は気候変動問題への対応として重要な要素である。一方、再生可能エネルギーの導入は特に途上国において進んでいない。本論文は、4つの理論的な研究フレームワークを紹介しながら、その導入に関わる促進・阻害要因及びアクターの役割を整理する。紹介する1つ目の研究フレームワークはWustenhagen et al.による社会的受容性のフレームワークである。2つ目のフレームワークは普及の様々な段階を描写したトランジション・マネージメント理論である。3つ目のフレームワークはアクター、制度、技術のネットワークの集合であるテクノロジカル・イノベーション・システムである。このフレームワークはシステム・ファンクションと呼ばれるイノベーションに関わる7つ主要な活動を整理している。4つ目のフレームワークはAnsell & Gashによって整理された協働的ガバナンスのフレームワークである。本論文の最後では、再生可能エネルギー技術の導入に必要だと考えられるアクターの役割についてこれら4つのフレームワークで捉えることができるか検討する。

Reviewing theoretical frameworks, factors, and drivers for the introduction of renewable energy technologies among developing countries

1. Introduction

The introduction of renewable energy technologies (RETs) is an important component to tackle against climate change. However, the diffusion rate of the renewables is quite slow, especially among developing countries. This article illustrates key factors, drivers, roles of each actor that affect the diffusion of RETs with reference to four theoretical frameworks. The first one is the social acceptance framework proposed by Wustenhagen et al. in 2007 (Wustenhagen et al., 2007). It introduces three dimensions of social acceptance namely socio-political, community and market acceptance and demonstrates that when the level of acceptance in the three dimensions are high, the social acceptance for the RETs is likely to be high. (Wustenhagen et al., 2007). The second framework being introduced in this article is the transition management framework focusing upon transition pathways and different stages of diffusion occurring among niche innovation, sociotechnical landscapes and regimes. It then develops five major transition pathways; reproduction, transformation, reconfiguration, technological substitution, and de-alignment and re-alignment. According to Geels and Schot, these pathways differ in combination of timing and nature of multi-level interaction (Geels & Schot, 2007).

The Technology Innovation System (TIS) is the third framework illustrated in this article and it focuses on the dynamics of a TIS which is a network of actors, institutions and technologies for emerging energy technology by mapping the development of seven key activities called system functions. A number of empirical studies are conducted based on the TIS framework including a case study on the automotive natural gas technology in the Netherlands between 1970–2007 (Suurs et al., 2010). The fourth framework is the collaborative governance framework being elaborated by Ansell & Gash (Ansell & Gash, 2008). A paper presented by Ansell and Gash conducts a meta-analytical study of the existing literature on collaborative governance with the goal of elaborating a contingency model of collaborative governance. The variables considered in this study include prior history of conflict or cooperation, the incentives for stakeholders to participate, power and resources imbalances, leadership and institutional design (Ansell & Gash, 2008).

2. Theoretical frameworks for the diffusion of RETs

This section introduces four theoretical frameworks with particular emphasis upon the key factors, drivers, and elements that are discussed under each framework that may contribute to the diffusion rate of RETs.

2.1 Introduction to the social acceptance framework

Social acceptance plays an important role in the diffusion of technologies but its deployment has progressed slowing in many countries. The people's perceptions of RETs are inhibiting factors for its complete utilization. For social acceptance to be effective, consumers need an adequate level of understanding regarding RETs which include the pros and cons of these technologies. Most developers tend to interpret initial support for RETs project as acceptance but it goes beyond this. The NIMBY (Not in my backyard) concept is often used to address what first seems to be a confusing "social gap" between the high levels of public support for renewable energy and the frequent local hostility towards specific project proposals.

Social scientists have conflicting ideas when discussing the NIMBY concept, while some believe that people accept RETs as long as its location is far from them, other believe that the loudest opposition comes from people who are not negatively impacted in any way (Devine-Wright, 2014). In a more explanatory way, the NIMBY concept presumes some of the reasons why opposition occurs. Some key points that contribute to NIMBY opposition include spatial proximity, personality of the individuals involved, irrational behaviours, uneducated information of RETs based on false assumptions, and man's selfishness in overlooking collective benefits of the RETs. However, it can be deduced that NIMBYism strongly influences the decisions of policymakers towards renewables.

Wustenhagen et al., contributes to the clarity of the social acceptance by categorizing the terminology into 3 major groups; Socio-political acceptance, community acceptance and market acceptance (Wustenhagen et al., 2007). The socio-political acceptance is the most common type of social acceptance and usually overshadows the others. The actors involved in the socio-political acceptance are the public (consumers), Key stakeholders and policymakers as shown in Figure 1.

Figure 1: The triangle of social acceptance of renewable energy innovation (Wustenhagen et al., 2007)

For the community acceptance, the NIMBYism concept develops here as the key element is participation in the planning stage of the projects. Local actors in an intended project site should be educated on the benefits of installing RETs in their community. According to Irwin, local people may become 'local experts' and fully engaging them in decision-making could mean a rich and contextualized knowledge of the local area, local dynamics and local contingencies can be drawn on, which are superior to relying on outside forecasts (Irwin, 1995). The local actors have expectations such as benefits sharing, impacts of the RETs as portrayed in the media, the behaviour of the developers and how their opinions in the decision-making will be considered. The primary ingredient to achieve community acceptance should be trust. The local actors should be able to trust the developers, this trust can restructure the NIMBYism opposition. The U-curve is the typical project pattern of a technology and occurs from a high level of acceptance at the project initiation to a low acceptance at the siting phase and back to a higher level of acceptance once the project is running (Wolsink, 2007).

In the market acceptance, the distinction between other forms of the social acceptance becomes clearer when discussing smaller scale renewables. There tends to be a conflict between the supply and the demand of green energy which can further widen the social acceptance gap. In order to narrow the gap in society, financial incentives can act as a bridge for the market acceptance.

2.2 Introduction to the transition management theory

The development of technologies does not appear suddenly. They go through a systematic process which are referred to as transition pathways. The transition management theory indicates that technological innovation is categorized into three levels which are the macro, meso and micro levels. According to the theory, the development of technologies is based on a nest hierarchy, where radical innovation emerges in niches, break through and overthrow the existing regime. It is less likely in systems with large infrastructures, where sunk investments and high entry barriers are important such as electricity systems (Verbong & Geels, 2010). These contributions, however, have become obsolete and the flaws identified describes the inadequately overemphasizing vertical circulations within the transition process, thus obstructing social practices view as constitutional elements of a sociotechnical system.

Rip and Kemp then introduces a framework called the Multi-Level perspective (MLP) in order to understand the process which leads to technological transitions (Rip and Kemp, 1998). The MLP understands transitions as the outcome of multi-dimensional interaction between radical niche-innovations, an incumbent regime and an external landscape. Transitions are about changes at the meso-level of socio-technical regime, which consists of three dimensions. These three dimensions in the RETs diffusion are classified as; 1) the technical elements of RETs –the resources and the cost of infrastructures like panels and turbines; 2) Network of actors-actors such as consumers, utility companies, developers, policymakers, NGOs; 3) cognitive rules and routines that control the action of actors– these include belief system, regulations, behavioural norms, principles and the media. Niches form the micro-level, the locus where novelties emerge. The technological niches act as 'incubation rooms' which protect new technologies from mainstream market selection. Such protection are performed by small network of actors who are willing to invest in the development of new technologies (Verbong & Geels, 2010). Experiments are also carried out in the technological niches to learn about the desirability of the technology and enhance the further development or the rate of the application of the new technology (Morone & Lopolito, 2010).

The macro-level is characterized as the socio-technical landscapes, which form an exogenous environment and occurs slowly like environmental awareness but impacts the niche and regimes. It encompasses both the intangible aspects of social values, political beliefs, world views and the tangible facets of the environment including institutions and the marketplace, hence, it occurs within the economic background of the socio-technical landscape. Once technology is developed and utilized, newer technologies performing the same tasks are difficult to be accepted and ensconced. The only opportunity for a breakthrough happens only when the three levels of the MLP are incorporated together (Geels & Schot, 2007; Verbong & Geels, 2010). For example, the socio-technical process can lead to pressure in the energy regimes whilst providing openings for new technologies (RETs) to establish themselves. Figure 2 illustrates the three levels including 1) the macro-level (socio-technical landscapes, 2) the meso-level (socio-technical regime), and 3) the micro-level (niche-innovation).

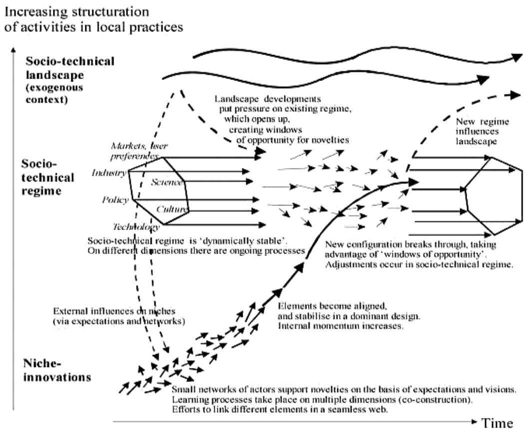

Figure 2. Multi-level perspective on transitions (Geels & Schot, 2007)

2.3 Introduction to the technological innovation system

Technology innovation system (TIS) is another important framework to be considered in the diffusion of technology. According to Rubler et al., the TIS is carried out to analyse and evaluate the development of a technological field in terms of the drivers that support or hamper it. The development of technology is often conceptualized through a life cycle model that process sequentially from birth (invention, innovation), to adolescence (growth), maturity (saturation), and ultimately senescence (decline due to competition by more recent innovation). The linear model has evolved and become unrealistic. The model that applies to

TIS is the chain-linked model where various drivers are linked together through a feedback channel as seen in Figure 3 (Grubler et al., 2012).

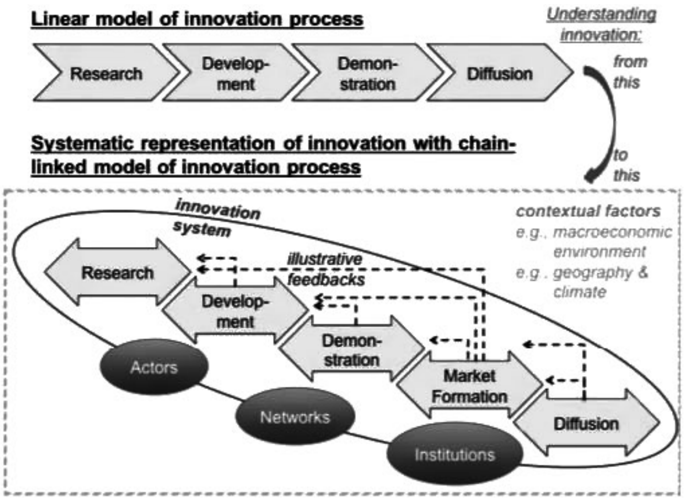

Figure 3: The evolution of Innovation Processes (Grubler et al., 2012)

The TIS does not only study the performance of new inventions or modifications of existing technologies such as energy efficient bulbs, clean cook stoves, renewable energy technologies. It also highlights the methods through which industries and markets develop the technologies and how the consumers utilize such technologies. The behavioural pattern of the actors involved in the process play an important role as well as the improved efficiency of such new technologies. Simply put, the TIS aims to explain the fact that technology does not fall from the sky but occurs as a result of various combination processes. Suurs et al. focuses on the dynamics of the build-up process for an emerging technology by mapping the development of seven key activities (system functions) (Suurs et al., 2010). The main contribution revolves around the notion of cumulative causation, or the phenomenon that the build-up of a TIS accelerates due to system functions reinforcing each other over time. For example, knowledge development is likely to benefit from entrepreneurial activities and entrepreneurial activities, in turn, will be induced by market formation. As an empirical basis, they provide an analysis of the historical development of the TIS around automotive natural gas technology in the Netherlands (1970–2007). Proposition on the functions of the TIS is listed in Table 1 with descriptions and typical examples.

Table 1: Functions of technological innovation systems (Suurs et al., 2010).

System function	Description	Event types associated
F1. *Entrepreneurial Activities*	At the core of any innovation system are the entrepreneurs. These risk takers exploit business opportunities and perform innovative commercial and/or practice oriented experiments	Projects with a commercial aim, demonstrations, portfolio expansions
F2. *Knowledge Development*	Technological research and development (R&D) are a source of variation in the system and are therefore prerequisites for innovation processes to occur. Non-technological knowledge is also of key importance	Studies, laboratory trials, pilots
F3. *Knowledge Diffusion*	The typical organisational structure of an emergent innovation system is the knowledge network, primarily facilitating information exchange	Conferences, workshops, alliances
F4. *Guidance of the Search*	This system function represents the selection processes necessary to facilitate a convergence in development	Expectations, promises, policy targets, standards, research outcomes
F5. *Market Formation*	New technologies often cannot outperform established ones. In order to stimulate innovation it is necessary to facilitate the creation of (niche) markets, where new technologies have a possibility to grow	Market regulations, tax exemptions
F6. *Resource Mobilisation*	Financial, material and human factors are necessary inputs for all innovation system developments	Subsidies, investments
F7. *Support from Advocacy Coalitions*	The emergence of a new technology often leads to resistance from established actors. In order for an innovation system to develop, actors need to raise a political lobby that counteracts this inertia, and supports the new technology	Lobbies, advice

In many cases, however, the diffusion of technology occur at a very slow pace. In rare situations, the diffusion of technology could proceed swiftly such as in the information and communication technology sector where the use of cell phones penetrates the market at a surprising rate (Grubler et al., 2012). On the other hand, the introduction of RETs have been slow with an uncertain long-term outlook.

Four key factors are considered for the slow pace of the RETs. The first factor is the intensity of the needed capital for investment. The initial Investments in RETs tend to be capital intensive when compared with non-RETs with low operating costs and zero fuel costs thereafter. These high up-cost investments are drawbacks to the utilization of the technology and is critical to the economic competitiveness of RETs in comparison to traditional generating technologies. When compared to non-renewables, the payback periods are longer and investors are sometimes sceptical to partake in these long wait periods.

The second factor relates to the future uncertainty of RETs. Investors also wonder if the RETs have found a permanent spot in the energy sector. Historically, they have often acted like a substitution in the time of crisis. A typical example is the rate at which the wind energy waned in the mid 60s through the availability of cheap oil and the oil crisis of 1973 renewed interest in the wind technology because the price of oil rose drastically. What could happen to the RETs if and when the environmental concerns wanes? Also, what happens after the estimated life cycle of most RETs, can they be recycled or become waste products? These questions contribute to the future uncertainties of RETs.

The third factor behind the slow pace of the RETs diffusion is the needed extended time for experimentation, learning and technology development from invention to innovation across many sectors, markets, and countries (Grubler et al., 2012). This experimental procedure aids in better understanding of the technology. Also, historical analysis will be carried out to operationalise and measure system functions by relating them to events (Kebede et al., 2015; Suurs et al., 2010)

The fourth factor is the changing laws, regulations, and government policies. Changing tax laws is a necessary first step if renewables are to capture a significant share of the market. Analysis of the three motors of innovation; entrepreneurial, market, and system building by Suurs et al. shows that the common barriers in the technology diffusion is the lack of long term policy and the risk aversion attitude of the government (Suurs et al., 2010). The national government should establish a regulatory framework that reduces uncertainty, thereby contributing to guidance of the search and market formation. This means that the government must strengthen policies and laws for diffusion of RETs to occur.

2.4 Introduction to collaborative governance

According to Ansell & Gash, collaborative governance is a form of governance where one or more public agencies directly engage non-stakeholders in a collective decision-making process that is formal, consensus-oriented, and deliberative and that aims to make or implement public policy or manage public programs or assets (Ansell & Gash, 2008). It tends to replace adversarial and managerial types of decision making through engagement of relevant public and private stakeholders. Collaborative governance emphasizes the collaboration of organizational entities across sectors. The theme of collaborative governance has also diffused to other fields, such as environmental policy, climate change adaptation, and natural resources management (Shih et al., 2016). Ansell & Gash identifies critical variables that determine the success of collaborative governance (Ansell & Gash, 2008). They include the prior history of conflict or cooperation, the incentives for stakeholders to participate power and resources imbalances, leadership, and institutional design. Previous approach required the government to take actions necessary for the well-being of the society, but in recent times, it can be deduced that this approach is not holistic or effective and is plagued with oppositions from the other stakeholders. This leads to an endless wait or in some cases a back and forth motion with no concrete achievement therefore losing valuable time and downstream implementation failures. Collaborative governance also has its own challenges which include identifying the key actors in a decision-making process, what standards should be set for the selection of the participants and the oppositions that could arise as a result of different ideologies leading to a prolonged decision-making process.

Ansell & Gash conducts a meta-analytical study on collaborative governance and suggests four broad variables made up of starting conditions, institutional design, leadership and collaborative process (Ansell & Gash, 2008). Figure 5 shows these four variables:

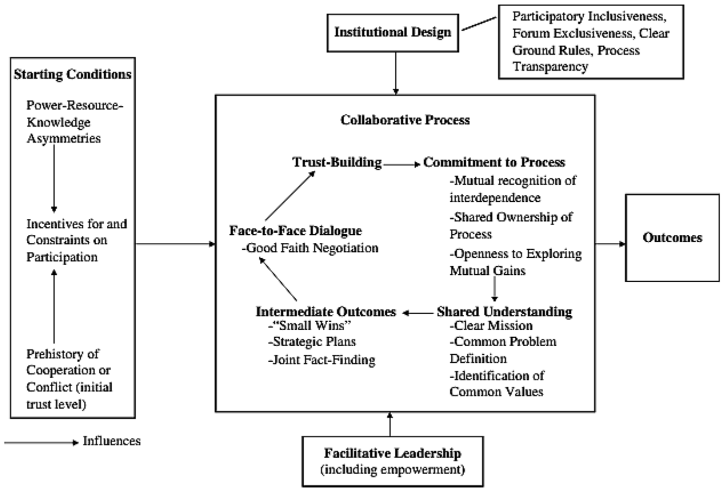

Figure 4: Model of Collaborative Governance (Ansell & Gash, 2008)

Gailing & Röhring indicates that collective citizenship initiatives and the active development of collective energy governance structures in cooperation with public administration can be important assets (Gailing & Röhring, 2016). Collaborative governance is important in the energy sector because prime movers in certain regions create a constellation for their benefits and this limits the penetration of new technologies such as the RETs. Prime movers promote new technologies through awareness, investments and legitimacy, this then leads to the diffusion of the technology. Local acceptance of RETs increases with the help of community engagements which fosters understanding and development. For the diffusion of RETs, the actors in the public sector includes the energy commission, the ministry and the state energy office; in the private sector, the actors are the investor-owned utilities, public utilities managers and the rural electric cooperatives. The civil society consists of numerous non-governmental organizations (NGOs) and community based participants/users. These actors are involved in every stage of the collaboration process.

3. Checking the importance of the roles of each actor under four theoretical frameworks

Renewable energy actors are a broad category of people with roles in supporting or implementing RET developments including policymakers, developers, consultants, PR and marketing companies, trade associations, financiers, technology manufactures, NGOs, and consumers. Consumers are made up of people in particular locations that are the focus of RET development. Companies comprise of developers, consultants, technology manufacturers, PR and marketing companies.

In the social acceptance of RETs, all actors play a part in the diffusion of RETs. A common barrier in this phase is the NIMBY (Not in My Backyard) opposition where the consumers are emotionally rather than rationally driven. Community benefits help to facilitate social acceptance through regular income reimbursement to local community organisation, benefits in kind, or specific employment-related measures

(Cass et al., 2010). NIMBYism has been criticized for focusing attention entirely on the public, hence blaming people for being concerned about their own self-interest and property value but no attention is given in such an account to what developer and technology promoters are doing and saying, and how decision processes are structure and enacted (Wolsink, 2000).

Wustenhagen et al. in their study state that NGOs were found to be trusted most and the industries least by the public (Wustenhagen et al., 2007). Therefore, the NGOs often play a key role in the diffusion of RETs because the people believe their intentions for the achievement of set goals and they must be willing participants in the diffusion process. Troncoso et al. explain how a local NGOs in Mexico was able to raise public awareness for air pollution caused by conventional stoves and called for better options to reduce fuel consumption and indoor air pollution (Troncoso et al., 2007).

Policymakers also play important role in the diffusion mix to enhance social acceptance. Through encouraging investment in RETs, such as investment incentives, tax incentives, and preferential tariffs for Consumers and R&D subsidies, tax and tariff incentives for developers, energy policies lead to increased innovation in renewable energy technologies. Companies' affect social acceptance through their investment behaviour. Because many of these companies own and manage significant parts of the grid, often still with regional monopolies, their position also affects the opportunities of other potential investors (Stern, 2007).

The Multi-Level Perspective (MLP) proposed by the transitional management theory is a global model that maps the entire transition process. As a global model, it tends to give less attention to actors. Nelson & Winter referred to the sociotechnical regime as shared cognitive routines in an engineering community and explained patterned development along 'technological trajectories' (Nelson & Winter, 1982). Geels & Schot expand the focus from engineers to include a wider range of social groups such as policymakers, financiers and suppliers (Geels & Schot, 2007). This accommodates broader community of social groups and their alignment of activities. Change occurs at the regime level incrementally and is geared to achieve optimization.

The MLP presents the interplay between niche, landscape and regimes depicting technological transitions. This model is heuristic and aids better understanding of the process. The main actors include the users of the end product who determine the transition level, the NGOs who provide pressure for change, the policymakers who create top-down pressure from regulation and the use of market incentives and the companies who interact through the supply chain and with other industry leaders to share best practice and create innovative ideas. The inertia of these actors is seen as an explanation of the difficulties in achieving transitions to sustainability.

In the Technological Innovation System (TIS), the actors are represented as a developer or adopter, or indirectly as a regulator, financier etc (Suurs et al., 2010). It is the actors of the TIS who through choice and actions generate, diffuse add utilize technologies. The development of the TIS would depend on the interrelation between all these actors. It is necessary that the government and the companies work together to grow the TIS model. For example, smaller companies may need financial assistance from the government to progress and the government should be a support system, in exchange, the companies should provide relevant information to the government for the implementation of policy support.

The critical component of the collaborative governance is 'governance'. It goes further to categorize actors into public agencies which include public institutions such as bureaucracies, courts, legislature, and other governmental bodies at the local, state or federal level. Although public agencies are typically the initiators or instigators of collaborative governance, participation by non-state stakeholders is mandatory (Ansell & Gash, 2008). These stakeholders could include individuals, communities, NGOs, and corporations.

Table 2 is a checklist of whether each research framework discussed in article pay attention to the importance of the roles of each actor. As shown in the table, all frameworks emphasizes the importance of the roles of each actor:

Table 2: Actors that impact the diffusion of RETs

Actors	Social Acceptance	Transition Pathway	Technology Innovation System	Collaborative Governance
Companies	○	○	○	○
NGOs	○	○	○	○
Consumers	○	○	○	○
Financiers	○	○	○	○
Policymakers	○	○	○	○

While the importance of each actor is highlighted under the theoretical frameworks, the interplay between these actors is a key driver of innovation and growth in this field. It is essential to note that while a centralized system of diffusion, where innovation generally follows a top-down pattern would have less impact on the diffusion of RETs, a decentralized diffusion system where RETs are influenced and controlled by the actors tend to achieve a better rate of diffusion. Innovations emerge in decentralized contexts, often supported by regulators, developers and users of an innovation. The decentralized system may tend to show a convergence type of communication, in which participants create and share information with one another in other to reach a common understanding. Most comforting is the fact that policymakers through earlier less stringent efforts such as the Kyoto protocol where they first gained awareness are reviewing policy efforts to fit into today's changing world. Since the reliance on renewable energy is not only possible, desirable and necessary, but an imperative, all actors must work together through these diffusion variables for RETs to dominate the world's energy supply system.

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複合汚染の環境リスク

田中　嘉成[*]

概要

河川や池沼、沿岸や海洋、土壌や森林など、実際の環境中には、複数の汚染物質が排出されることが珍しくない。したがって、実際の環境中での化学物質の環境リスクを評価する際には、このような複合汚染のリスクを考慮に入れる必要がある。一方、化学物質の環境管理に用いられる毒性データのほとんどは、複合影響を考慮せず、単一物質ごとの毒性試験結果に基づいている。最終的な管理目標である人の健康や生態系の保全と、毒性情報やリスク管理手法の間にこの点でギャップが存在すると言える。本研究は、化学物質の複合影響の評価手法と管理法について、近年の環境毒性学研究における進展を総説し、著者が提唱している一般濃度加算モデルについて解説する。化学物質の複合影響で発展した解析手法は、化学物質と他の環境かく乱因子（温暖化、富栄養化など）との複合影響にも応用できる可能性がある。このテーマに関しては今後の研究による進展が期待される。

Environmental Risk of Compound Pollution

Yoshinari Tanaka

Abstract

In actual environments such as rivers and ponds, coasts and oceans, soils and forests, it is common that multiple pollutants are emitted. Therefore, when assessing the environmental risk of a chemical substance in an actual environment, it is necessary to take into account the risk of such compound contamination. On the other hand, most of the toxicity data used for environmental management of chemical substances is based on toxicity test results for each single substance without considering compound effects. It can be said that there is a gap in this respect between the conservation of human health and ecosystem which is the ultimate management objective and toxicity information and risk management methods. This study reviews progress in environmental toxicology research in recent years on the evaluation method and management method of mixture effects of chemicals and explains the general concentration addition model proposed by the author. The analytical method developed by the combined effect of chemical substances may be applicable to the combined effect of chemical substances and other environmental disturbance factors, e.g., global warming, eutrophication etc. As for this subject, further progress by future research is needed.

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複合汚染の環境リスク

1. はじめに　複合影響とは何か？

有害な化学物質は1つではなく、多くの化学物質が水や大気を通して人や野生生物に有害な影響を及ぼすことがある。このように複数の物質が同時に悪影響を及ぼすことを「複合影響」もしくは「複合汚染」という。化学物質は多数存在することから、複数の化学物質が同時に人や野生生物に取り込まれれば、複合影響がもたらされる危険が長年指摘されてきた。かつては、専門の環境科学研究者の間のみでなく、広く一般にも複合影響のリスクが叫ばれたこともあった（有吉佐和子 1975）。実際、河川や土壌、飲用水中の化学分析を行うと、多数の化学物質が検出されることは珍しいことではない（Belden et al. 2007）。環境化学や環境毒性学では、複数の異なる化学物質による人や野生生物に対する有害作用のことを複合影響もしくは混合物効果という。本稿では、化学物質の複合影響を科学的にどう評価し、適正に管理に繋げたらよいか、おもに数理モデルや解析手法の側面からレヴューしたうえで、著者が近年提案している新しい解析手法を紹介する。

2. 化学物質間の相互作用

いくつかの化学物質の複合影響とは、それらを成分とする混合物の毒性を意味する。いま、化学物質Aと化学物質Bの溶液から混合物を作るとしよう。混合物 v L（リットル）中に、化学物質AとBをそれぞれ x mg、y mg 混入させれば、各成分濃度は x/v mg/L、y/v mg/Lであり、$x:y$ を成分比（fraction）という。

混合物の毒性が、各成分の毒性（上記の例では、x/v mg/Lの化学物質Aおよび y/v mg/Lの化学物質B）を足し合わせたものとして予測できるとき、各成分の効果は足し算のように作用している、つまり加法的に作用していると考えられる。混合物の毒性が加法効果より強く現れるとき相乗効果、弱く現れるとき相殺効果という。相乗効果と相殺効果は、異なる化学物質の間で効果を強め合ったり弱め合ったりして生じる作用であり、相互作用と見做すことができる。

毒性単位

混合物中の化学物質成分が互いに相互作用を及ぼすことなく、単に加法的に働いて混合物全体の毒性を決めるのであれば、各成分の毒性の強さを総和すれば混合物の毒性を推定することができるはずである。各成分は違う化学物質なので、単位濃度あたりの毒性は違うのが普通である。したがって、成分量を、ある一定の毒性を示す濃度で基準化し、指標で表す必要がある。化学物質濃度を毒性値に対する比率として表した指標を毒性単位（TU, toxic unit）と言う。基準となる毒性値としては、半数致死濃度（LC_{50}, median lethal concentration）もしくは半数影響濃度（EC_{50}, median effect concentration）等の急性毒性値が用いられるのが一般的である。毒性単位は、ある成分濃度が c のとき、

$$\mathrm{TU} = \frac{c}{\mathrm{LC}_{50}}$$

と表される。TUは1のとき、急性毒性値と同じ強さの毒性（半数致死）であることを示す。

すべての成分の毒性値と濃度がわかれば、各成分のTUの和として、混合物の毒性を予測することができる。ある混合物の全成分TUの和を毒性単位の和（toxic unit summation）と言い、ΣTUと書く。混合物の毒性は、成分の毒性単位の和として、

$$\Sigma \mathrm{TU} = \sum_{i=1}^{n} \frac{c_i}{\mathrm{LC}_{50(i)}}$$

と書くことができる（若林 2003; Kortenkamp et al 2009）。ここで、c_i、$\mathrm{LC}_{50(i)}$ は、それぞれ i 番目の成分の濃度および半数致死濃度、n は混合物中の成分数である。ΣTUが1のとき、各成分の毒性を総和すると、半数致死濃度相当の毒性が予測されることを意味する。また、ΣTUによって成分比や成分濃度の異なる混合物の毒性の強弱を比較することができる。例えば、半数致死濃度が5mg/Lと10mg/Lの2つの成分（成分1と2）からなる2種類の混合物（混合物AとB）を考えよう。混合物Aは成分1を3mg/L、成分2を1 mg/L含み、混合物Bは成分1を1 mg/L、成分2を4mg/L含むとする。このとき、混合物AのΣTUは、3/5 + 1/10 = 0.7であるのに対して、混合物BのΣTUは、1/5 + 4/10 = 0.6である。混合物Aは混合物Bより、成分の総量では少ないものの（混合物A: 4mg/L、混合物B: 5mg/L）、より毒性の強い成分1の成分比が高いために、混合物としての毒性はわずかに高くなることが予想される。

成分の作用が加法的であれば、混合物の毒性単位の和が1になるように成分の濃度を調整したとき、混合物の毒性の強さは、毒性単位を定義した際の毒性の強さ（半数致死濃度であれば死亡率0.5）に等しくなるはずである。この事実を利用して、実験的に推定した混合物の毒性を、毒性単位の和から理論的に予測される毒性反応と比較することによって、成分の相互作用の有無を推測することができる（図1）。ΣTU=1 になるように調整した混合物の反応率（死亡率）が0.5であれば加法的、0.5 を超えれば相乗的、0.5を下回れば相殺的と判断する。また、特定の成分比の混合物に対して、混合物の反応率が実際に0.5となるときの各成分の濃度を複合影響試験から決定できたとき、各成分の濃度と毒性値から求めた毒性単位の和ΣTUが、1を超えるかどうかによっても同様の推測を行うことができる。この場合、ΣTUが1より小さくなった場合は相乗的、1より大きくなった場合は相殺的である。なぜなら、加法性の予測より少ない成分量で反応率0.5が達成された場合、成分間の相乗的な相互作用が示唆されるからである。

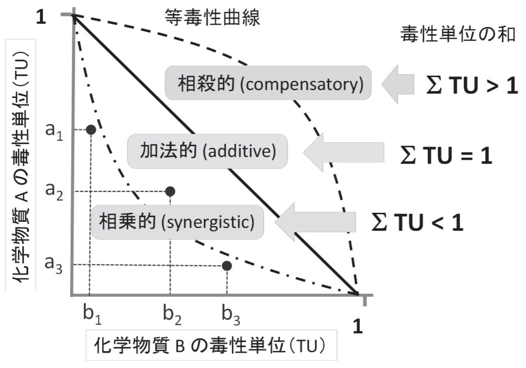

図1. 混合物中の2成分間の相互作用を表すアイソボログラム

混合物の毒性指標

混合物の毒性単位の和が1であれば、混合物の複合影響は毒性単位を個々の物質で定義した際の毒性の強さに等しくなる。この性質を根拠として、毒性単位の和と類似の手法が混合物の複合影響の評価や規制に適用される。一般的に、リスクベースによる化学物質の規制は、化学物質の環境基準値（無影響予測濃度PNECや耐容1日摂取量TDI）に対する環境中暴露濃度や1日摂取量の比率を指標とし、それが1を超えるかどうかによって判断する。その比率をハザード指数（HQ, hazard quotient）と言う。同じ環

境に類似の毒性を持つ化学物質が複数検出される場合、それらの環境影響や健康影響は個々の物質の影響を集計した複合影響として評価することが望ましく、個々の物質で算定したハザード係数の総和を指標として判断する場合がある。このような指標をハザード指標（HI, hazard index）と言う。ハザード指数は

$$\mathrm{HI} = \sum_{i=1}^{n} \frac{x_i}{\mathrm{TDI}_i}$$

と定義される（Reffstrup et al 2010）。TDI_iはi番目の化学物質の耐容1日摂取量、x_iは摂取量である。対象が環境動植物の場合は、TDIをPNEC、摂取量を環境中濃度cに変更する。

各化学物質の無影響予測濃度PNECもしくは耐容1日摂取量TDIは、無影響濃度（NOEC, no observed effect concentration: 有害な作用を示さない化学物質濃度の限界値）もしくは無影響用量（NOAEL, no observed adverse effect level: 有害な作用を示さない最大用量）を、毒性情報の不完全性や室内実験で得られた毒性データを野外の環境に外挿する際の誤差を考慮した不確実係数（UF, uncertainty factor）で除した値として求められる。

毒性等量

ダイオキシン類のように、少しずつ化学構造に違いがあり毒性の強さも異なるが、作用機構は類似であると考えられる複数の化学物質成分から成る混合物を評価する際、混合物の量（濃度）を、各成分の毒性の強さに応じて各成分の量を基準とする成分に換算して表す方法がある。このように、各成分の量を毒性の強さに基づいて基準化して表す方法を毒性等量（TEQ, toxic equivalent）と言う。毒性等量は、特定の成分（通常は最も毒性の強い成分）に対する相対的な毒性の強さによって重み付けした成分濃度の総和である。すなわち、

$$\mathrm{TEQ} = \sum_{i=1}^{n} \mathrm{TEF}_i \cdot \mathrm{C}_i$$

と表される。ここで、TEF_iは、i番目の成分の毒性等価係数（toxic equivalent factor）で、基準となる成分（基準物質）に対する相対的な毒性の強さを示す。C_iはi番目の成分濃度である。すなわち、TEQは、混合物の量を、同じ毒性を示す基準物質の量で表したものである。

ダイオキシン類の毒性等価係数は、最も毒性が強く代表的なダイオキシンである2, 3, 7, 8-TCDDを基準とし、それに対する相対的な毒性の強さを示すように各同族体に割り当てられている。毒性は同じ同族体列内でも最大3桁の違いがある。ダイオキシン類のTEQは、全同族体の量を同じ毒性を示す2, 3, 7, 8-TCDDの量に換算して表したものである。

3. 相互作用のない複合影響モデル

幾つかの化学物質から成る混合物を1つの評価単位としてその環境や人健康への影響を評価するためには、複合影響の強さを各成分の濃度から定量的に推定することが必要になる。成分間に相乗作用や相殺作用を伴う非加法的な相互作用が無いと判断できれば、複合影響を各成分の毒性と濃度のみから定量的に推定することができる。このような方法を「成分ベースのアプローチ（component-based approach)」と言う。

成分ベースのアプローチでは、複合影響の作用に関する相反する仮定に基づいた2つの複合影響モデル、独立作用モデルと濃度加算モデルが提案され、最も仮定が少なく成分間の相互作用を仮定していないモデルであることから参照モデル（reference model）と呼ばれている（Kortenkamp et al 2009）。これらの方法では、各成分の濃度（用量）反応関係がわかっていれば、成分濃度から混合物の複合影響を予測することができる。

独立作用モデル（independent action model）は、毒性が発現する作用機構の異なる化学物質から成る混合物を想定しており、各成分の作用が他の成分の作用とは無関係に発現し、人や野生生物の生存や繁殖などの特性に独立に作用する。各成分の作用は確率的に独立な事象と仮定される。いま、混合物が2つの成分から成り、各成分の反応率（死亡率など）を濃度の関数として$R_1(x_1)$、$R_2(x_2)$と表されるとする（x_1およびx_2は成分1と2の濃度）。各成分の反応率とは、各成分の化学物質を単独で試験した時に得られる毒性反応の大きさを、毒性反応の最大値に対する比率で表した数値のことである（たとえば、致死の場合は、対照区の死亡率を除外した死亡率、繁殖阻害の場合は、対照区の産卵数に対する毒性反応による産卵数の減少率）。独立作用モデルは、混合物の反応率$R_m(x)$を$R_m(x) = 1-(1-R_1(x_1))\,(1-R_2(x_2))$と予測する。2つの化学物質の毒性がランダムに作用するとき、集団中に反応を起こさずに済む個体がどれだけいるかを考える。1番目の成分によって毒性反応を起こさなかった個体の比率は$1-R_1(x_1)$である。2番目の成分による毒性作用が独立事象と見なせれば、2番目の成分の作用によっても毒性を起こさなかった個体の比率は$(1-R_1(x_1))\,(1-R_2((x_2))$となる。これ以外の個体はどちらかの成分もしくは両方の成分の作用によって反応を起こすことになり、その率つまり$1-(1-R_1(x_1))\,(1-R_2((x_2))$が反応率の予測となる。任意の数$n$の成分について、独立作用による反応率の予測は

$$R_m(\mathbf{x}) = 1 - \prod_{i=1}^{n}(1 - R_i(x_i))$$

に従う。ここで、$R_i(x_i)$は濃度がx_iのときの成分iの反応率である。独立作用モデルでは、各成分の反応率がわかれば、濃度（用量）反応関係がわからなくても、その混合物の複合影響を推定することができる。たとえば、ある混合物における成分の反応率がR_1=0.1、R_2=0.2であれば、$R_m = 1-(1-0.1)(1-0.2) = 0.28$と推定できる。ただし、任意の成分濃度に対して混合物の複合影響を推定するためには、各成分の濃度反応関係が関数関係で与えられていることが必要である。

混合物中の全ての成分濃度が非常に低い時（$R_i \ll 1$）、独立作用モデルの予測は次式の通り各成分の反応率の和にほぼ等しくなる。

$$R_m(\mathbf{x}) \cong \sum_{i=1}^{n} R_i(x_i)$$

このような複合影響モデルを、毒性反応レベルで加算性が成り立っているという意味で反応加算モデル（response addition model）という場合がある。全ての成分に対する毒性反応がほとんど現れない低濃度暴露では、独立作用モデルは反応加算モデルと近い関係にあり、複合影響を低く推定する傾向にある。

濃度加算モデル（concentration addition model）は、独立作用モデルとは逆に、毒性が発現する作用機構が類似している化学物質から成る混合物を想定し、各成分の作用は他の成分の作用と同等であるた

めに、成分濃度を加算すること（累積すること）によって複合影響が求められる。ただし、各成分の毒性の強さ（単位濃度もしくは単位用量あたりの毒性反応の大きさ）は物質間で異なるのが一般的なので、もちろん成分濃度をそのまま足し合わせて複合影響を推定することはできない。

濃度加算モデルの仮定は、希釈原理（dilution principle）によって最も端的に表される。希釈原理とは、2つの化学物質成分を取り上げるとき、片方の成分を適当な倍率で希釈すれば他方の成分と毒性学的には同一の物質とみなすという考え方である。この原理によれば、片方の物質を適当な倍率で希釈すれば2つの物質の濃度反応曲線は重なり、しかも成分間には相乗作用や相殺作用などの非相加的な相互作用が無いことになるので、同じ物質を加えていく場合と同様に2つの物質を混合させる場合も濃度を加算すれば反応を予測できることになる。

実際に混合物の複合影響を濃度加算によって計算する場合には、特定の反応率を示す濃度（EC_x : x%影響濃度）を尺度にして濃度のスケールを基準化する。このとき、成分の濃度と混合物の複合影響の間に次に示す「濃度加算の定理（concept of concentration addition）」が成り立つことが知られている（Berenbaum 1985; Kortenkamp et al 2009）。「混合物の毒性が反応率x%である場合、各成分の濃度のEC_xに対する比率を全成分について加算した総和は常に1になる。」すなわち、

$$\sum_{i=1}^{n} \frac{c_i}{\mathrm{EC}_{x(i)}} = 1$$

である。$EC_{x(i)}$はi番目の成分のEC_xを示す。

濃度加算の定理の意味を図によって解説しよう。いま、化学物質A、B、Cの3成分からなる混合物を考える（図2）。その前に、3成分のそれぞれが単一物質として示すx%影響濃度をそれぞれ$EC_{x(A)}$、$EC_{x(B)}$、$EC_{x(C)}$とする。ここで注意すべき点は、3つの各成分で考えている反応率は同じ大きさ（x%）で、混合物が

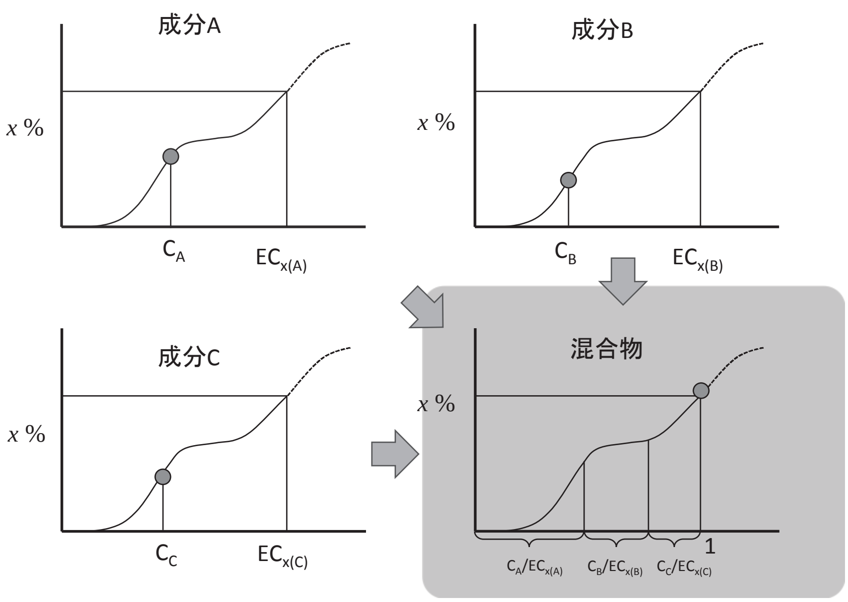

図2. 濃度加算の定理に従う2物質の混合物の濃度反応曲線

示す反応率と等しいということである。さらに、3成分の濃度がそれぞれC_A、C_B、C_Cで、x%影響濃度に対する比率を合計すると1になる、つまりx%影響濃度を3成分で分割しているとする。このとき、3成分を混合する過程は、同じ成分の物質を徐々に足し合わせていく過程と同じように考えれば良いはずである。最初に、濃度C_Aの成分Aに濃度C_Bの成分Bを加える。この時、この混合物の反応は濃度C_Aの成分Aに濃度$(C_B / EC_{x(B)})\ EC_{x(A)}$の成分Aどうしを加えた時の反応と同じになるはずである。このとき、濃度C_Aの成分Aの反応率や、さらに濃度C_Bの成分Bを加えた時の反応率がわからなくても構わない。さらに、濃度C_Cの成分Cを加えることは、上記の混合物に濃度$(C_C / EC_{x(C)})\ EC_{x(A)}$の成分Aを加えることに等しい。積算された成分A相当の濃度$\{C_A+(C_B / EC_{x(B)})\ EC_{x(A)}+ (C_C / EC_{x(C)})\ EC_{x(A)}\}$を$EC_{x(A)}$で割ると$\frac{C_A}{EC_{x(A)}}+\frac{C_B}{EC_{x(B)}}+\frac{C_C}{EC_{x(C)}}$となるが、これは1に等しいので、その反応率も$x$ということになる。

濃度加算の定理を使うことによって、各成分の任意の濃度から混合物の複合影響を予測することができる。ただし、独立作用モデルと違って、繰り返し計算による式の評価（求解）が必要である。独立作用モデルと同様に、まず各成分の単独作用における濃度（用量）反応関数が求められていなければならない。ここでは3成分の濃度反応関数をそれぞれ$F_A(C_A)$、$F_B(C_B)$、$F_C(C_C)$とし、その逆関数（つまりR ×100%影響濃度）を$F_A(R)^{-1}$、$F_B(R)^{-1}$、$F_C(R)^{-1}$と書く（Rは反応率である）。このとき、複合影響の大きさは、$\frac{C_A}{F_A(R)^{-1}}+\frac{C_B}{F_B(R)^{-1}}+\frac{C_C}{F_C(R)^{-1}}=1$を満たす$R$として求められる。実際の計算には、適当な初期値（推定値）をRに当てはめ、上式の左辺が1に等しくなるように逐次計算によって正しい反応率Rの解を求める。

化学物質の複合影響を予測するための成分に基づくアプローチにおいて、独立作用モデルと濃度加算モデルは代表的なモデルであり、これ以外に代替モデルがないと考えられている（Kortenkamp and Altenburger 2011）。2つのモデルの基本的な仮定が対照的であるために、成分の化学構造や作用機構の類似性とある程度の対応関係が付けられる可能性がある。独立作用モデルは成分の毒性の発現が独立事象とみなせることを仮定しており、作用機構の異なる化学物質による複合影響で成り立ちやすい。このような化学物質を、非類似作用化学物質（dissimilarly acting substances）と言う。一方、濃度加算モデルは成分間の相加的な作用を仮定しており、類似の化学構造や作用機構を持つ化学物質間で成立しやすい。このような化学物質を類似作用化学物質（similarly acting substances）と言う。

このような混合物成分間における作用機構の類似性と2つの複合影響モデルの妥当性との関係は、実験的にも検証されている。発光バクテリア（*Vibrio fischeri*）を用いた生物発光阻害試験によって、非類似作用化学物質の複合影響は独立作用モデルに、類似作用化学物質の複合影響は濃度加算モデルにほぼ従うことが証明された（Altenburger et al 2000; Backhaus et al 2000）。Altenburgerらの研究グループは、作用機構が異なると考えられる多様な化学物質（殺菌剤、界面活性剤など14物質）からなる混合物、および作用機構が類似ないし同一と考えられるフェノール誘導体16物質からなる混合物を一定の混合比（各成分のEC_{50}およびEC_1に比例するように設定された）で多数作成し、発光バクテリアの発光阻害をエンドポイントとする複合影響試験を行った。また、単独物質の毒性試験で求めた濃度反応関数から、独立作用モデルおよび濃度加算モデルによる阻害率（反応率）の予測値を計算し、得られた複合影響の観測値と比較した。その結果、非類似作用化学物質の組み合わせでは独立作用モデル、類似作用化学物質の組み合わせでは濃度加算モデルの予測が適合する傾向が見られた（図3参照）。

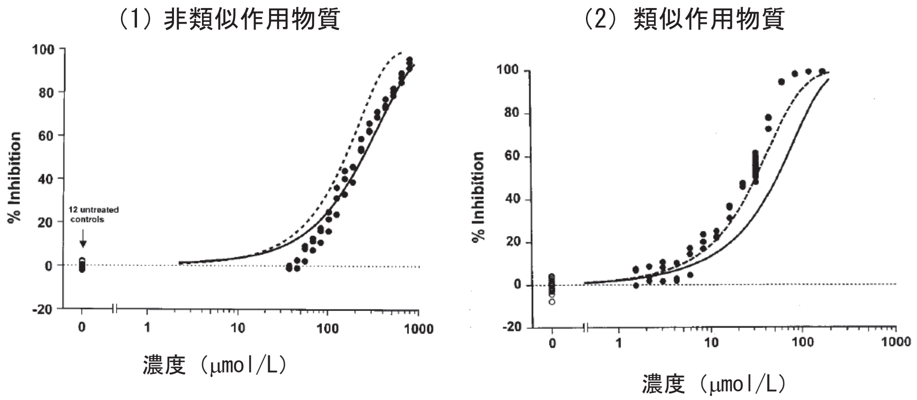

図3. 非類似化学物質群（1）および類似化学物質群（2）の混合物が示す濃度-反応曲線．直線は独立作用モデル、破線は濃度加算モデルの理論曲線を示す

データは Altenburger et al. (2000), Backhaus et al. (2000) より.

混合物の管理と複合影響モデル

化学物質の混合物をどう評価し管理するべきかと言う問題は、単に科学的ないし技術的な問題を超えて、環境保全の便益とコストを勘案しなければならない意味で業界等との合意形成も含めた環境政策の側面を持つ。日本の主要な化学物質管理制度の一つである化学物質審査規制法では、基本的にアメリカ化学会が発行するCAS（Chemical Abstract Service）番号に準じて登録番号を作成し、物性や毒性、製造・輸入量、排出量などを把握したうえで、リスク評価と管理を行なっている。分解性・蓄積性などの物性や毒性情報の入手が困難な物質について、化学構造が類似な物質の情報から類推すること（リードアクロス）や、あるアテゴリーに分類した化学物質間で物性および毒性情報を推計すること、さらに、化学構造が類似しており個々には評価が困難な物質群をまとめて評価単位とすることが例外的に認められるが、基本的には個々の化学物質を評価単位とすることに関して保守的である。評価単位の合理化は、海外の動向も踏まえながら進める必要があるだろう。

はじめに述べたように、化学物質の複合影響が問題になりうるのは、まず複数の化学物質の暴露が時間的および空間的に重なることが必要条件となる。環境中における多成分の分析によると、主要先進国の環境では、無影響濃度を超えるような高濃度で同時に検出される化学物質は少数であること、またそれらの化学物質間に明らかな相互作用が存在することは稀であることがわかっている。たとえば、Olmstead and LeBlanc（2005）は、米国の河川で検出された農薬類9物質について、環境中濃度に比例する成分比からなる混合物を使ってオオミジンコ（*Daphnia magna*）の遊泳阻害試験を行った結果、毒性に寄与したのは混合物中の1つ、もしくは高々2、3の主要成分であった。成分間の相互作用は検出されなかった。

また、環境中での複合暴露の可能性がどの程度かを考慮する前に、そもそも物質間の相互作用が従来考えられてきたより低頻度であることを示す知見も集められている。Belden et al（2007）は、過去の207の毒性試験を総説し、研究事例の88パーセントで濃度加算モデルの予測が実測値の2倍の範囲内であり、顕著な相互作用は検出されていないことを示した。殺虫剤混合物においても、明確な相互作用は一般的でなく、濃度加算モデルの予測が成り立つことが報告されている（Rodney et al 2013）。したがって、スクリーニングや1次リスク評価の段階では、化学物質間の非相加的な相互作用を考慮せず、2つの参照モデ

ルに基づいて影響を評価するのが実際的と考えられる（Kortenkamp et al 2009; Cedergreen 2014）。

検出された化学物質の化学構造などから作用機構が類似しているかどうかの情報が得られれば、独立作用モデルと濃度加算モデルのどちらを使うのがより妥当であるか判断できる。すなわち、作用機構が物質間で異なると判断できれば独立作用モデル、作用機構に違いがないと判断できれば濃度加算モデルに基づいて複合影響を評価することが他の方法より適切である。環境中に多くの有害化学物質が検出され、化学構造もしくは作用機構に基づいていくつかのカテゴリーに分類できる場合は、カテゴリー内の物質間で濃度加算モデルを適用し、カテゴリー間の有害効果を集計する際は独立作用モデルを適用する混合モデルも提案されている。ただし、作用機構がある程度わかっている化学物質、つまり特定のリセプターへの結合性が知られている化学物質は、膨大な数の化学品の一部であり、現実的には複数物質間の作用機構が類似しているかどうか判断するのは困難である。

一般的に、濃度加算モデルは独立作用モデルより複合影響を大きく予測することが知られている。つまり、どちらのモデルが妥当であるか判明しない場合、濃度加算モデルを採用した方が安全側の影響評価を行うことになる。また、一般化学物質の作用機構は、麻酔作用（narcotics）と呼称される特殊なリセプターを介さないものと考えられており、作用機構が明確に区別される独立作用の仮定は満たされない。つまり、濃度加算の仮定は、それを大きく逸脱する作用機構を持つ物質が少ないという意味でより一般的であると考えられる（Backhaus and Faust 2012）。したがって、複合影響の研究者および関係者の間では、化学物質間で毒性作用が独立であることを十分に検証するデータがない限り、濃度加算モデルが最も一般的な解析ツールとして有効であると考えられている（Belden et al. 2007; Kortencamp et al. 2009; Backhaus and Faust 2012; Cederegreen 2014）。

4. 相互作用を含む複合影響モデル

環境中に共存する化学物質の間では、ほとんど非加法的な複合作用がみられないとしても、ある化学物質の間では相乗作用や相殺作用の明瞭な非加法的な相互作用が実験的に立証されており、そのような化学物質から構成される混合物の複合影響を評価する場合は、化学物質間の相互作用を取り入れたモデルを考慮する必要がある。そのような相互作用を含む複合影響モデルは、成分単体の毒性データ以外に混合物の毒性データを必要とすることから、「混合物ベースのアプローチ（mixture-based approach）」と呼んでいる。ただし、非加法的な相互作用のある化学物質の複合影響をうまく予測できるモデルは非常に限られている。

理論的に最も普遍妥当性の高い複合影響モデルは、HewlettとPlackettらのモデルだろう（Hewlett and Plackett 1957, 1959）。彼らの理論は、化学物質に対する感受性の（生物もしくは人の）個体間の分布に基づいている。化学物質に対する毒性反応が示す濃度（用量）反応曲線は、化学物質の暴露を受けた集団の個体間で化学物質に対する感受性が違うこと、集団全体でみると個体の感受性に分布があることによってもたらされると仮定されている。その分布は対数正規分布などの一山型の確率密度関数によって表される。2つの化学物質の複合影響を予測するには、それぞれの化学物質に対する感受性を変数とする2変量正規分布を重積分する。そのためには、2物質に対する感受性の相関係数、2物質より多い場合は各成分に対する感受性の相関行列のデータが必要である。それらの推定は通常の毒性試験からは得られず、試験生物の多成分に対する感受性を個体ごとに測定する特殊な実験計画を考案し実施しなければな

らない。また、化学物質に対する毒性反応における濃度（用量）反応関係は、必ずしも集団内の感受性の分布のみによっては説明されないと考えられている（Newman and McCloskey 2000）。

比較的近年開発されたより実際的で汎用性の高い複合影響モデルは、相互作用を表す補正が参照モデルに追加された形をしている（Haas and Stirling 1994; Haas et al. 1996; Jonker et al. 2005）。C. N. Haasらが開発した反応表面モデル（response surface model）は、濃度加算の定理を次のように変形している。

$$\sum_{i=1}^{n}\frac{c_i}{f_i^{-1}(x)}=\exp(G)$$

ここで、xは反応率。$f_i(c)$ は成分iの濃度反応関数で、$f_i^{-1}(x)$ はその逆関数であり$EC_{x(i)}$と等しい。Gは偏差関数で、非加法的作用による参照モデルからのずれを示し、化学物質間の相互作用の大きさを意味する。$G = 0$のとき、式の右辺は1となり、濃度加算の公式と等しくなる。偏差関数は、具体的には様々な数理モデルが考案されており、複合影響の試験データ、特にアイソボログラムにおける等毒性曲線からモデルのパラメータを推定する方法が考案されている（Haas et al. 1996; Jonker et al. 2005）。モデルに必要なパラメータを複合影響試験のデータから推定すれば、任意の成分濃度から複合影響を予測することができる。

このように、複合影響の予測モデルには、成分単体の濃度（用量）反応関係以外に、混合物の複合影響に関する試験データが必要になる。私は、最も少ない複合影響データから、複合影響予測モデルを導く方法として、濃度加算の定理を一般化することによって相互作用効果を考慮した複合影響モデル、一般濃度加算モデル（GCA, generalized concentration addition approach）を提案している（Tanaka and Tada 2016）。

一般濃度加算モデル

化学物質の毒性反応を記述する濃度反応曲線は、化学物質に対する感受性に集団内の個体変異によってもたらされるのではなく、個体の反応の大きさが量的に変化することによってもたらされると仮定すると、濃度反応曲線は物質間の相互作用を概念的に表すものと考えられる。複数の化学物質の相互作用を考える前に、単一物質の相互作用を考えてみよう。単一物質の相互作用とはどういうことだろうか。ここで言う

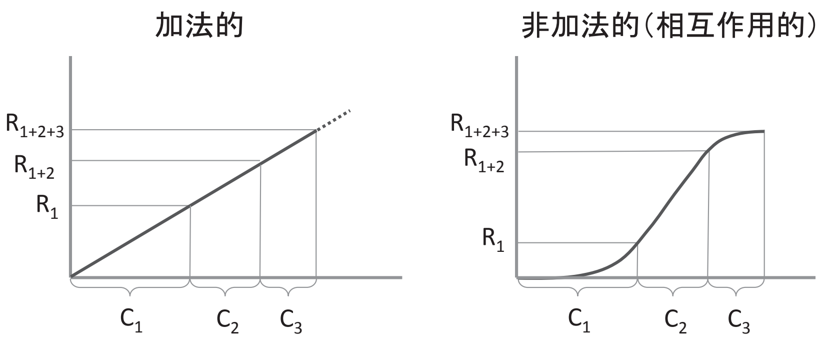

図4. 化学物質の毒性発現における加法性もしくは非加法性（相互作用効果）が濃度-反応曲線とどのような関係にあるかを示す模式図

「相互作用」とは、ある量の物質によってもたらされる毒性反応が、(同種の化学物質であるかどうかに関わらず) 他の物質によって影響を受けることを意味する。この意味では、厳密に相互作用がない加法的な場合は、毒性反応が化学物質濃度に対して (上限値に至るまで) 直線的に増加する場合のみである (図4左側)。一般的には、単一物質の濃度反応曲線はシグモイドなどの物質に特有の曲線を描くと考えられているので、化学物質の毒性の作用には物質特有の相互作用が存在することを示している (図4)。いま、単一の化学物質の濃度をC_1, C_2, C_3ずつ増やしていき、そのときの量的な反応を観測したとする (図4参照)。

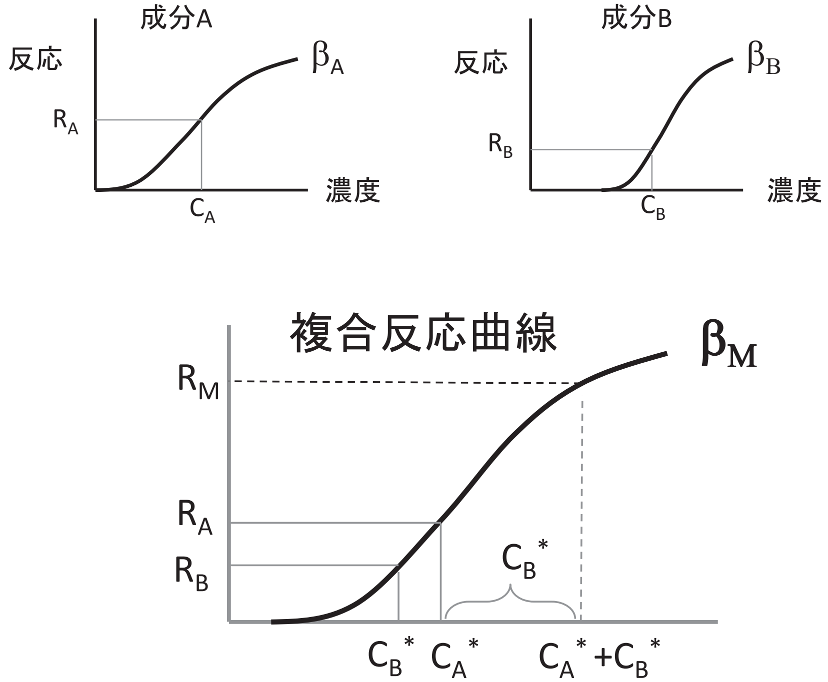

図5. 任意の相互作用を示す2物質を混合した場合の濃度-反応関数を一般濃度加算モデルで予測する際の考え方を示した模式図

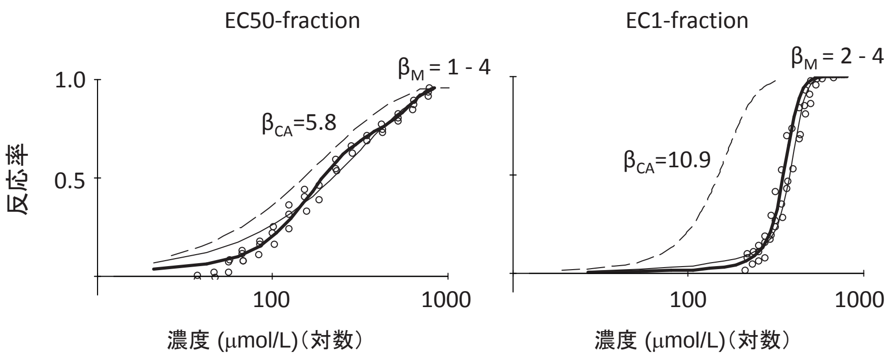

図6. 非類似作用化学物質を混合した場合の濃度-反応関係と一般濃度加算モデル (太実線) の適合. 細実線は独立作用モデル、破線は濃度加算モデルの適合を示す

データはBackhaus et al. (2000) より.

最初にC_1だけ暴露したときの反応は、さらにC_2暴露させたときの反応より、単位暴露量あたりをみても小さい。つまり、$R_1 / C_1 < (R_{1+2} - R_1) / C_2$である。さらに$C_3$暴露したときに得られる反応率は、図4の右グラフの場合、再び低下する。このように、化学物質に対する反応率（暴露濃度の単位増加分による反応の増加分）が暴露濃度に依存するということは、新たに加えられた化学物質の毒性作用が、すでに個体が暴露されて体内に入っていた化学物質の量に左右されるということであり、物資間に相互作用があると解釈することができる。ただし、ここで言う相互作用は、最終的な毒性エンドポイントとして量的に観測された毒性反応を理論上ないし統計的に解釈したものに過ぎないので、実際の作用機構において物質が相互作用を持つかどうかを意味するものではない。また、複合影響の分野で使う「相互作用」あるいは「非加法的相互作用」という用語は、ここでは、2つの異なる化学物質を混合するときの相互作用が、同じ化学物質の量を増加させるときに生じる相互作用と比較して大きいかどうか（同じ場合は非相互作用的、異なる場合は相互作用的）を意味する（Berenbaum 1985）。

濃度反応曲線の形として表される化学物質の毒性作用における相互作用のことを、毒性相互作用ルール（TIR, toxic interaction rule）と呼ぶことにする。TIRは同一物質内の相互作用だけでなく、異なる物質間の相互作用にも拡張することができ、同じ種類の化学物質であるかどうかに関わらず、物質どうしを加えたときの毒性反応を予測する際に必要となる。2つの異なる化学物質を混合する場合は、3つの異なるTIRが存在する。各成分のTIRが2つと、2成分を混合する際のTIRが1つで、これを「成分加算のTIR」と呼ぶ。3つのTIRが同じときのみ、2成分間で希釈原理が成り立ち、濃度加算の公式が成り立つことになる。

毒性データを解析する際は、まず各成分単体の毒性データに次の濃度反応関数を当てはめる。

$$\mathrm{R(C)} = \mathrm{F}\left[\left(\frac{C}{\theta}\right)^{\beta}\right]$$

ここで、Cは成分濃度、θはEC_{50}などの濃度のスケール因子である。F[z] はパラメータに依存しない反応関数形（ワイブルモデル、対数ロジスティックモデル、プロビットモデルなど）である（単純化のため、各成分の濃度反応関数も成分間の加算を表す反応関数も同じ関数に従うと仮定する）。βは反応の非線形性を表す反応勾配パラメータで、濃度反応曲線の形を決めるのでTIRを表す。反応勾配パラメータβが大きな値を取るほど、濃度反応曲線はスケール因子の周辺で急な勾配となり、物質間の強い相互作用を表す。つまり、低濃度ではほとんど影響が現れず、スケール因子の近くで急に毒性が強く現れるようになる。

2つの成分AとBを混合する場合、各成分の濃度反応関数とは別に、異なった成分を混合する際に生じる毒性反応を表す濃度反応関数（成分加算の濃度反応関数）を仮定する。各成分で反応勾配パラメータβ_A, β_Bを決めておき、混合物の成分濃度と反応の関係を表す反応勾配パラメータ（成分加算の反応勾配パラメータ）をβ_Mとおいて、各成分濃度C_A, C_Bを成分加算の濃度反応関数上の濃度C_A^*, C_B^*に変換する。成分加算の濃度反応関数では、濃度のスケールは1($\theta = 1$) と設定されるので、$C_A^* = (C_A / \theta_A)^{\beta A / \beta M}$, $C_B^* = (C_B / \theta_B)^{\beta B / \beta M}$と変換される（下添え字のAとBは成分を示す）。$C_A^*$と$C_B^*$は、成分加算の濃度反応関数を使って加算すれば混合物の反応率となるはずなので、次式の予測値と混合物の毒性反応の観測値が一致する（もしくは差異が最小になる）ように成分加算の反応勾配パラメータβ_Mを推定する。

$$R_M = F\left[\left((C_A/\theta_A)^{\beta_A/\beta_M} + (C_B/\theta_B)^{\beta_B/\beta_M}\right)^{\beta_M}\right]$$

化学物質の成分が2つより多い場合も同様の計算によってβ_Mを決定する。

いったん成分加算の反応勾配パラメータβ_Mが推定できれば、その値がほぼ一定であるとみなせる範囲の成分比や成分濃度の混合物がもたらす複合毒性を、各成分濃度から予測することができる。ただし、β_Mの値は、成分比や（成分比が一定でも）成分濃度に応じて変化する場合がある。β_Mの一定性が低い混合物の場合は、混合物の毒性データを多く収集し、成分比や成分濃度に対するβ_Mの依存性を検定し、必要な場合は考慮に入れる必要がある（図5参照）。

また、各成分が加法的に作用し、濃度加算の定理が成り立つとき、この手法により求めたβ_Mは各成分のβの重み付け平均（β_{CA}）にほぼ等しくなることが示されている（Tanaka and Tada 2016）。よって、算定されたβ_Mをβ_{CA}と比較することにより、成分間が相互作用的（非加法的）であるかどうかを判断することができる。

表1は、亜鉛と銅の複合影響がオオミジンコ（*Daphnia magna*）の遊泳阻害に与える影響を検定した生態毒性試験に一般濃度加算モデルを適用した例を示している。この研究例では、亜鉛と銅の間に顕著な相互作用がみられる。単物質の毒性試験から、亜鉛および銅の半数影響濃度EC_{50}は、11μg/L, 889μg/Lと推定された。これらのデータをもとに、2成分のEC_{50}に対する相対値の合計が1になるように相対比を変化させ、混合物の毒性試験を行った。混合物で推定されたβ_Mの値はβ_{CA}よりいずれも大きく、強い相互作用が示唆された。また、亜鉛より銅の混合比が高いほうが強い相互作用が現れる傾向があり、成分加算の反応勾配パラメータβ_Mは、成分比依存的であることを示唆している。

表1．オオミジンコ *Daphnia magna* における銅イオン(Cu)と亜鉛イオン(Zn)の遊泳阻害に対する単独毒性と複合影響

Cu		Zn		Cu + Zn		反応勾配	
濃度 μg/L	% 阻害	**濃度 μg/L**	% 阻害	成分比* Cu / Zn	% 阻害	β_M	β_{CA}
7.3	20	**377**	35	1 / 0	35	-	-
10.6	55	**533**	45	0.8 / 0.2	95	**13.7**	**5.68**
14.9	90	**753**	45	0.6 / 0.4	90	**11.5**	**6.32**
15.2	80	**779**	60	0.4 / 0.6	85	**11.0**	**6.86**
16.9	80	**889**	60	0.2 / 0.8	50	-	-
19.2	100	**1015**	75	0 / 1	40	-	-

* 成分比は EC50 スケール　　　　データ：　多田満（国立環境研）

先に紹介した、非類似作用を持つ14化学物質の複合影響を海洋バクテリア（*Vibrio fischeri*）の生物発光阻害で試験したデータに、一般濃度加算のアプローチを適用した（図6）。試験した化学物質は構造の類似性が低いカテゴリーから選ばれており、ほぼ独立作用の仮定が成り立つ。したがって、成分濃度を加算していく一般濃度加算の方法には適さない例と考えられるが、実際には、独立作用モデルより観測された反応にうまく適合できることがわかる。図6の太い実線で示された一般濃度加算モデルの予測値は、各

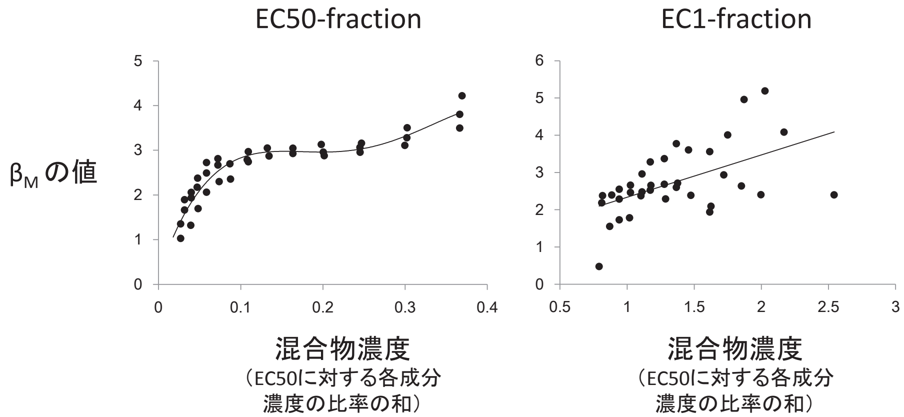

図7.　一般濃度加算モデルの反応勾配パラメータβ_Mの混合物濃度に対する依存性

データは Altenburger et al. (2000), Backhaus et al. (2000) より.

データ点で算定したβ_M値に基づく複合影響の計算値を結んだものである。半数致死濃度EC_{50}を成分比とする複合影響は、低濃度において独立作用モデルからの乖離が大きく、予測値が過大推定となる。

成分加算の反応勾配パラメータβ_Mを混合物の濃度（EC_{50}に対する濃度比率の成分和）に対してプロットすると、相互作用の強さに濃度依存性があり、それが成分比（EC_{50}比とEC_1比）によって異なることがわかる（図7）。それでも、β_Mは広い範囲の成分濃度と成分比で概ね3であり、一般濃度加算モデルによる予測は可能と考えられる。

複合影響を予測する他の理論

化学物質の複合影響モデルの研究例として、これまで述べてきた方法と異なるアプローチが試みられている。その1つは、生物リガンドモデル（BLM, biotic ligand model）を化学物質、特に重金属類の複合影響の予測に応用した研究である（Kamo and Nagai 2008）。BLMは、もともと魚の鰓を介する化学物質の取り込みを想定し、重金属類の生態毒性が取り込みの競争物資である溶存有機炭素などによって低下することを予測する理論である（Di Toro et al. 2001）。重金属の環境基準を、環境中の汚濁レベルや他の重金属類の濃度を考慮に入れて検討する際に有効な手段となるだろう。

5. おわりに

今後、化学物質の複合影響を実際の化学物質管理に取り入れるうえでは、2つの参照モデル、特に濃度加算モデルの適用がおもな課題となるだろう。化学物質審査規制法や農薬取締法などにおける化学物質リスク評価手法に、将来、複合影響への配慮を導入する際には、類似の構造を持つ化学物質のグループをリスク評価の単位としてどう扱うか等に関し、化学物質混合物毒性研究の成果を踏まえたより包括的な検討が望まれる。

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Co-effect of Irrigation Method and Fertilizer Management on Soil Nitrate Dynamics

— A Case Study in an Arid Region of China —

Zhou M*, Deng J** and Huang, G***

Abstract

Proper agricultural management of water and fertilizer is beneficial to the sustainable development of the watershed when agriculture is the pillar industry. The challenge is greater in arid region where water is a constraint and a primal factor simultaneously when seeking environmental, social and economic development. The middle reaches of Heihe River Basin (HRB), a typical inland river basin located in the arid region of Northwest China, is such an area with intensive agriculture expansion causing severe water deficit on ecological process and groundwater contamination. The present study aims to investigate the co-effect of irrigation and fertilizer management on soil nitrate dynamics and try to discuss its influence on the sustainable development of HRB. This study also intends to pursue the potential of drip system that has been expanding in this region. Social survey was conducted on the purpose of understanding the current agricultural practice and social perception on drip system. On-site monitoring on the dynamics of nitrate in arable layer of fields with different irrigation methods was performed. The results reveal that nitrogen fertilizer application of conventionally irrigated fields is surprisingly high with a rate of 600.1 kg ha^{-1} y^{-1}, while that of the fields with drip irrigation system is more than 30% decreased. For water management, well water irrigation may consume 24% less water than river water irrigation and 33% of groundwater can be saved if drip irrigation system adopted in well water irrigated fields and managed properly. For eliminating the biases and expanding drip irrigation system, government support on initial cost and trans-villages sharing of experience among farmers is considered efficient.

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灌漑方法と化学肥料管理による土壌硝酸含有量への影響

――中国の乾燥地域における事例研究――

周曼茹・鄧　婕・黄光偉

概要

農業中心の地域では、その地域に合わせた適当な水と化学肥料のマネジメントは持続可能な農業発展に役立つ。水資源の限られている乾燥地域にとって、環境、社会、そして、経済の発展を求めるには、その挑戦が一層大きくなる。黒河中流地域は中国北西部の乾燥地域に位置する典型的な内陸流域であり、過激な農業発展に伴い、生態系システムを維持する水資源の量でさえ赤字になり、地下水も汚染されつつある。本研究は黒河中流地域の農業における水と化学肥料のマネジメントによる総合作用は、如何に土壌硝酸を変動させるのを調査し、さらに、黒河流域の持続可能な発展への影響を討論するのが主旨である。そして、すでに発展中のドリップ式灌漑システムの可能性を探索するのも目的である。現在の水と肥料のマネジメントを社会調査で把握し、ドリップ灌漑システムへの意識調査を行った。多様な灌漑システムで、肥料のインプットによる耕作層土壌硝酸変動のモニタリングも実施した。社会調査と土壌実験により、従来の灌漑システムの農地の窒素肥料使用量は600.1 kg ha^{-1} y^{-1}で著しく高くなっているのに対し、ドリップ灌漑システムの導入で30% 以上の量を節約できるのが分かった。灌漑のマネジメントにおいては、河水に比べて井戸水の使用で24% の水資源を節約でき、井戸水灌漑の農地にドリップ灌漑システムの導入と有効管理で、さらに33%の地下水を節約できるのを発見した。けれども、農民たちがこのシステムへの偏見をなくすために、政府からの経済支援とトランスビリッジの経験交流が有効だと考えられる。

Co-effect of Irrigation Method and Fertilizer Management on Soil Nitrate Dynamics — A Case Study in an Arid Region of China —

1. Introduction

As one of the results of worldwide growing population, the demand for water is growing as a matter of course. The challenge is greater especially in arid regions where evaporation typically is larger than precipitation. How to manage the limited natural water resources for human activities, economic development and the conservation of ecosystem is continuously being a subject to research.

Water scarcity has become an increasingly severe issue in China, especially in the inland arid region in northwest China (Kang, 2000; Ji et al., 2005; Du et al., 2010). Heihe River Basin (HRB) is the second biggest inland watershed located in the arid region of the northwest China. The HRB is known for its diversity of geographies and ecosystems. From south to north, it is originated from the alpine of Qilian Mountain in Qinghai, extending through oases in Gansu and ceasing the flow to terminal lakes in the dessert of Inner Mongolia (Li et al., 2001; Wu, F., et al., 2015). The ecological value of natural water resources in HRB is enormous, because the water supply is the foundation of oasis composition and restricts the fringe of desert from expanding in this region (Guo et al., 2009). From 1960s, the increasing consumption of water resources for irrigating the growing crop cultivation land in the middle reaches of HRB, where human activities are concentrated, (Guo et al., 2009) generated serious damages to the ecological environment, such as the shrink of natural wetland (Zhao et al., 2013), the drying up of terminal lakes (Xiao et al., 2004) and more frequent sandstorms (Chen et al., 2014). Obviously, the sustainability in HRB depends largely on the ways of water resources utilization and the key of solving water related issues in HRB is to manage the water consumption in agriculture in the middle reaches.

The middle reaches of HRB has been consuming very large quantity of water from Heihe River for agricultural production. At the same time, natural wetland area in the middle reaches is observed decreasing rapidly from the 1970s because of ecological water deficit (Zhao et al., 2013). As the reclamation of new farmland from natural wetland had expanded by 15.38% during 1965–1986 and 43.60% during 1986–2007 and the percentage of farmland reached 70%. As a result, the amount of surface water used for irrigation had almost doubled from 1956 to 2010 (Nian et al., 2014). Therefore, with the big gap of evaporation and precipitation and the growing of the irrigated agriculture, the consumption of water resources is also increasing.

Though the dramatic increase of agriculture contributed to the economic growth, the current agriculture need to be shifted to water-saving agriculture under the contradiction of water scarcity and water consumptive agriculture. Among all the strategies that have been carried out for alleviating the deterioration of ecosystem in the HRB, the Ecological Water Diversion Project (EWDP) initiated by the Chinese government started to come into play from around 2000 (Hao, 2001), stating the middle reaches must transfer 9.5×10^8 m^3 of water to the lower reaches per year to meet the ecological water demand (Hu et al., 2015). Many efforts have been done to meet the mission. For instance, with the support of government policy, wheat –maize intercropping was substituted to seed corn as the main crop, which can save 29% irrigation water (Huang, 2015). Other strategies, the 'grain for green' policy (farmers who have converted farmland to forest or grassland be provided with free grain and cash payment), has been also carried out. In terms of irrigation water management, most of the irrigation canals have been paved in order to prevent water leakage and to raise the water efficiency (Wang et al., 2013). Recently, differing from the conventional flooding irrigation, the implement of drip irrigation system is spreading and its potential of saving water and fertilizer is accessed in this study. Although the water diversion mission to lower reaches has been accomplished commendably and the ecosystem has recovered gradually, over exploitation of ground water (Tian et al., 2015), low awareness of saving water in local farmers (Xu et al., 2014), low irrigation efficiency (Wu, X., et al., 2015) and other water management related issues are still lying there to be resolved.

Excessive irrigation and high chemical fertilizer rates that used by grain farmers as an 'insurance' for yield, are considered conventional agriculture practices in this region (Yang & Wang, 2011). Nitrogen fertilizer is crucial to crops, because it supplies a big part of available nitrogen for crop assimilation. Higher yields typically requiring increased nitrogen inputs, but some studies on grain yield and nitrogen fertilizer rate also suggested increased amount of nitrogen fertilizer after a certain level did not give a significant grain yield increase (Selassie, 2015). Excessive nitrogen fertilizer application in farmlands, inducing nitrate accumulation in soil layers and threatening groundwater by pollution via the mechanism of nitrate leaching (Al-Kaisi & Yin, 2003; Yang et al., 2006). It is reported that the total amount of nitrogen fertilizers applied on corn fields was more than 300 kg ha^{-1} y^{-1} in amount of nitrogen one decade ago and had an increase to more than 450 kg ha^{-1} y^{-1} has also been witnessed (Su et al., 2007), while the optimal nitrogen fertilizer rate in farmland of the middle reaches is suggested to around 304.9 kg ha^{-1} y^{-1} (Yin et al., 2014).

The big quantity of nitrogen fertilizer input makes the agriculture areas highly venerable to nitrate accumulation in soil profile and groundwater. Nitrate is proved leaching to deep soil layers and groundwater in the middle reaches of HEB in recent years and causing nitrate contamination of groundwater, the source of drinking water. The nitrate level in natural environment is often very low, a long term (1982–2001) study conducted in this region found nitrate accumulated in most subsoil layers, with major impact in 20–140 cm depth when continuous chemical fertilizer applied to farmland (Yang et al., 2006). A nitrate-nitrogen level of 403 mg kg^{-1} in soil is revealed with the peak of concentration occurring in the 140 to 160 cm soil layer and the occurrence of nitrate is found most of the samples above 300 cm soil depth (Fan et al., 2004). The nitrate-nitrogen concentration level in groundwater was around 10.66 mg L^{-1} with 32.4% of the wells estimated exceeding 10 mg L^{-1} were found rather in crop cultivating areas than in urban or natural wetland areas (Yang & Liu, 2010). A study that investigated groundwater samples from drinking wells, irrigation wells, hand-pumping wells and groundwater table observation wells, found the percentages of sample exceeding 10 mg L^{-1} were 13, 33.3, 52.4 and 50.0%, respectively. (Yang & Su, 2009). Despite of the progress of ground water contamination, the fertilizer management is not as highly respected as the water management in the middle reaches of HRB.

Agriculture management, including seeding, tillage, irrigation, fertilizer…, is significant for crop productivity. The effects of long term chemical fertilizer input on the agriculture in middle reaches of

HRB have been fully studied by researchers, however study on short term effect of fertilizer and irrigation management is not sufficient. This study pays special attention to the co-effect of water and fertilizer management which has strong impact on the sustainable development of HRB and access the drip irrigation system on reducing the nitrate accumulation in soil and the consumption of water resources in the middle reaches as well.

2. Study area and methods

2.1 Study area

The main course of Heihe River is as long as 821 km (Wu, F., et al., 2015). According to The State Council Information Office of the People's Republic of China (SCIOC) (2015), The middle reaches of HRB, as shown in *Figure 1* is from Yingluoxia Valley to Zhengyixia Valley, including Zhangye, Linze and Gaotai cities, covering 10.8 thousand km² area and has a population of around 1.3 billion (Huang, 2015). The middle reaches concentrate 95% of the arable land, 91% of the population and 89% of GDP in HRB. While 83% of the overall water consumption taking place in the middle reaches (SCIOC, 2015), the intensive water dependent agriculture has been utilizing the majority portion of the basin, 75% of available water resources (Nian et al., 2014).

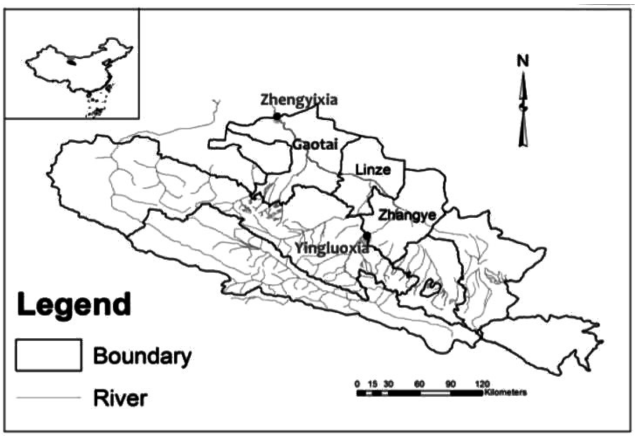

Figure 1. The middle reaches of Heihe River Basin

In the middle reaches, maize, which accounts for 33% of the total planting area by 2016, has been developed to the dominant cash crop since the 2000s (Huang, 2015). Agriculture activities are conducted during the farming season from March to November (Yin & Wang, 2015). In the farming season, water resources from the discharge of Heihe River are allocated by a traditional canal type irrigation system to thousands pieces of fields. There are five levels of canals: the main, branch, lateral and field canals, and field ditch and more than 75.6% of all the villages have canals passing through (Jiao & Ma, 2002). Annually, for maize cultivation, canal irrigation activities are conducted about 4 or 5 times and 3 times of fertilizer application, in middle April, June and July depending on the growth stage, are carried out in the limited farming period.

The study area of the present study is set to Zhangye District, the economic center at the south part of the middle reaches of HRB. Maize is intensively cultivated as the main crop while cash crops are also cultivated in large scale in agricultural areas around the city center. Multiple irrigation methods such as: 1) conventional canal type irrigation system using river water, 2) well water irrigation and 3) drip irrigation system using groundwater can be found increasing fast in this city.

2.2 Methods

The present study centers on irrigation and fertilizer management by combining social investigation approach and scientific experiment approach. The co-effect of irrigation and fertilizer management was investigated. The knowledge and perception of local farmers on drip irrigation system, which is under expanding in the study area, was investigated for accessing its potential of saving water and fertilizer. The study period is from July 8th, 2017 – August 12th, 2017.

The aims of social investigation are surmised as: 1. To obtain knowledge of the current nitrogen fertilizer rate, irrigation water amount and costs. 2. To survey the perception and intention on using drip irrigation system in the future among farmers who do not use it at present. 3. To survey the perception to drip irrigation system among farmers who are using it. In all, 20 villages in Zhangye District were visited and 125 farmers were interviewed.

For the experiment approach, this study chose 4 maize fields with 3 different irrigation methods (conventional flooding irrigation using canal to allocate river water (RW), flooding irrigation using well water (WW) and drip irrigation using groundwater (D)). The sampling fields are listed as below in *Table 1*.

Table 1. Description of sampling fields

Short Form	Crop	Village	Location	Irrigation Method	Sampling Period
S-RW	Maize	Songwangzhai	N38° 53′ 34.8″ E100° 31′ 31.0″	River water	7.21–8.3
H-WW	Maize	Huajiawa	N38° 51′ 44.6″ E100° 28′ 06.7″	Well water	7.12–7.25
S-D	Maize	Sanshilidian	N38° 49′ 29.8″ E100° 26′ 41.9″	Dripping system River water*	7.14–7.27
Y-D	Maize	Yangjiadun	N38° 51′ 40.1″ E100° 28′ 12.6″	Dripping system	7.8–7.21

*River water irrigation was conducted once to the field when the soil was extremely dry before sampling.

The soil samples of arable layers (Upper: 0–10 cm; Middle: 10–20 cm; lower: 20–30 cm) of each sampling field were monitored 4 times in 13 days. As a local practice, irrigation water is applied in the same day after the input of fertilizer. In each field, the first sample was taken on the day before the input of irrigation water and nitrogen fertilizer, the following sampling activities were performed 3 days after the previous sample.

For nitrate contents test, dry soil sample (5 g) was added into deionized water (25 mL), then the mixture was shaken for 30 minutes and filtered for nitrate extraction. Nitrate concentration of the extracted liquid was measured using an RQ flex plus 10 reflect meter (Fujiwara Scientific Co. Ltd., Japan).

Soil nitrification potential is a good indicator for the richness of nitrification bacteria that transfer urea to nitrate in the surface layer of soil. Thus 3-days nitrification potential of each upper layer soil sample was also tested. For this experiment, the first sample of each field was used. After the Water Holding Capacity (WHC) was tested, the moisture level of soil sample (4 g) was adjusted to 60% of its WHC, at which the nitrification bacteria were most active. Then, the sample was added with urea solution (200 mg L^{-1}) and incubated at room temperature for 3 days. The difference of nitrate contents before and after urea incubation reflected the nitrification potential.

3. Results and discussions

3.1 Fertilizer management

For understanding the current agricultural management, nitrogen fertilizer usage and its cost is interviewed and the results are shown in *Figure 2*.

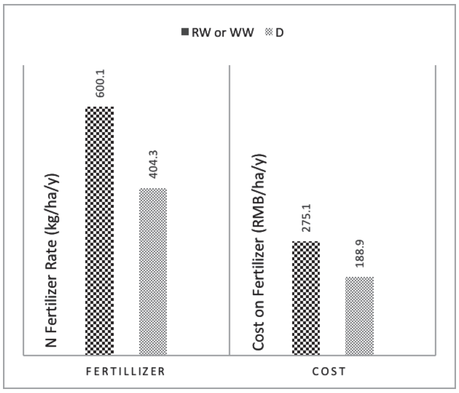

Figure 2. Nitrogen fertilizer usage (kg / ha / y) and fertilizer cost (RMB /ha/ y)

Among the maize farmers using conventional irrigation methods, the rate is around 600.1 kg ha^{-1} $year^{-1}$ costing 4126.5.1 RMB in average. Surprisingly, the nitrogen fertilizer applied has a largely greater amount than Su et al. (2007) found a decade ago and is almost twice of the suggested optimal amount by Yin et al. (2014). Nitrogen fertilizer efficiency is supposed incredibly low in this situation. As a consequence, the excessive nitrogen ends up leaching the deep soil layers, hopelessly being absorbed by maize crops. But from the farmers' point of view, nitrogen fertilizer has become a kind of 'insurance' in the competition of yield and it is hardly possible for them to reduce without a convincing reason.

On the other hand, the average nitrogen fertilizer rate is 404.3 kg ha^{-1} $year^{-1}$ and with a cost of 2833.5 RMB for farmers who have adopted drip irrigation system. Compared to the conventional management, saving percentages of 33% and 31% are achieved, meaning the nitrate contamination to soil and groundwater of HRB can be sharply reduced with less agricultural cost. The nitrogen fertilizer level is still higher than the optimal level suggested by Yin et al. (2014), it is thought because a portion of users report that a slight decrease on yield is perceived from their cultivation experiences so they accuse the drip irrigation system for not inputting enough fertilizer and tend to apply more regardless of the instructed amount. As a matter of fact, the fertilizer management in drip irrigation field is just recommended to a low rate, but it is not clearly regulated. The potential of the new system on saving fertilizer and reducing the nitrate accumulation in soil profile and groundwater is highly evaluated even though clear regulation on fertilizer rate is needed for further progress.

3.2 Water management

With the expansion of agriculture, the water demand increases without a doubt. Since the available water resources of the middle reaches are limited, there is a necessity to promote the water use efficiency and irrigation water management for controlling the water demand.

Basically, the surface water from Heihe River is allocated to individual field about 4 or 5 times a year, depending on the precipitation during the cultivating period. The schedule of the allocation and the water quantity for each village is well planned, but there is no system for monitoring the irrigation water usage of individual fields, and farmers just irrigate their fields by experience or by the time length briefly. The charge for river water usage is decided based on an average usage in a village scale instead of individual field. The situation makes calculating the exact amount of irrigation water in individual field quite difficult.

As introduced previously, the obligation of diverting a certain amount of river water to the downstream according to the EWDP makes the surface water insufficient to water demand in the middle reaches, villages using well to exploit groundwater for irrigation increased a lot. Accordingly, in the middle reaches, the land use from 2000 to 2011 changed in large scale and the farmland area increased by 12%, moreover, most of the newly reclaimed farmlands are irrigated by ground water causing an increase of 68% of groundwater exploitation (Hu et al., 2015). As a matter of fact, the overexploitation of groundwater is serious because the use of well water is regulated poorly (Tian et al., 2015). In drip irrigation fields, the water source is rather well water than river water and more frequent irrigation activities, 8 or 10 times every 10 days, are required than well water flooding irrigation which happens 5 or 6 times. The payment for water usage from well consists of water resources fee and the charge for electricity used for pumping groundwater.

This study tried to calculate the irrigation water amount in the study area on the basis of the farmers' payments for water usage and the price of each water resource. The results reveal that the water used for one-time irrigation is 1,800, 1,095, 405 m^3 ha^{-1} of river, well and drip irrigation water, respectively. Taking the irrigation plan of 2017 as an example, there are 4, 5 and 9 times of irrigation using river water, well water and drip system, respectively, the water consumption of 1 ha field will be 7,200, 5,475 and 3,645 m^3. It means conventional well water irrigation may consume 24% less water than river water irrigation and 33% of groundwater can be saved if drip irrigation system adopted in well water irrigated fields. Considering the potential of drip irrigation system on saving groundwater resources, it will definitely come true that the wetland in the middle reaches of HRB be restored step by step and the ecosystem of the whole basin be maintained.

3.3 Soil data analysis

Soil nitrate concentration level is an indicator of water and fertilizer management in agricultural activities. Conventionally, once the nitrogen fertilizer, generally granular urea in this region, emplaced in field, the hydrolytic action will take place after the input of irrigation water and the chemical equation is as below:

$$CO\,(NH_2)_2 + 2H_2O \Rightarrow CO_3^{2-} + 2NH_4^+$$

Thus, with the hydrolysis of urea, ammonium is generated. A part of the irrigation water evaporates and the other part infiltrates from the surface to soil body becomes available for plant root absorption. With the soil moisture reaching to 60% and proper conditions (soil pH, temperature and availability of O2), nitrification bacteria start to work. The nitrification process equations are as below:

$$2NH_4^+ + 3O_2 \Rightarrow 2\,NO_2^- + 2H_2O + 4H^+\,;$$

$$2NO_2^- + O_2 \Rightarrow 2NO_3^-$$

However, for drip irrigation as an integrated water and fertilizer technology, the granular urea has to be pre-dissolved into the irrigation water, so the hydrolytic action take place before irrigating not after and ammonium is generated faster, as a result, the nitrification processes are expected to be more efficient.

Since the majority of plant available nitrogen is nitrate in the region, the key of high nitrogen fertilizer efficiency is nitrification potential. The 3-day nitrification potential of upper layer soil from each field is tested. According to the results shown in *Table 2*, all of the fields tested have high nitrification potential, while fields with drip irrigation system show lower level of nitrification potential than fields with flooding irrigation systems.

The monitoring results of nitrate contents in soil layers of maize fields can be found in *Table 3*. Generally, in the upper layer, the nitrate level of the first sample is lowest and the peak is observed at the second or third sample. In the middle and

Table 2. Nitrification potential in 3 days of sampling fields (mg/kg)

S-RW	H-WW	S-D	Y-D
1435	1406	938	730

Table 3. Results of nitrate contents in soil layers of Maize fields and tomato fields (mg/kg)

Field	S-RW				H-WW				S-D				Y-D			
Sample	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Upper	30	340	95	130	100	280	255	175	30	390	315	305	40	65	65	45
Middle	25	80	85	65	40	140	195	110	45	335	150	170	155	90	75	35
Lower	12	85	35	35	50	170	175	100	45	175	120	110	35	25	45	20

lower layers, the same tendency of nitrate level is found in most fields, indicating the phenomenon of nitrate leaching. The highest potential is found in S-WW.

In *Figure 3*, S-D has the highest peak of nitrate contents, indicating a higher efficiency of on-site urea fertilizer transformation as predicted though the laboratory experiment nitrification potential is low. On the contrary, the other drip irrigation field Y-D showed lowest nitrate dynamics. Why does this big gap between the two fields with drip irrigation happen? Looking back to the description of sampling fields, the difference on water management is found. The soil in Y-D was extremely dry when sampling, but river water irrigation was conducted once to the S-D field when the soil was extremely dry before sampling, implying the moisture level in S-D, which is higher than Y-D, is the main factor to the higher level of on-site nitrification process. With this finding, an increased frequency of drip irrigation to keep a reasonable level of soil moisture is suggested as an improved water management strategy. The frequency is suggested to be once in every 7 days, considering the feasible irrigation cycle is reported 7 days and less water amount with more frequent irrigation is better for both grain crop yield and water use efficiency in this region (Du et al., 2010).

On the other hand, flooding irrigation with river and well water shows lower nitrate contents in upper layer soil at the peak though the nitrification potential is higher. In this situation, the fertilizer efficiency is low since a portion of the applied fertilizer end up with not being transformed to nitrate, the most available form of nitrogen to crop plants.

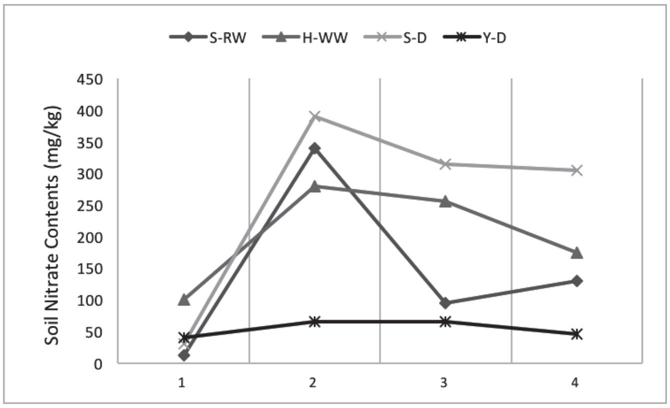

Figure 3. Nitrate dynamics in upper layer soil of sampling fields (mg/kg)

3.4 Social perception and intention on drip irrigation

Summarizing the co-effect of water and fertilizer management on soil nitrate dynamics, the integrated beneficial part of drip irrigation system on conservation of water resources, fertilizer saving and agricultural cost reduction is supposed as high as 30%, approximately. However, the newly under developing system can be accepted by farmers or not is another question. The results from the social investigation on farmers' perception and intention on drip irrigation system are shown in *Figure 4* and *Figure 5*.

The satisfaction of drip irrigation system users is high, with 90.9%, 81.8% and 84.8% of users interviewed feel it save water, fertilizer and manual work respectively. And the percentage of users who will continue the system is as high as 90.9%. 95.7% of the farmers who do not have experience on using drip irrigation system know it, however, there are 38.6%, 40.9% and 44.3% of them do not think drip irrigation system save water, fertilizer and manual work. It seems that farmers feel it beneficial better and are more motivated on using the system when actual experience on using it is earned. Therefore, trans-villages communication for sharing the experiences of users to users to be will eliminate to misunderstanding of drip irrigation.

Farmers with intention of adopting it is only 56.8%. The bias that stopping the 43.2% of farmers from trying drip irrigation system is expressed as high initial cost in a majority. When asked if government support the head cost, 69% of these farmers changed their intention to want to try. So the key factor of developing develop drip irrigation system is the cost.

Another bias is they believe the ploughing up to make soil flat for spreading the drip pipelines will reduce the soil fertility. This point is possibly right, since it is identical to the nitrification potential experiments, which find fields with the drip system show lower potential than the conventionally irrigated fields. But the performance of fertilizer use efficiency in drip irrigation field can be better than conventionally irrigated field with improved water management keeping a proper moisture of soil.

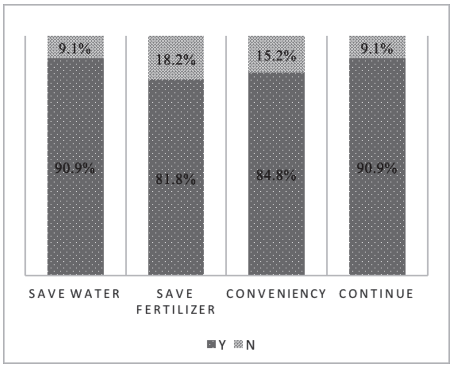

Figure 4. Perception and intention on drip irrigation among users

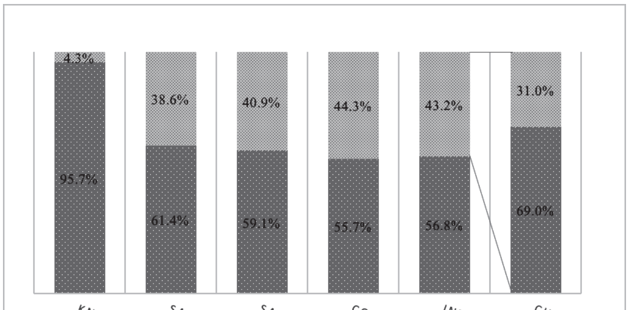

Figure 5. Perception and intention on drip irrigation among non users

4. Concluding remarks

Under the contradiction of water scarcity and huge agricultural water demand, the sustainable development of HRB counts highly on the sustainable development of agriculture in the middle reaches. Policies and strategies for more efficient management of Heihe river water allocation and better ecological environment have been carried out in recent years, but the development in the watershed is still largely driven by economic benefits from the expanding agriculture, which result in growing water and fertilizer demand, leading to the overexploitation of groundwater and nitrate contamination. Though the issues have been studied for many years but the condition has not been improved and solutions are to be developed. The present work targeted the co-effect of water and fertilizer management on nitrate dynamics and found that the drip irrigation system potentially saves approximately more than 30% of groundwater water resources and fertilizer compared to conventional irrigation systems with advanced management, such as clear regulation on fertilizer rate and suitable soil moisture keeping by irrigation frequency. Base on these findings, it is concluded that further promotion of the drip irrigation system is one of the steps toward achieving the goals of sustainable development of not only agriculture in the middle reaches but also the whole Heihe River Basin.

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Global Climate Bond Strategy for Financing Green Economy

John Joseph Puthenkalam

Abstract

The Paris Agreement builds upon the Rio Convention (1992) and Kyoto Protocol (1997) and –for the first time– brings all nations into a common cause to undertake ambitious efforts to combat climate change and adapt to its effects, with enhanced support to assist developing countries to do so. As such, it charts a new course in the global climate effort. The Paris Agreement's central aim is to strengthen the global response to the threat of climate change by keeping a global temperature rise this century well below 2 degrees Celsius. Additionally, the agreement aims to strengthen the ability of countries to deal with the impacts of climate change. To reach these ambitious goals, appropriate financial flows, a new technology framework and an enhanced capacity building framework will be put in place, thus supporting action by developing countries and the most vulnerable countries, in line with their own national objectives. In this context, it is important to discuss, "appropriate financial flows" and mechanism. Let us analyze the emerging "Global Climate Bond Strategy for Financing Green Economy" in this article.

グリーンエコノミのためのグローバル候変ボンド戦略

プテンカラム　ジョン　ジョセフ

概要

1992年の連環境開発会議で採択された国連気候変動枠組条約、1997年の京都議定書体制の期間後、2015年12月12日に、パリで開かれた国連気候変動枠組条約第21回締約国会議（COP 21）で、パリ協定が採択された。パリ協定は、その後1年を待たず、2016年11月4日に要件を満たし、発効した。世界の多くの国が参加する国際環境条約で、採択から1年以内に発効する事例は極めてまれである。本論文では、パリ協定の課題を分析し、気候ガバナンスにおけるパリ協定の位置づけを示すとともに、途上国が気候変動の影響に対応し、公正で持続可能な発展の道へ、また、クリーンエネルギーへとシフトするために、必要な気候資金と気候ファイナンス～新しい資金通してのLombard Odier Global Climate Bond Strategyを参考し、議論したい。

Global Climate Bond Strategy for Financing Green Economy

Introduction

Recently, there was a news briefing about the investment Sophia University made in Lombard Odier Global Climate Bond Fund. This new investment upholds Sophia university priority engagement with environmental issues as it has become one of the Branding Projects that brings together experts from various Faculties and Departments to streamline Sophia mission in the 21st century, under the auspice of Global Environment Studies and Research. In this context, let us analyze the emerging "Global Climate Bond Fund for Financing Green Economy" in this article.

Nations in a Single Climate Agreement

The COP 21 Paris Agreement in 2015[1] unites all the world's nations in a single agreement on tackling climate change for the first time in history. The Paris Agreement builds upon the Rio Convention (1992)[2] and Kyoto Protocol (1997)[3] and –for the first time– brings all nations into a common cause to undertake ambitious efforts to combat climate change and adapt to its effects, with enhanced support to assist developing countries to do so. As such, it charts a new course in the global climate effort. The Paris Agreement's central aim is to strengthen the global response to the threat of climate change by keeping a global temperature rise this century well below 2 degrees Celsius above pre-industrial levels and to pursue efforts to limit the temperature increase even further to 1.5 degrees Celsius. Additionally, the agreement aims to strengthen the ability of countries to deal with the impacts of climate change. To reach these ambitious goals, appropriate financial flows, a new technology framework and an enhanced capacity building framework will be put in place, thus supporting action by developing countries and the most vulnerable countries, in line with their own national objectives. The Agreement also provides for enhanced transparency of action and support through a more robust transparency framework. According to Article 4 paragraph 2 of the Paris Agreement, each Party shall prepare, communicate and maintain successive nationally determined contributions (NDCs)[4] that it intends to achieve. Parties shall pursue domestic mitigation measures, with the aim of achieving the objectives of such contributions stated in *nationally determined contributions*. The Paris Agreement requires all Parties to put forward their best efforts through "nationally determined contributions" (NDCs) and to strengthen these efforts in the years ahead. This includes requirements that all Parties report regularly on their emissions and on their implementation efforts.

Coming to a consensus among nearly 200 countries on the need to cut greenhouse gas emissions is regarded by many observers as an achievement in itself and has been hailed as "historic". The Kyoto Protocol of 1997 set emission cutting targets for a handful of developed countries, but the US pulled out and others failed to comply. The Paris agreement lays out a roadmap for speeding up progress. On 5 October 2016, the threshold for entry into force of the Paris Agreement was achieved.

Status of Ratification: The Paris Agreement entered into force on 4 November 2016, thirty days after the date on which at least 55 Parties to the Convention accounting in total for at least an estimated 55% of the total global greenhouse gas emissions have deposited their instruments of ratification, acceptance, approval or accession with the Depositary. The first session of the Conference of the Parties serving as the Meeting of the Parties to the Paris Agreement (CMA 1) took place in Marrakech, Morocco from 15–18 November 2016 and in November 2017 CMA 2 took place in Bonn, Germany. Let us have a brief glance at the essential elements of Paris agreement. The agreement lays out a roadmap for speeding up progress.[5]

- To keep global temperatures "well below" 2.0C (3.6F) above pre-industrial times and "endeavour to limit" them even more, to 1.5C
- To limit the amount of greenhouse gases emitted by human activity to the same levels that trees, soil and oceans can absorb naturally, beginning at some point between 2050 and 2100
- To review each country's contribution to cutting emissions every five years so they scale up to the challenge
- For rich countries to help poorer nations by providing "climate finance" to adapt to climate change and switch to renewable energy.

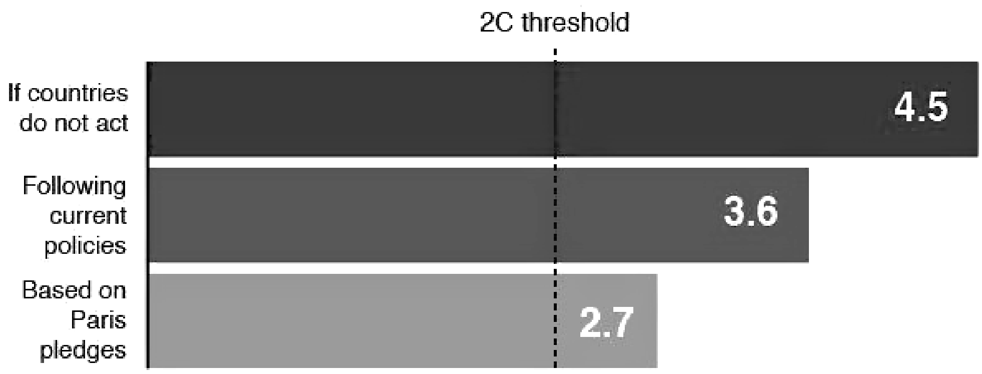

Figure 1 : Average warming (C) projected by 2100

Source: Climate Action Tracker, data compiled by Climate Analytics, ECOFYS, New Climate institute and Potsdam institute for Climate impact Research.

Issues of "Climate Finance"

- Money has been a sticking point throughout the negotiations.
- Developing countries say they need financial and technological help to leapfrog fossil fuels and move straight to renewables.
- Currently they have been promised US $100bn (£67bn) a year by 2020 –not as much as many countries would like.
- The agreement requires rich nations to maintain a $100bn a year funding pledge beyond 2020, and to use that figure as a "floor" for further support agreed by 2025.

◇ The deal says wealthy countries should continue to provide financial support for poor nations to cope with climate change and encourages other countries to join in on a voluntary basis.

◇ "The starting point of $100bn per year is helpful, but remains under 8% of worldwide declared military spending each year."[6]

Challenges of Green Finance

On 5th September 2016, G20 Green Finance Study Group published a Report[7] that brings out the necessity as well as challenges of Green Finance. The GFSG has been launched under China's Presidency of the G20. Its mandate is to "identify institutional and market barriers to green finance, and based on country experiences, develop options on how to enhance the ability of the financial system to mobilize private capital for green investment." The G20 Green Finance Study Group (GFSG)'s work supports the G20's strategic goal of strong, sustainable and balanced growth. The challenge is to scale up green financing, which, based on a number of studies, will require the deployment of tens of trillions of dollars over the coming decade. The GFSG was established to explore options for addressing this challenge. "Green finance" can be understood as financing of investments that provide environmental benefits in the broader context of environmentally sustainable development. These environmental benefits include, for example, reductions in air, water and land pollution, reductions in greenhouse gas (GHG) emissions, improved energy efficiency while utilizing existing natural resources, as well as mitigation of and adaptation to climate change and their co-benefits. Green finance involves efforts to internalize environmental externalities and adjust risk perceptions in order to boost environmental friendly investments and reduce environmentally harmful ones. Green finance covers a wide range of financial institutions and asset classes, and includes both public and private finance. Green finance involves the effective management of environmental risks across the financial system. Green finance faces a range of challenges. While some progress has been made in green finance, only a small fraction of bank lending is explicitly classified as green according to national definitions. Less than 1% of global bonds are labeled green and less than 1% of the holdings by global institutional investors are green infrastructure assets. The potential for scaling up green finance is substantial. However, the development of green finance still faces many challenges. Some are largely unique to green projects, such as difficulties in internalizing environmental externalities, information asymmetry (e.g., between investors and recipients), inadequate analytical capacity and lack of clarity in green definitions. Others are more generic to most long term projects in some markets, such as maturity mismatch. Options to address these challenges are emerging. Many countries have adopted measures such as taxes, subsidies and regulations to deal with environmental challenges. These actions make significant contributions to enhancing green investment, but overall the mobilization of private capital remains insufficient. Over the past decade, various complementary financial sector options have emerged in many G20 countries, from both private and public actors, to support the development of green finance. These include, among others, voluntary principles for sustainable lending and investment, enhanced environmental disclosure and governance requirements, and financial products such as green loans, green bonds, green infrastructure investment trusts, and green index products. International collaboration among central banks, finance ministries, regulators and market participants is also growing, focused in large part on knowledge sharing of country experiences and capacity building.

Emerging from the GFSG's work are a number of options for the G20 and country authorities, for consideration for voluntary adoption, to enhance the ability of the financial system to mobilize private capital for green investment.

Key options are highlighted below:

1. Provide strategic policy signals and frameworks: Country authorities could provide clearer environmental and economic policy signals for investors regarding the strategic framework for green investment e.g., to pursue the Sustainable Development Goals (SDGs) and the Paris Agreement.
2. Promote voluntary principles for green finance: Country authorities, international organizations and the private sector could work together to develop, improve, and implement voluntary principles for and evaluate progress on sustainable banking, responsible investment and other key areas of green finance.
3. Expand learning networks for capacity building: The G20 and country authorities could mobilize support for the expansion of knowledge based capacity building platforms such as the Sustainable Banking Network (SBN), the UN backed Principles for Responsible Investment (PRI), as well as other international and domestic green finance initiatives. These capacity building platforms could be expanded to cover more countries and financial institutions.
4. Support the development of local green bond markets: On request of countries that are interested in developing local currency green bond markets, international organizations, development banks and specialized market bodies could provide support via data collection, knowledge sharing and capacity building. This support could include, in working with the private sector, the development of green bond guidelines and disclosure requirements as well as capacity for verifying environmental credentials. Development banks could also play a role in supporting market development, for example by serving as anchor investors and / or demonstration issuers in local currency green bond markets.
5. Promote international collaboration to facilitate cross-border investment in green bonds: Country authorities or market bodies could promote cross-border investment in green bonds, including through bilateral collaboration between different green bond markets, where market participants could explore options for a mutually accepted green bond term-sheet.
6. Encourage and facilitate knowledge sharing on environmental and financial risk:
   To facilitate knowledge exchange, the G20 / GFSG could encourage a dialogue, involving the private sector and research institutions, to explore environmental risk, including new methodologies related to environmental risk analysis and management in the finance sector.
7. Improve the measurement of green finance activities and their impacts:
   Building on G20 and broader experiences, the G20 and country authorities could promote an initiative to work on gre en finance indicators and associated definitions, and to consider options for the analysis of the economic and broader impacts of green finance[8]

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	Banking	Bond market	Institutional investors	practices to address challenges
Externalities	Inadequate compensations for positive externalities of green projects; Inadequate penalties for negative externalities of polluting projects Inadequate price signals			In addition to fiscal and environmental policies: guarantees, concessional loans, PPP, **demo projects**, **adoption of risk management principles and methods**, green labeling, etc.
Maturity mismatch	Lack of appropriate financing instruments for long-term green projects			**Green bonds**, yieldcos, **collateralized lending**
Lack of clarity in green definitions	Lack of green loan definition	Lack of green bond definition	Lack of green asset definition	**Development of green definitions and indicators**
Information asymmetry	Lack of info on borrowers; excessive risk aversion	Lack of info and monitoring on use of proceeds	Lack of info on assets (environmental impacts and risks)	Voluntary disclosure guidelines for environmental impact and related financial risks, **green bond verification, risk mitigation, policy signals, demo projects, anchor investments**
Lack of analytical capacities	Lack of capacity to assess impact on credit risk	Lack of capacity to assess impact on credit risk	Lack of capacity to assess impact of asset valuation	**Risk modeling, training, ratings, indices**

Figure 2 : General Challenges to Green Finance and Selected Country / Market Practices to Address such Challenges

Key Options for Developing Green Finance

There are five general challenges to green finance –externalities, maturity mismatch, lack of clarity about green finance, information asymmetry, and lack of analytical capacities. These challenges, relevant to most financial market segments and players, are summarized in the above Table, which also shows the specific forms they may take and how they have been addressed by countries and/or financial institutions. This table offers a simple framework for understanding the linkages between the general challenges and specific actions.

Many green finance options such as the development of green financial products, as well as risk analysis and management methodologies involve innovations by the private sector. However, wider application of green finance could be facilitated by improved knowledge sharing, capacity building, stronger policy signals and improved clarity in definitions of green finance activities. In our view, these elements constitute the ulk of the "enabling environment" for green finance.[9]

Climate Bonds as a Green Finance Mechanism

Issuing of bonds financed infrastructure initiatives over the past century or two to meet environmental and social challenges. These included sewer construction that helped address the blight of cholera in Europe and the development of the national energy grids to fuel the economic growth of the 20th century. These bonds are long-term debt instruments that are repaid at pre-agreed upon rates and guaranteed by governments. The latest Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment report sends a stark message that it is imperative that the world shifts to a low-carbon and resilient economy *now*.[10] A 2013

World Economic Forum report projected the need for global investment in the low carbon economy at $5.7 trillion annually by 2020 to avert the most serious consequences of climate change.[11] There is international agreement that to address this investment gap, governments are somewhat limited especially in the light of a recovering global economy and thin public sector balance sheets. The pressing need to accelerate our climate mitigation efforts has brought a spotlight to bear on targeting private financing. Climate bonds are proving to be a valuable tool in the climate finance arena garnering considerable attention from both investors and environmentalists. Richard Kauffman, former advisor to the U.S. energy secretary commented that, “New strategies don’t require going to the lab; they involve applying financing techniques that have already been invented and are used widely in other parts of the economy, but have not yet been applied to this sector.”[12] Climate bonds fit Kauffman’s definition of a new strategy; they are essentially infrastructure bonds tailored specifically to finance climate solutions. The scope of projects that can be financed is determined by the issuer and can be broad or specific.

Global Bond Market

The greatest share of institutional funds is allocated to the global bond market. The value of these bonds as of the end of 2010 was $95 trillion with 72% of those bonds being held by long-term investors such as pension funds, mutual funds, and insurance firms.[13] While conventional investors are waiting for policy signals, others are actively demonstrating their commitment by investing in bonds and other financial instruments that support low-carbon project development at scale. This has set the stage for a market for climate (green) bonds, defined as asset-backed bonds that furnish capital to climate change mitigation projects that yield credible reductions in emissions, or strengthen adaptation measures. The green bond market is currently just 0.4% of the global bond market. Bonds are ideally suited to funding the long-term environmental infrastructure needed to develop the low-carbon economy. Bonds allow one to borrow against future economic benefits to allow for the investment needed now to deliver those benefits.[14]

The required upfront investment needs are often balanced by significantly lower operating costs especially in the building, energy, industrial, and transport sectors. Outstanding bond totals in 2012 were $174bn and increased to $346bn by the end of 2013.[15] Of this outstanding 2013 bond total, $163 billion were deemed as investment grade bonds (risk, currency, and issue size compatible with institutional investors). The top tiers are dominated by transport ($263bn), energy ($41bn), and finance ($32bn). In the U.S. the most established government bond programs directed at green investment stem from the American Recovery and Reinvestment Act (ARRA). These include the Qualified Energy Conservation Bonds (QECBs), which typically fund energy efficiency projects in government owned/operated buildings and the Clean Renewable Energy Bonds (CREBs), which fund clean energy projects. There was negligible CREB issuance in 2013, but around $230m worth of QECBs were issued.[16] Climate bonds typically mature in the 5–10 year range, which is appropriate to climate mitigation project timelines. The fact that the market is seeing multiple issues and reissues in this sector indicates that both the issuers and investors are generally satisfied with these bonds as a credible and growing investment class. According to IFSL Research, climate bonds could be issued each

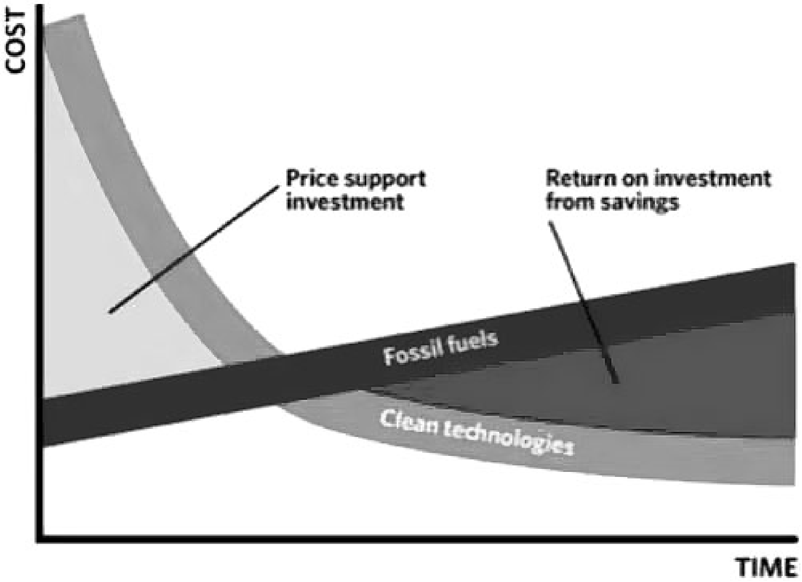

Figure 3 : Short-term price support for climate friendly projects to achieve economies of scale will result in long term cost savings. Source: Climate Bond Initiative, U.K.

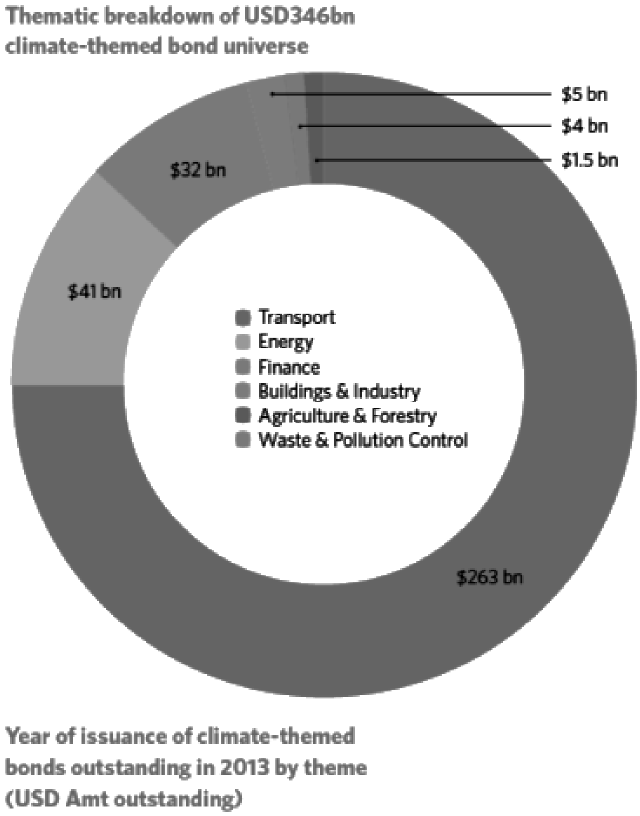

Figure 4 : Breakdown of Thematic Bond Universe[7]

Year of issuance of climate-themed bonds outstanding in 2013 by theme (USD Amt outstanding) year up to a level of $0.5 trillion for the next 20 years and still not exhaust the capacity of the global market. Figure 4 shows the Breakdown of Thematic Bond Universe.[17]

30% of the issued bonds yield less than 1% while 40% of them are in the 1–3% range. Around $35bn of outstanding climate bonds deliver 3% or higher. A 2011 report by investment consultant firm, Mercer, concluded that institutional allocation of investment in "climate sensitive assets (infrastructure, agriculture, timberland, and real estate) could help de-risk portfolios from the impacts of climate change compared to a business-as-usual scenario."[18] Figure 5 shows the Ratings distribution of Bonds.[19]

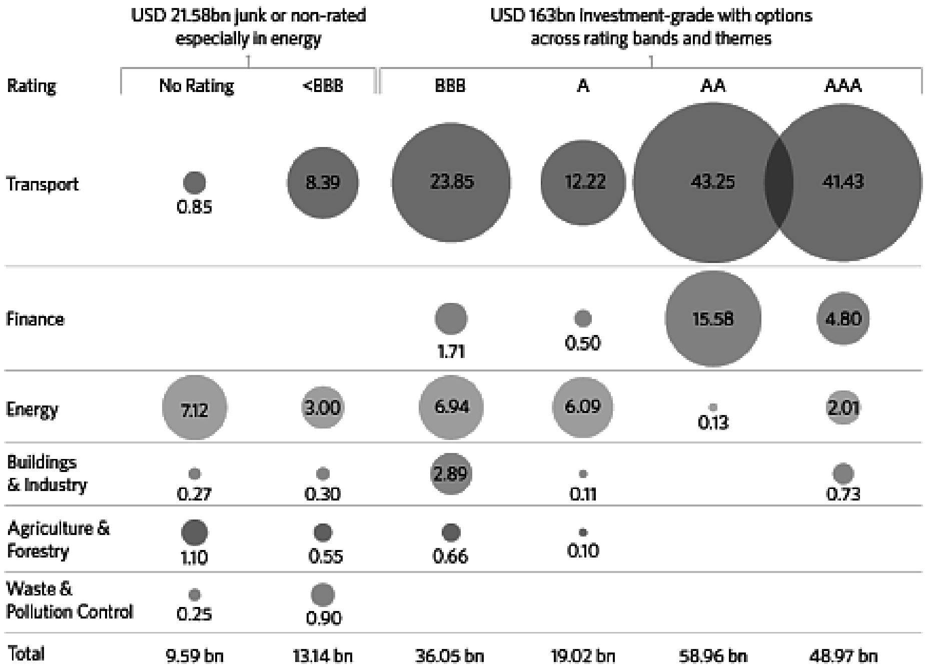

Figure 5 : Ratings distribution of bonds by index-type rules[9]

Climate Bond Benefits

Institutional investors are often challenged to support climate friendly financial instruments since many of them come with additional parameters that include alternative coupon payments, liquidity constraints, and variable maturities. Energy and infrastructure projects often require secure long-term revenue streams to enable the establishment of up-front finance. This has resulted in increased cost of capital for these types of climate friendly projects, and climate bonds could become the key to unlocking the vast potential of the international bond market to bridge the financing gap.[20] The European Investment Bank (EIB) issued the first climate bond in 2007. EIB's program of Climate Awareness Bonds totaled more than a billion euros and was used to fund renewable energy projects. Instead of offering a fixed return or coupon, the bond was held for five years before it was redeemed at face value plus an amount driven by the performance of the FTSE4Good Environmental Leaders Europe 40 index (a 5% minimum return was guaranteed).[21] 2013 saw a "breakthrough for investor awareness of labeled bonds," according to the Bonds and Climate Change report commissioned by HBC. The International Finance Corporation (IFC) and Export-Import Bank of Korea (Kexim) issued a $1 billion bond and $500 million bond respectively. Both were oversubscribed in just a few hours with 50%–70% of the buyers originating in the US and Europe. In recent years, Ford and Microsoft made their support for climate smart investments clear. They invested in a $1 billion bond for climate projects issued by IFC. The bond transaction was reported to be heavily oversubscribed and had investors from firms such as BlackRock, Deutche Bank, Ford, and Microsoft.[22] The rapid pace of subscription is a common element for climate bond issuances. Also, the new Canadian Export Development Bank received $500m in bond orders on a$300m bond in 15 minutes. The New York State Energy Research and Development Authority (NYSERDA) recently took advantage of a bond issuance to finance $24.3 million in loans that support energy efficiency improvements. [14] Climate Bonds has posted a new item, The European Investment Bank (EIB) launched its first Sterling Climate Awareness Bond, a GBP500 million, 6-year bond. EIB was initially targeting GBP350 million, but the issuance was upsized due to high demand primarily from UK SRI investors and major bank treasuries, some of which have dedicated SRI portfolios.

PRI and Mission Statements

Market observers predict increased uptake in the climate bond arena. The heightened focus and implementation of ESG (environmental, social, and governance) screens of the Principles of Responsible Investment (PRI) to fixed income portfolios will mobilize over 1,000 PRI signatories who represent $32 trillion in assets under management. Pursuing environmental investments enables institutional investors a way to adhere to their mission statements and reduce risk exposure to the potential impacts of rising emissions levels. The California State Teachers' Retirement System pension fund has a charter to integrate climate risk into their asset allocation and investment strategy. Denmark's' ATP pension fund has targeted $1biilion for the investment into climate change areas.[23] This demarcation of climate friendly investment is a growing trend and suits the emerging climate bond instrument. The retail and consumer segments also find appeal in climate bonds since these investments support their environmental goals, local communities being impacted by a changing climate, and the diversification of their portfolios. A secondary influence on this market is the guidelines regularly issued by the Global Investor Coalition on Climate Change to asset managers commanding $22 trillion in assets. These institutional investors are attempting to proactively position themselves in accordance with the 2015 climate agreement in Paris. The growing climate bond market is now able to present governments with a range of policy options to stimulate private investment into low-carbon projects. Governments could support the market further through preferential tax treatment, or through the provision of partial guarantees. While still a nascent market, the climate bond universe offers considerable promise. Attracting private sector investment to help bridge the climate finance gap, and to sign up for debt instruments that finance environmental capital projects is a viable solution. The current small scale of the bond market offers tremendous scope for growth, as shown by the LO Funds-Global Climate Bond Fund. While increasing environmental awareness will buoy demand, only structure and return will govern the successful outcome of these investment vehicles.[24]

Lombard Odier Global Climate Bond Fund

Lombard Odier Investment Managers has partnered with Affirmative Investment Mangement (AIM) for the launch of a global climate bond investment strategy that aims to help combat climate change.[25] This follows a strategic partnership between the Swiss group and the UK-based fixed income manager dedicated to impact strategies. The LO Funds-Global Climate Bond Fund consists of a diversified investment grade portfolio seeking to simultaneously deliver a low carbon and climate resilient economy, or mitigate some of the effects of climate change whilst targeting a higher yield than a typical investment grade portfolio with lower turnover. The management team will identify investments providing positive climate-related outcomes such as renewable energy, resource efficiency, land management, water resources, physical infrastructure and marine environment. Also opportunities in other areas such as climate change adaptation will be considered. The portfolio will be monitored by the risk management team of LOIM. Carolina Minio-Paluello, global head of Sales and Solutions at Lombard Odier IM, commented: "Climate bonds offer a beacon of hope for closing the gap between the current and required levels of investment into climate change solutions in order to meet the COP21 objective to limit climate change to two degrees. The increased size and dynamism of the green bond market also goes a long way to improving how impactful investors can be. The new fund enables our investors to mobilize their capital with a clear understanding of how their assets will be deployed, while generating the same returns for the same risk as a conventional bond portfolio." Stephen Fitzgerald, co-founder and chairman of AIM stated: "Transparency is a key consideration for investors in the rapidly growing climate bond market, where guidelines around issuance can still appear vague or arbitrary, with no single standard for qualifying projects as being environmentally sound. Expert selection is therefore crucial to ensure investors have a more comprehensive coverage of the full labelled and climate-aligned universe."[26] Lombard Odier group had CHF223bn (€209.6bn) of assets under management as at the end of June 2016.

Conclusion

Greening global economic growth is the only way to satisfy the needs of today`s population and up to 9 billion people by 2050 , driving development and well-being while reducing greenhouse gas emissions and increasing natural resource productivity. Considerable progress has been made in transitioning to green growth. Global investment in renewable energy in 2011 hit another record; up 17% on 2010 to US$ 257 billion. This represented a six-fold increase from 2004 and was 93% higher than in 2007, the year before the global financial crisis. Global agricultural productivity growth rates are exceeding overall population growth rates, and since 1990, more than 2 billion people have gained access to improved drinking water sources. Energy efficiency is widely recognized as providing economic opportunities and improved environmental security, while the fuel efficiency of vehicles has more than doubled since the 1970s. Developing countries are playing a growing role in scaling up green investment. Cross-border and domestic investment originating from non-OECD countries grew 15-fold between 2004 and 2011 at a rate of 47% per year (compared with 27% per year for OECD-originating investment), albeit from a low base. Clean-energy asset financing originating from developing countries in 2012 is on track for the first time to exceed those originating from developed countries. This investment is due in part to the creation of green growth strategies by a number of developing country governments –to advance water resources, sustainable agriculture, and clean energy. Developing country public finance agencies can accelerate this trend by targeting more of their funds to leverage private finance. Progress in green investment continues to be outpaced by investment in fossil-fuel intensive, inefficient infrastructure. As a result, greenhouse gas levels are rising amid growing concerns that the world is moving beyond the point at which global warming can be contained within safe limits. A recently published World Bank report warns that the world is on track for a global average temperature increase of at least 4°C above pre-industrial levels, bringing further extreme heat-waves, hurricanes and life-threatening rises in sea levels. Natural resource productivity is not increasing quickly enough to stem the depletion of critical resources, notably water and forests. Soil erosion is accelerating and fish stocks are declining precipitously. Such trends, combined with growing climatic instability, are driving up commodity prices, threatening food security in a growing number of communities. Greening investment at scale is a precondition for achieving sustainable growth. The investment required for the water, agriculture, telecoms, power, transport, buildings, industrial and forestry sectors, according to current growth projections, stands at about US$ 5 trillion per year to 2020. Such business as usual investment will not deliver stable growth and prosperity. New kinds of investments are needed that also achieve sustainability goals. Beyond the known infrastructure investment barriers and constraints, the challenge will be to enable an unprecedented shift in long-term investment from conventional to green alternatives to avoid locking in less efficient, emissions-intensive technologies for decades to come. Leadership by governments, international financial institutions and private investors is needed to address the green investment gap.[27]

Some highlights of recent announcements include:

- Europe's offshore wind-power industry has attracted investments of $15 billion in first six months of 2016.
- The World Bank Group has signed an agreement with the International Solar Alliance (ISA), consisting of 121 countries led by India, to collaborate on increasing solar energy use around the world, with the goal of mobilizing $1 trillion in investments by 2030.
- And the central bank of Bangladesh is launching a US$200 million fund to green the country's clothing factories.

These are but some of the inspiring examples that the UNFCCC has collected.[28] We have been analyzing the Paris Agreement at COP 21 and the need to build sufficient fund for the mitigation and adaptation of developing countries to fulfill the commitment of developing countries' NDCs declaration under the UNFCCC. While the expectation of developed countries' contribution towards ODA and green fund is shrinking, it is time to look at other alternatives. Let us hope emerging "Global Climate Bond Fund for Financing Green Economy", be a reality in the 21st century that will benefit sustainable development as well as future generations of our common home, planet earth.

Notes

1. For details about COP 21, see, http://unfccc.int/meetings/paris_nov_2015.
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Consumer Perceptions of the Social and Environmental Sustainability of Robotic Vehicles

Björn Frank[1]

Abstract

The development of robotic, self-driving vehicles is set to revolutionize the automotive industry. Such vehicles are expected to improve human life, but also to reduce the negative effect of transportation on society and the environment. This research collects data on consumer perceptions of the sustainability of robotic vehicles in several countries, and uses multivariate analysis to elucidate the specific types of social and environmental sustainability associated with robotic vehicles.

自動運転車の社会的・環境的持続可能性に関する消費者知覚

フランク ビョーン[1]

概要

自動運転車というロボット自動車の開発は，自動車業界に大革命をもたらすことが予測される．この技術には，生活の質が上がり，交通や運搬の社会・環境への悪影響が軽減されるという期待がある．本研究は，自動運転車の持続可能性に関する消費者知覚についてのデータを数か国から収集し，多変量解析を通じて自動運転車の持続可能性の具体的な社会的・環境的次元を解明する．

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Consumer Perceptions of the Social and Environmental Sustainability of Robotic Vehicles

1. Introduction and research objectives

Robotic vehicles are self-driving cars, which drive without intervention by a human driver (Fagnant & Kockelman 2014; Gao et al. 2014; Howard & Dai 2014; Jiang et al. 2015; Silberg et al. 2013). A robotic vehicle consists of a regular car equipped with sensors to identify objects in the car's surroundings, with Internet linkup to draw on real-time map and traffic information and to leverage cloud computing power, and with intelligent software to interpret the information and take intelligent decisions (Fagnant & Kockelman 2014; Howard & Dai 2014; Silberg et al. 2013). As this emergent technology is expected to revolutionize the automotive industry, automotive companies such as Toyota and Volkswagen, automotive suppliers such as Continental, and even IT firms such as Google and Apple are competing to develop this new technology in order to dominate the future automotive industry (Fagnant & Kockelman 2014; Gao et al. 2014; Howard & Dai 2014; Jiang et al. 2015; Silberg et al. 2013). The currently available, partially autonomous driving technology already enables equipped vehicles to drive autonomously on expressways, but for legal and technological reasons, the driver is expected to be ready to take over the steering wheel at any time and is liable for accidents (Jiang et al. 2015). However, in the future, automotive firms hope to develop fully autonomous driving technology with the ability to drive autonomously anywhere without human intervention and with higher safety than could be achieved by a human driver. Due to loss of human control, this would require a change in laws passing the legal responsibility from the human driver to the technology providers (Gao et al. 2014; Jiang et al. 2015).

In parallel with the movement toward advanced autonomous driving technology, the world also is moving toward a reduction of the social drawbacks and environmental footprint of deployed transportation technology (Gao et al. 2014). Resulting from rising public awareness of social and environmental problems (Sen et al. 2006), this move is evidenced by the recent push toward lower emissions of gasoline vehicles, alternative engine technologies such as electric and hydrogen vehicles, and environmentally friendly products and processes in general. From a marketing and public policy perspective, it thus would be desirable to leverage autonomous driving technology into a reduction of the negative consequences of transportation on society and the environment. Based on this rationale, the objective of this present research was to investigate customer perceptions of the social and environmental benefits and drawbacks of autonomous driving technology, as compared with conventional driving technology. This research sought seek to explore these perceptions for the two scenarios of far-future fully autonomous driving technology and currently available partially autonomous (semi-autonomous) driving technology.

2. Research method

In order to achieve these research objectives, the literature and public press regarding potential benefits and drawbacks of robotic vehicles was reviewed with special attention paid to social and environmental aspects. Following this review, a questionnaire survey was developed, asking respondents about their perception of these benefits and drawbacks of robotic vehicles, as compared with conventional, human-operated vehicles. The construct operationalization in the survey draws on theory and methodology used in analyzing consumer intentions to adopt new products (Frank et al. 2015).

These questions were repeated for the two scenarios of fully autonomous and partially autonomous robotic vehicles, as compared with conventional vehicles. Based on pre-tests, this survey was discussed with consumers and experts, and improved repeatedly.

In the next phase, it was translated to multiple languages, and data were collected in multiple countries. Data analysis based on multi-variate statistics was used to verify the consumer perceptions of the social and environmental benefits and drawbacks of robotic vehicles.

3. Results and conclusions

The results are fairly consistent across countries and lead to the following conclusions. Consumers regard economic benefits, which refer to resource and cost efficiency, as the largest benefit of robotic vehicles, as compared with conventional vehicle technology. This result holds for both fully autonomous and partially autonomous robotic vehicles. Specifically, consumers strongly perceive robotic vehicles as being able to choose automatically an optimal itinerary and driving mode that minimize gas consumption and emissions. They also perceive robotic vehicles as having the ability to quickly find low-priced parking opportunities automatically, thus minimizing consumer expenditures and emissions during the search for parking opportunities. Hence, these economic benefits of robotic vehicles relate to both consumer expenditures and the environmental footprint of automotive transportation.

Secondarily, consumers identify robotic vehicles as having functional benefits that strongly relate to social sustainability. They regard robotic vehicles as being safer than conventional vehicles, leading to fewer accidents and having a lower likelihood of traffic-related injuries and deaths. Moreover, consumers perceive robotic vehicles as providing the ability to transport individuals that are unable to drive a conventional vehicle as the consequence of disabilities, alcohol consumption, and health emergencies. These benefits would provide for greater social inclusion of disabled people, would reduce injuries and deaths caused by driving under the influence of alcohol, and would reduce the time for people to reach a hospital during health emergencies and thus increase survival rates. In addition, consumers perceive robotic vehicles as allowing them to sleep in their cars, thus turning a stressful commute into an opportunity to recover from lack of sleep, which is a prevalent problem in many societies that impairs the immune system and limits pleasure and work performance. Likewise, consumers regard robotic vehicles as providing benefits for mental health by offering a more relaxed and pleasurable driving experience.

While all of these perceived benefits hold for both fully autonomous and partially autonomous vehicles, as compared with conventional vehicles, they are more pronounced for fully autonomous than partially autonomous vehicles. At the same time, some consumers worry that partially autonomous vehicles might introduce new safety hazards due to malfunctions that would not be an issue in case of fully autonomous vehicles. These results indicate that further technological development of robotic vehicles would increase the social and environmental sustainability of automobiles.

From a managerial perspective, the obtained results suggest that the social and environmental sustainability aspects of robotic vehicles are perceived clearly by consumers and thus might be a driver of consumer demand for robotic vehicle technology in the face of rising concern for sustainability issues (Sen et al. 2006). This fits into the stream of research showing that consumers value social and environmental issues to a degree causing them to spend financial resources and even to take personal risks in consumption activities for the sake of higher-order social and environmental benefits (Frank & Schvaneveldt 2014, 2016).

Future research might seek to quantify the social and environmental sustainability of robotic vehicles in terms of real physical benefits and drawbacks, rather than consumer perceptions of such benefits and drawbacks.

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Mainstreaming biodiversity within the United Nations

Adopting and implementing the Cancun Declaration across a global organization

Iain Hall and Anne McDonald

Abstract

The protect and conservation of global biodiversity has long been an aim of the United Nations (UN), with the opening for signing of the Convention on Biological Diversity (CBD) at the 1992 United Nations Conference on Environment and Development (UNCED) in Rio, Brazil representing a significant step towards achieving this. Subsequent efforts and activities under the CBD and across the UN system have made considerable further progress yet there remains much to be done to stop the ongoing loss of the world's biodiversity. Recognition of the need to prioritise biodiversity conservation has led to *The Cancun Declaration on Mainstreaming the Conservation and Sustainable use of Biodiversity for Well-Being,* under which signatories to the CBD have agreed to make additional efforts in the implementation of both the CBD and the Strategic Plan for Biodiversity 2011–2020. Such implementation, including that of the Cancun Declaration itself, is to a great extent in the hands of national and local governments. It is, however, also useful to consider the UN itself, and the programmes that it's varied organisations have developed to drive the mainstreaming of biodiversity. With a dearth of published literature considering this matter, this thought paper explores a number of United Nations organisations and programmes, and the projects and activities that they develop, as a preliminary examination of the system under which the Cancun Declaration was developed. This is turn identifies areas for future research and raises questions regarding the role of the United Nations system as instigator or implementor (or both) of environmental policy.

国際連合における生物多様性の主流化
――グローバル組織の枠を超えたカンクン宣言の採択および実施――

まくどなるど　あん

概要

世界的な生物多様性の保護・保全は長く国際連合（UN）が目指すところであり、ブラジル、リオで開催された1992年度環境と開発に関する国際連合会議（UNCED）において行われた生物の多様性に関する条約（CBD）の調印が始まりとなり、これは目的達成に向けての重要なステップであった。以降、この条約の下、国際連合組織全体で推進された努力と活動はかなりの成果を上げたが、世界で継続している生物多様性の消失を食い止めるためにするべきことはまだ多く残っている。生物多様性の保全を優先する必要性を認識することが、福利のための生物多様性の保全および持続可能な利用の主流化に関するカンクン宣言に結びつき、この宣言の下、CBD調印国はCBDおよび2011年以降2020年までに達成すべき生物多様性に関する世界目標の両方の実施に向けさらなる努力をすることに同意した。カンクン宣言の実施そのものを含むこのような実施の大部分は政府および地方自治体が管理するところである。しかし、国際連合そのもの、および生物多様性の主流化を推進するため様々な組織が開発したプログラムを考察することも有益である。本件を考察する発行文献が不足しているため、本学術論文では多くの国際連合組織およびプログラム、またそれらが開発したプロジェクトや活動などを、カンクン宣言が生まれたシステムの予備審査として探索した。これは、将来の研究対象を特定し、環境政策の主体者もしくは実施者（あるいは両方）としての国際連合の役割に関する問題点を提起するきっかけとなるであろう。

Mainstreaming biodiversity within the United Nations

Adopting and implementing the Cancun Declaration across a global organization

Introduction

The value of biodiversity lies not only in its existence, but in its role as the bedrock upon which humanity is able to develop and prosper, providing as it does food security, fresh water, clean air and climate change resilience. Yet there continues an ongoing and increasing loss of biodiversity the world over. It has been estimated that species extinction rates are currently approximately 500 times the background rate (Ceballos et al., 2015; Steffen et al., 2015). In response to this loss, a number of international agreements and instruments have been designed and developed to support the conservation and sustainable management of marine and terrestrial biodiversity around the world.

Principal amongst those working to protect and conserve global biodiversity is the United Nations (UN), with the Convention for Biological Diversity (CBD; CBD, 1992) being at the forefront of biodiversity policy. Opened for signing in 1992 at the United Nations Conference on Environment and Development (UNCED) in Rio, Brazil, the CBD has been followed by an ever-increasing prominence given to biodiversity within the activities of various of the organisations that make up the UN system. This is seen in the Strategic Plan for Biodiversity 2011–2020 and the Aichi Biodiversity Targets that were agreed in 2010 as a framework for biodiversity for the whole United Nations system (CBD, 2010). Both the Aichi Targets and the Strategic Plan contribute to the much broader Sustainable Development Goals (SDGs) that underpin the 2030 Agenda for Sustainable Development (United Nations, General Assembly, 2015), with significant consideration having been given to how biodiversity relates to and supports the successful implementation of each of the SDGs (Secretariat of the Convention on Biological Diversity, 2016).

Such recognition by, and integration into, policy beyond the UN system remains a challenge, however. Speaking at a recent symposium focussing on what is being done to achieve the Aichi Targets, Executive Secretary of the Convention on Biological Diversity Dr Cristiana Pașca Palmer described how biodiversity is still not recognised as a political priority, in spite of it being the basis of survival (Pașca Palmer, 2017). There remains, therefore, a clear need for further awareness of biodiversity across all sectors of society, and to ensure biodiversity is a key consideration in the operations of all governments, industries and societies. It is this need that has driven the development of *The Cancun Declaration on Mainstreaming the Conservation and Sustainable use of Biodiversity for Well-Being* (CBD, 2016).

The Cancun Declaration

Coming into effect in late 2016, *The Cancun Declaration on Mainstreaming the Conservation and Sustainable use of Biodiversity for Well-Being* (the Cancun Declaration) acknowledges that more needs to be done to effectively implement those biodiversity-focused instruments already developed under the UN

(CBD, 2016). It identifies the need to "*make additional efforts to ensure the effective implementation of the Convention on Biological Diversity, the Strategic Plan for Biodiversity 2011–2020 and its Aichi Biodiversity Targets*" (CBD, 2016). The Cancun Declaration is, therefore, a way to direct attention towards, and gain commitment for, raising the levels of effort devoted to the protection of biodiversity from signatories to the CBD. It is intended to promote the mainstreaming of biodiversity across all sectors of government, industry and society such that biodiversity, and it's importance, be recognised by decision making bodies, businesses and individuals, and efforts to protect it be incorporated into all aspects of policy, trade and daily life.

Mainstreaming biodiversity to such an extent naturally drives attention to the actions of national and local governments, who are righty considered central to successful implementation. In Japan, the Ministry of the Environment's Committee for the United Nations Decade on Biodiversity has produced the *My Declaration* programme, a short list of actions designed to encourage the general public to raise their awareness of biodiversity and consider biodiversity in their daily activities (Okuda, 2017). Industry and the private sector are also increasingly central to the success of international agreements such as the Cancun Declaration. The Declaration itself identifies trade, agriculture, fisheries, forestry and tourism as just some of the sectors with which closer collaboration is required. Again in Japan, the coming to the fore of private enterprise can be seen through the actions of the Japan Business Initiative for Biodiversity. This organisation works to mainstream biodiversity in the private sector by assisting companies to support biodiversity throughout supply chains and manufacturing, leading to a number of practical tools focused on making businesses more sustainable, and helping to conserve biodiversity, in cost-effective ways (Adachi, 2017).

In addition to these clearly defined targets for implementation, it is also of interest to consider the degree to which the Cancun Declaration is being implemented by the organisation within which it was developed, i.e. the CBD and, by extension, the United Nations Environment Program (UNEP) and the UN system as a whole. As an organisation consisting of 35 diverse but collaborating organisations, programmes and funds, with a workforce of over 75,000 people worldwide, and an operating revenue of almost US$50 billion in 2016, the United Nations is larger both in size and economy than some countries (United Nations, 2016; International Monetary Fund, 2017). A system of such magnitude should, therefore, be incredibly well placed to develop and support programmes to drive forward the cross-sectorial mainstreaming of biodiversity globally, regionally and the country level, with which the Cancun Declaration is concerned.

Mainstreaming biodiversity in the United Nations

There is very little information, beyond that produced by the UN itself, regarding its own implementation of environmental policy and protection, even in the broadest terms. In particular, to date there has been no assessment or exploration of how the environmental policies developed within the UN system are implemented by that same system, making this line of enquiry both relevant and useful.

In terms of monitoring its own progress towards achieving the Aichi Targets, and therefore also the Strategic Plan for Biodiversity 2011–2020, the Biodiversity Mapping Tool identifies activities across seventeen UN organisations and secretariats, against each of the twenty Aichi Targets (UNEMG, n.d.). What this tool demonstrates is that all but three of the UN organisations considered by the tool have work streams in place to support all four Aichi Targets underpinning the strategic goal of mainstreaming biodiversity. It should be noted, however, that this tool is not exhaustive, offering information on only around half of the 35 UN organisations and secretariats. There is, for example, no information relating to the activities of UN-Habitat; with a focus on socially and environmentally sound urban development, this organisation undoubtedly has a significant role to play in mainstreaming biodiversity (UN-Habitat, 2012).

By exploring specific example activities of a small selection of those UN organisations with very apparent links to the environment, it is possible to start building a clearer picture of how UN activities are supporting the mainstreaming of biodiversity and ensuring the successful implementation of the Cancun Declaration (and, therefore, the agreements that the Cancun Declaration in turn supports). This exploration will consider the overall mission and example programmes and activities of the following organisations: the Food and Agriculture Organization of the United Nations (FAO); the United Nations Development Programme (UNDP); the United Nations Environment Programme (UNEP), and the United Nations Educational, Scientific and Cultural Organisation (UNESCO), to offer some preliminary insight into this matter.

Food and Agriculture Organization of the United Nations

The FAO focuses on food security for all, with its three aims being the eradication of hunger, food insecurity and malnutritrion, the elimination of poverty, and the driving forward of economic and social progress for all (FAO, 2017a). Within its work, the FAO recognises the link between food security for all and the maintenance of healthy biodiversity, and in 2015, the FAO Commission on Genetic Resources for Food and Agriculture endorsed a set of voluntary guidelines for mainstreaming biodiversity into national plans and policies regarding nutrition (Secretariat of the Commission on Genetic Resources for Food and Agriculture, 2016). These guidelines recognise the importance of biodiversity for nutrition, and support the implementation of activities that integrate biodiversity for food and agriculture into nutrition-related policies.

Part of the FAO commitment to delivering biodiversity conservation is the Globally Important Agricultural Heritage Systems (GIAHS) programme, which acknowledges and certifies agricultural systems around the world that blend a unique mix of social and environmental elements. The hallmarks of GIAHS are the globally significant biological diversity that is the result of a community's ongoing and sustainable utilisation of, and interaction with, its environment. Such systems have shaped the landscapes within which they sit and have, over time, developed high levels of resilience against natural disasters, climatic changes, and sociopolitical changes (FAO, n.d.).

With 39 such sites around the world since its launch in 2002, and a further ten proposed, GIAHS demonstrate the great variety of ways in which man has evolved with the environment. GIAHS include sites as diverse as *satoyama* systems in the Noto Peninsular and on Sado Island in Japan, amongst the eight designations in Japan (FAO, 2017b), and the *qanat* underground irrigation tunnels in the Isfahan Province of Iran.

It is the agro-biodiversity within the GIAHS that makes them so relevant to the concept of mainstreaming biodiversity; healthy agricultural biodiversity is essential to the ongoing success and sustainability of these systems and the communities that they support.

United Nations Development Programme

The focus of the UNDP is to assist countries to build and share solutions in the areas of sustainable development, democratic governance and peace building, and climate and disaster resilience (UNDP, 2017a). The UNDP purports to have the largest biodiversity and ecosystems portfolio in the UN system, with more than 500 projects being undertaken across 132 countries (UNDP, 2017b). It would be impossible to consider each of these projects and the individual roles they play in mainstreaming biodiversity. However, the Biodiversity Finance Initiative (BIOFIN) provides some insight into the more wide-ranging impact the UNDP is having on biodiversity conservation through financial mechanisms (UNDP, 2016).

Current spending on biodiversity is estimated at approximately US$52 billion per year (Parker, et al, 2012), while it is considered that between US$150 and US$440 billion worth of spending is actually required (CBD, 2012), demonstrating a significant disparity between need and reality. Through the identification and use of cross-sectorial financial mechanisms that go beyond traditional government funding and donor-based methods of supporting biodiversity at a country level, BIOFIN aims to support the sustainable management of biodiversity by making it a priority for investment (UNDP, 2016).

The BIOFIN methodology results in a national-level Biodiversity Finance Plan, which puts forward a suitable mix of financial solutions to reduce the shortfall in biodiversity funding (UNDP, 2017c). This takes into account government funding as well as public and private expenditures that benefit biodiversity. So far, more than 30 countries are implementing this approach as a way of securing and increasing biodiversity finance (UNDP, 2017c). In this way, BIOFIN supports the mainstreaming of biodiversity across a number of sectors by emphasising its importance in sound business and financial planning.

When the UNDP is considered at regional and country levels, relevant individual projects come to the fore, such as the “Mainstreaming Biodiversity Management into Medicinal and Aromatic Plants (MAPs) Production Processes in Lebanon” project, which has focused on encouraging the sustainable harvesting of sage to ensure those communities that rely on the income it generates can continue to do so into the future (GEF-UNDP-LARI, 2014). Other specific projects include the mainstreaming of biodiversity conservation into the development of the tourism sector in Jordan (UNDP in Jordan, n.d.), and the improvement monitoring and enforcement of environmental regulations in Guyana's gold mining sector to better protect biodiversity (UNDP in Guyana, n.d.). It is worth noting that each of these projects commenced significantly prior to the enactment of the Cancun Declaration.

From these few examples it is apparent that the UNDP demonstrates that mainstreaming biodiversity is integrated in its work at different levels, from cross-sectoral financial instruments such as BIOFIN to individual project works.

United Nations Environment Programme

UNEP is focused on the implementation of the environmental aspect of sustainable development. It is responsible for developing programmes and instruments to support the responsible management of the global environment. Naturally, the CBD, and therefore also the Cancun Declaration, were developed under the broader umbrella of UNEP (CBD, n.d.). The array of conventions within UNEP that naturally impact biodiversity provides for a complex situation, and this is addressed in the 2016 UNEP publication *Understanding synergies and mainstreaming among the biodiversity related conventions* to aid in (UNEP, 2016). This document discusses in some detail the challenges and opportunities related to the cross-sectoral mainstreaming biodiversity, effectively outlining the importance of the, at the time of publication, forthcoming Cancun Declaration.

At the regional level, only UNEP Asia Pacific explicitly addresses mainstreaming biodiversity in its regional initiatives, listing its efforts in doing so as involving the protection of agricultural crop genetic diversity, the introduction of market-based instruments, as well as the prevention and management of alien species (UNEP Asia Pacific, n.d.). However, when individual UNEP projects are examined, it is clear that the concept of mainstreaming biodiversity has been incorporated into UNEP projects for some time. For example, a project to mainstream agrobiodiversity conservation and use in Sri Lankan agro-ecosytems commenced in 2013 (UNEP, 2014).

UNEP also organises national workshops focused on mainstreaming biodiversity around the world, such as the South Africa workshop on mainstreaming biodiversity conservation in production sectors, and those examining mainstreaming biodiversity and ecosystem services held in Georgia and Moldova, all held in 2017 (UNEP, n.d.).

It is perhaps not surprising to see mainstreaming biodiversity addressed in such ways as UNEP displays. Being the UN organisation under whose umbrella the Cancun Declaration has been developed, it is incumbent upon it to ensure it not only mainstreams biodiversity it in its own work, but also provides direction on how this can be done by policy makers and organisations around the world.

United Nations Educational, Scientific and Cultural Organisation

UNESCO coordinates global cooperation in education, science, culture and communication, with the intention that everyone have access to good quality education, live in a culturally rich and diverse society that allows full freedom of expression, and fully benefit from scientific advances (UNESCO, 2017a). With such a broad remit, it would be easy for biodiversity to get lost within the broader mix of activities. However, biodiversity is one of the special themes that UNESCO focusses on, with it being clearly incorporated into the other areas of focus for UNESCO. This can be seen in the programme areas of Biodiversity, Science and Policy, Biodiversity & Society, Culture and Ethics, and Biodiversity & Education (UNESCO, 2017b)

That education is a key focus for UNESCO is clear. The Global Action Programme (GAP) on Education for Sustainable Development aims to contribute to the 2030 Agenda on Sustainable Development by providing opportunities for everyone to understand and appreciated sustainable development and incorporate the values of sustainable development into their daily lives, while also strengthening educational programmes that promote sustainable development (UNESCO, n.d.). The GAP develops and delivers various training and educational programmes to support these aims.

In addition to this work, UNESCO supports international conservation days that focus on specific ecosystems to raise awareness of their importance, such as the 2016 International Day for the Conservation of the Mangrove Ecosystems. Much work focussing on the health and diversity of ocean ecosystems is also undertaken by UNESCO through the Intergovernmental Oceanographic Commission.

Through these activities UNESCO actively mainstreams biodiversity through supporting educational initiatives and through its public-facing environmental awareness campaigns.

Evidence from funding mechanisms

Established concurrently to the Convention on Biological Diversity, The Global Environment Facility (GEF) is a partnership between the United Nations, development banks and non-governmental organisations (GEF, 2017). The GEF operates a financial mechanism for the Convention on Biological Diversity, as well as the United Nations Framework Convention on Climate Change (UNFCCC), the Stockholm Convention on Persistent Organic Pollutants (POPs), the United Nations Convention to Combat Desertification (UNCCD), and the Minamata Convention on Mercury (GEF, 2017). Supporting projects in developing countries and countries in transition, the GEF project database demonstrates that funding has been provided for 968 biodiversity-focused projects over the past 25 years, 696 of which have been implemented by UN organisations (GEF, 2017b).

The GEF 2016 review of experience in biodiversity mainstreaming states that the GEF supported 427 biodiversity mainstreaming projects between 2004 and 2016, to a value of almost US$ 20 billion (GEF, 2016). That these projects all predate the Cancun Declaration provides further evidence for the concept of mainstreaming biodiversity having been embedded in the UN system for some time.

Overall, therefore, we see that a great number of projects are undertaken across the UN system to support biodiversity and biodiversity mainstreaming, and it is clear that the majority of these pre-date the Cancun Declaration. What does this suggest about biodiversity mainstreaming in the UN, and the role of the UN as either an instigator of environmental policy, or an implementer of those policies it drives forward.

Discussion

This preliminary of the UN system in relation to its implementation of the Cancun Declaration suggests a number of things, and raises a number of questions and areas for further research.

It is apparent that much of the work and projects in those organisations examined here incorporated mainstreaming biodiversity to some extent. This suggests that mainstreaming biodiversity is well integrated into the UN system. Interestingly, however, there is little direct emphasis on 'mainstreaming biodiversity', i.e. very few activities present mainstreaming biodiversity as an explicit goal or outcome. That being said, a great number of projects and streams of work that clearly involve mainstreaming biodiversity predate the Cancun Declaration, which further supports it being embedded in the working of the UN system.

The fact that the work of all organisations within the UN is to a degree measured against the SDGs also goes some way to support this notion, given that mainstreaming biodiversity forms the first strategic goal of the Aichi Targets, which are themselves aligned with the SDGs. In addition, there is clear evidence that the terminology of "mainstreaming biodiversity" has been used for some years within the United Nations system; a CBD meeting entitled "Regional Workshop on Mainstreaming Biodiversity and Climate Change" was held in Dehra Dun, India in April 2003.

Taken together, these impressions may lead to the conclusion that the UN is leading by example in terms of the need to mainstream biodiversity laid out in the Cancun Declaration. However, this would be over-reaching based upon the preliminary exploration undertaken here, and significantly more in-depth research would be required to determine if this is indeed the case. It should, therefore, also be considered that the need for increasing efforts towards biodiversity conservation that led to the Cancun Declaration also exists with the UN system itself. This may explain the general lack of emphasis of mainstreaming biodiversity seen within the work of the organisations examined. Again though, this claim cannot be supported by the few examples presented here, and further, in-depth analysis of the multitude of biodiversity-related projects undertaken within the UN system would be required to establish if this were in fact the case.

It may also be the case that, 12 months after the Cancun Declaration was brought into being, the results of its implementation are yet to be seen within an organisation as large and diverse as the UN is. Ongoing monitoring and more detailed evaluation of various United Nations programmes could demonstrate any changes in emphasis in language or activities with the UN towards or away from mainstreaming biodiversity over the period prior to the Cancun Declaration, and for some time after it's introduction.

These considerations also lead to the much broader question of the role of the UN; it is enough for the UN to drive forward policies to be taken up by governments and organisations around the world, or should it in fact be demonstrating leadership, where possible, in those areas of policy that are created under its aegis? In the case of the Cancun Declaration specifically, should the UN be directing other in what to do, or should it be leading by example in the work and projects the various UN organisations support and the ways in which they are executed?

With these considerations, this paper identifies clear areas for further research analysing the mainstreaming of biodiversity within the UN system, and to what degree the UN itself achieves the aims of the Cancun Declaration. It also opens up an area for debate regarding the UN in terms of its role as instigator or implementor (or both) of global environmental policy.

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一般均衡と環境ゲーム
――プロトタイプモデルを用いて――

鷲田　豊明

概要

地球環境問題をめぐって、一方で経済は均衡し、また市場価格が成立し、一方で国際交渉が行われているという状況を想定することはそれほど無理なことではない。気候変動問題のシミュレーションは、多くは、これまで応用一般均衡タイプの分析あるいはラムゼイタイプの最適成長モデルが用いられてきた。ただし、最近注目されているゲーム論の組み込みは、主に後者のモデルを用いられて行われてきていて、一般均衡モデルは使われてこなかった。

筆者は他の研究者と共同して、すでに貿易も含む世界経済の一般均衡モデルと基本的な地球温暖化メカニズムを組み込んだ統合モデルを用いて、複数の地域のゲーム的状況を分析するモデルを提示して、その結果を公表してきた¥cite{washida2015}。ただ、このモデルは数万本の連立方程式からなるもので、極めて複雑で全体の構造が見えにくい。そこで、本稿では、その原型とも言える単純なモデルで、一般均衡モデルをゲーム論的に利用する上での基本的な問題を明らかにすることを目的としている。極めて単純なモデルではあるが、上記の複雑なモデルの本質的な特徴もとらえている。

General Equilibrium and Environmental Game
—— Proto type Model ——

Toyoaki Washida

Abstract

It is not hard to imagine the situation that on the one hand, economic systems are in equilibrium and have the equilibrium prices, and on the other hand international negotiations are performed for the global environmental issues. The Ramsey types of model or applied general equilibrium models have been used for the simulations for global warming so far. However, when we analyze game theoretic situation of global warming, we have a little use the general equilibrium model.

The author published the paper in which we analyze the effects of global negotiation for global warming on the integrated assessment model that includes the global economic system with international trade and the climate system. The negotiation process on it are expressed by game theoretic frame works. The model is so complex, however, that we grasp the over view of the function of the system.

The purpose of this paper is to show the fundamental function of the game theoretic model with general equilibrium using the prototype of the model. Although the model is quite simple, it can show us the essential features of this type of models.

一般均衡と環境ゲーム—プロトタイプモデルを用いて—

鷲田豊明*

1　はじめに

地球環境問題をめぐって、一方で経済は均衡し、また市場価格が成立し、一方で国際交渉が行われているという状況を想定することはそれほど無理なことではない。気候変動問題のシミュレーションは、多くは、これまで応用一般均衡タイプの分析あるいはラムゼイタイプの最適成長モデルが用いられてきた。ただし、最近注目されているゲーム論の組み込みは、主に後者のモデルを用いられて行われてきていて、一般均衡モデルは使われてこなかった。

筆者は他の研究者と共同して、すでに貿易も含む世界経済の一般均衡モデルと基本的な地球温暖化メカニズムを組み込んだ統合モデル、複数の地域のゲーム的状況を分析するモデルを提示して、その結果を公表してきた [1]。ただ、このモデルは数万本の連立方程式からなるもので、極めて複雑で全体の構造が見えにくい。そこで、本稿では、その原型とも言える単純なモデルで、一般均衡モデルをゲーム論的に利用する上での基本的な問題を明らかにする。極めて単純なモデルではあるが、上記の複雑なモデルの本質的な特徴もとらえている。

2　外部性のない純粋交換均衡

まず、2 地域 2 財の純粋交換均衡を考えてみよう。2 財は、エネルギー財と農業生産物を表していると考えればよい。また、交換はすなわち貿易を表していると考えればよい。それぞれの地域がそれぞれの財の一定程度を賦存量として保有している。地域は、a と b ないしは A と B で区別し、財は、1, 2 で区別しよう。このとき、各地域の最適化問題は、

$$L_i = U_i(X_{i1}, X_{i2}) + \lambda_i\{P(\overline{X}_{i1} - X_{i1}) + \overline{X}_{i2} - X_{i2}\} \qquad i = a, b \tag{1}$$

を最大にする問題である。以下すべて $i = a, b$ であり、$j = 1, 2$ である。

$$U_i^1 - P\lambda_i = 0 \tag{2}$$

$$U_i^2 - \lambda_i = 0 \tag{3}$$

ただし、

$$U_i^j = \frac{\partial U_i}{\partial X_{ij}}$$

である。

これに次の市場均衡条件が加わる。

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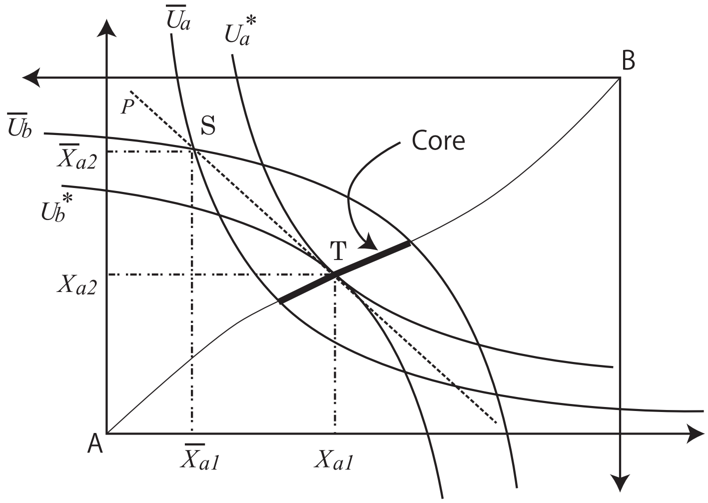

図 1: 純粋交換均衡

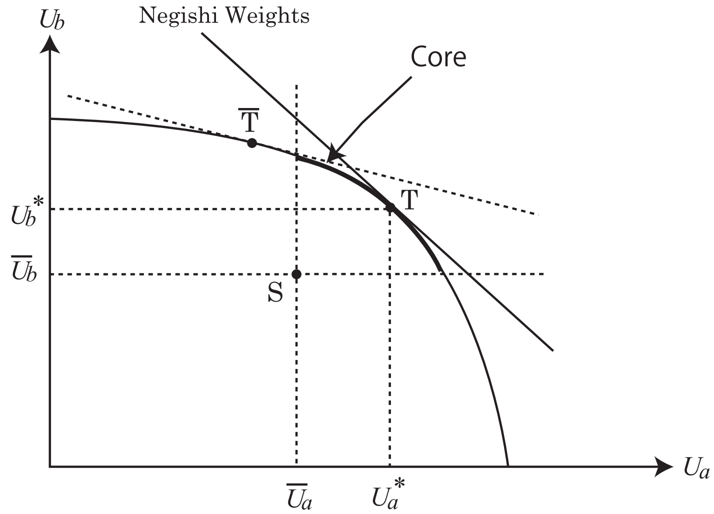

図 2: 実行可能厚生水準と効率フロンティア

$$\overline{X}_{aj} + \overline{X}_{bj} = X_{aj} + X_{bj} \tag{4}$$

ただし、市場均衡条件式 $j = 1, 2$ のうち、一つはワルラス法則によって自動的に成立する。$P, X_{ij}, \lambda i$ の 7 つの未知数があり、予算制約式 2 本と、(2), (3)、それぞれ 2 本ずつの式、市場均衡条件式 1 つの合計 7 つの式で一般均衡が解ける。必ずしも解けない場合もあり、複数解もあり得るが、ここでは単純に解は一つに決まるとしよう。これらの状況は、図 1 のように描くことができる。

この状況を、両地域の効用に関して図を描くことができて、図 2 のようになる。

図には、両地域の効用水準の実現可能領域が示されていて、初期の資源／資本保有量では S が実現しているが、交換によって両者は効率的なフロンティア上の T へ状態を変えることができる。そこはまた、一般均衡状態である。

3　根岸ウェイトについて

根岸ウェイトの一般均衡論的意味について確認しておこう [2]。図 2 の T であらわされる一般均衡の効用配分点 T は、それぞれの地域の効用に何らかのウェイトをつけて最大化した点であることは容易に理解できる。いま、このウェイトを ϕ_i として、このウェイトがどのようなものであるかを調べてみよう。最大化問題は次のラグランジアン L_g の最大化問題として定式化できる。

$$L_g = \sum_{i=a,b} \phi_i U_i + \sum_{j=1,2} \delta_j (\overline{X}_{aj} + \overline{X}_{bj} - X_{aj} - X_{bj}) \tag{5}$$

必要条件は、

$$\phi U_i^j - \delta_j = 0 \qquad i = a, b, j = 1, 2 \tag{6}$$

となる。いま、一般均衡問題の必要条件式、(2), (3) と (6) が同形となるための、条件は、

$$P\lambda_i = \frac{\delta_1}{\phi_i} \tag{7}$$

および

$$\lambda_i = \frac{\delta_2}{\phi_i} \tag{8}$$

であり、これらの条件から、

$$\frac{\frac{1}{\lambda_b}}{\frac{1}{\lambda_a}} = \frac{\phi_b}{\phi_a} \tag{9}$$

をえる。ここで、λ_i は、ラグランジ乗数の定義から、所得の限界効用を表している。したがって、**根岸ウェイトはそれぞれの地域の所得の限界効用の逆数に一致しなければならないことを意味する**。この根岸ウェイトについては、次の点に注意が払われなければならない。

1. 所得の限界効用の逆数としての根岸ウェイトが、一般均衡点を与えるための条件は、外部性がない一般均衡モデルであること。

2. 所得の限界効用自身も、その地域の最適化問題だけでは確定できない。逆に、根岸ウェイトを用いた一般均衡解と、通常の需要関数を用いた一般均衡解は同値である。

3. 外部性があるモデルに根岸ウェイトを適用したり、一般均衡論的に整合性のない根岸ウェイトを用いると、コアを外したフロンティア上の点（$\overline{T}$）に解が陥る可能性がある。

4　外部性のある一般均衡モデルとゲーム状況

ここでの外部性のある一般均衡モデルとは、**外部性をもたらす、したがって環境負荷をかけるメカニズムとその被害関数をともに含んだモデル**であり、単に環境税を組み込んだだけの政策評価モデルとは異なることをまず注意しておく。

効用関数を次のように拡張する。

$$U_i = U_i(X_{i1}, X_{i2}, \beta_i, E) \tag{10}$$

E は、環境の水準をあらわし、β_i は、i 地域の環境負荷排出コントロール変数である。ただし、想定をわかりやすくするため、$0 \le \beta_i \le 1$ と仮定する。$\beta_i = 1$ は、排出抑制策をとらないことを意

味し、$\beta_i = 0$ は、排出しないことを意味する。このような形で、β_i によって排出量が制御できて、第 1 財（エネルギー財）だけが環境負荷をかけるとし、E は次のように表されると想定しよう。

$$E = \beta_a X_{a1} + \beta_b X_{b1} \tag{11}$$

モデルには環境汚染物質による環境の悪化と、そのインパクトがともに含まれている。

また、当然、次のような関係が想定される。

$$\frac{\partial U_i}{\partial \beta_i} > 0 \qquad \frac{\partial U_i}{\partial E} < 0$$

前者は、排出抑制策には費用がかかることを表し、後者は、環境悪化は効用水準の低下をもたらすことを表す。

まず、簡単にわかることは、両者のコントロール変数が与えられれば、それに応じて一般均衡水準を得られる可能性があることである。β_i が一定のもとで、効用関数が必要な条件を満たせば、一般均衡が決定できる可能性がある。ただし、この条件がどのようなものかは単純に示すことができない。しかし、ここでは一般均衡がユニークに決まると仮定しよう。このとき、価格 P が決定され、両地域の消費水準も決定できる。したがって、両地域の効用水準も決定できる訳である。それによって、次のような両地域のコントロール変数に依拠した効用関数 V_i を得ることができる。V_i は、両地域の効用関数 (10) に最適解を代入して得た効用水準である。

$$V_i = V_i(\beta_a, \beta_b) \qquad i = a, b \tag{12}$$

この関数がどのような数学的性質をもつかは、はなはだ難しい問題である。が、いま、β_i が与えられた下での、お互いの効用水準に関するこの関数を、二つの地域が知っていたとしよう。このとき、どのような排出水準をそれぞれの地域は決定するだろうか。あるいは、協調するだろうか、非協力的に行動するだろうか。すなわち、ここでゲーム論的な問題が発生する。

5　一般均衡とゲーム：理論的枠組み

ゲーム論的に最もわかりやすい状況を検討しよう。いま、(12) 式について次のような仮定を導入しよう。

1. 与えられた相手の排出制御変数 $0 \leq \beta_{-i} \leq 1$（$i = a$ ならば、$-i = b$ であり逆は逆）に対して V_i を最大にする唯一の β_i が決定され、その値が関数 $\beta_i = R_i(\beta_{-i})$ として表される。この関数を地域 i の反応関数と呼ぼう。

2. 二つの反応関数は、$0 \leq \beta_{-i} \leq 1$ の領域で、交点 $\mathrm{N}(\beta_a^N, \beta_b^N)$ を持つ。N は非協力ゲームのナッシュ均衡点である。

3. 任意の $0 \leq \eta \leq 1$ に対して、(12) を制約条件として $\eta V_a + (1-\eta) V_b$ が最大値を持ち、これらの最大値 (V_a, V_b) の領域のうちには、N に対して、パレート優位の領域が存在する。

4. 領域 $\{(V_a, V_b) | 0 \leq \beta_a \leq 1, 0 \leq \beta_b \leq 1\}$ は凸集合である。

以上のような最小限満たすべき条件を確定した上で、状況は図 3 のように描くことができる。ゲーム論的問題の核心は、この非協力ゲームのナッシュ均衡状態から、パレート効率的な点が選択される必要条件、必然性を語ることにある。Prof. Zili Yang 氏らによる統合評価モデル（RICE モデル）の上での提携ゲームを使った議論、あるいは、鷲田（『環境ゲーム論』12 章）による同じく、

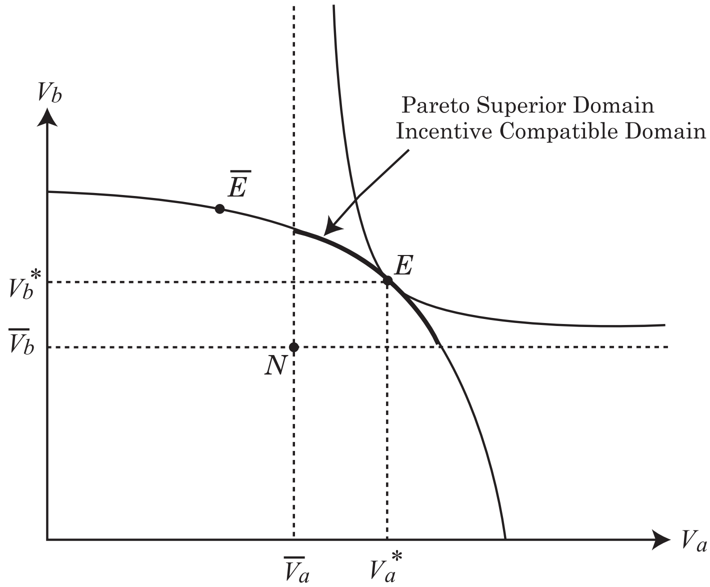

図 3: ナッシュ均衡とパレート効率フロンティア

地域分割型統合モデルとナッシュ交渉解を使った議論があり得る。ただし、これらのモデルは、一般均衡モデルではない。各地域は、1 財のラムゼイ最適成長モデルに依拠したものである。

すべての当事者が納得するゲームの協力解は、図 3 において、ナッシュ均衡点の北東側に広がる効率的フロンティア領域でなければならないが、恣意的なウェイトで両地域の効用最大化を行うと、$\overline{E}$ 点のような、パレート最適ではあっても地域 a は納得しない、つまり単独で行動した方がよい利得を得るような解となる。

6　一般均衡とゲーム：数値計算例

上記モデルを特定化して、数値例を示そう。効用関数を次のように特定化する。

$$U_i = (\beta_i X_{i1})^{\alpha_i} \left(\frac{X_{i2}}{1+\sigma_i E^{\gamma_i}} \right)^{1-\alpha_i} \qquad i = a, b \tag{13}$$

この効用関数において、最初の括弧に含まれる $\beta_i X_{i1}$ は、排出係数 β_i をゼロに近づければ近づけるだけ、第 1 財（エネルギー財）の実質量を減らす形で削減費用がかかることを表す。一方、総排出量 E はは、第 2 財（農業生産物）の消費量を削減する形で外部不経済、すなわち環境被害を発生させる。被害関数が、

$$\frac{1}{1+\sigma_i E^{\gamma_i}}$$

で表されている。

いま、与えられた排出係数 β_i の下での一般均衡を需要関数から求める。そのための、条件付き最大化のラグランジアンは次のような式となる。

$$L_i = (\beta_i X_{i1})^{\alpha_i} \left(\frac{X_{i2}}{1+\sigma_i E^{\gamma_i}} \right)^{1-\alpha_i}$$

$$+\delta_i(E-\beta_a X_{a1}-\beta_b X_{b1})$$
$$+\lambda_i\{P(\overline{X}_{i1}-X_{i1})+\overline{X}_{i2}-X_{i2}\}$$

このとき、必要条件式は、上記の中にある排出量に関する式、および予算制約式、さらに市場均衡式 (4) の他に、需要関数を表す次のような式が求められる。

$$\frac{\partial L_i}{\partial X_{i1}}=\alpha_i\beta_i(\beta_i X_{i1})^{\alpha_i-1}\left(\frac{X_{i2}}{1+\sigma_i E^{\gamma_i}}\right)^{1-\alpha_i}-\delta_i\beta_i-\lambda_i P=0$$

$$\frac{\partial L_i}{\partial X_{i2}}=\frac{1-\alpha_i}{1+\sigma_i E^{\gamma_i}}(\beta_i X_{i1})^{\alpha_i}\left(\frac{X_{i2}}{1+\sigma_i E^{\gamma_i}}\right)^{-\alpha_i}-\lambda_i=0$$

$$\frac{\partial L_i}{\partial E}=(1-\alpha_i)(\beta_i X_{i1})^{\alpha_i}\left(\frac{X_{i2}}{1+\sigma_i E^{\gamma_i}}\right)^{-\alpha_i}\frac{-X_{i2}\alpha_i E^{\gamma_i-1}}{1+\sigma_i E^{\gamma_i}}+\delta_i=0$$

β_i 以外のパラメータを表 1 のように与える。

表 1: 設定パラメータ群

α_a	α_b	γ_a	γ_b	σ_a	σ_b	$\overline{X}_{a1}$	$\overline{X}_{a2}$	$\overline{X}_{b1}$	$\overline{X}_{b2}$
0.5	0.5	1.3	1.3	1.0	1.0	20	50	50	20

初期資源量をのぞく、他のパラメータはすべて A, B について同じにしている。初期資源量が非対称的であり、第 1 財（エネルギー財）が汚染財、第 2 財（農業生産物）が被害財になっているので、全体としては非対称的な結果になることが予測される。

パラメータ β_a, β_b を 0.1 から 0.9 までの 9 段階で変化させたシミュレーション結果を示そう。GAMS を使って解いた。まず、すべてのパラメータの組み合わせ（81 通り）について、一般均衡が内点解として成立している。それを確認するために、図 4 に価格の結果を示した。価格は、0.73

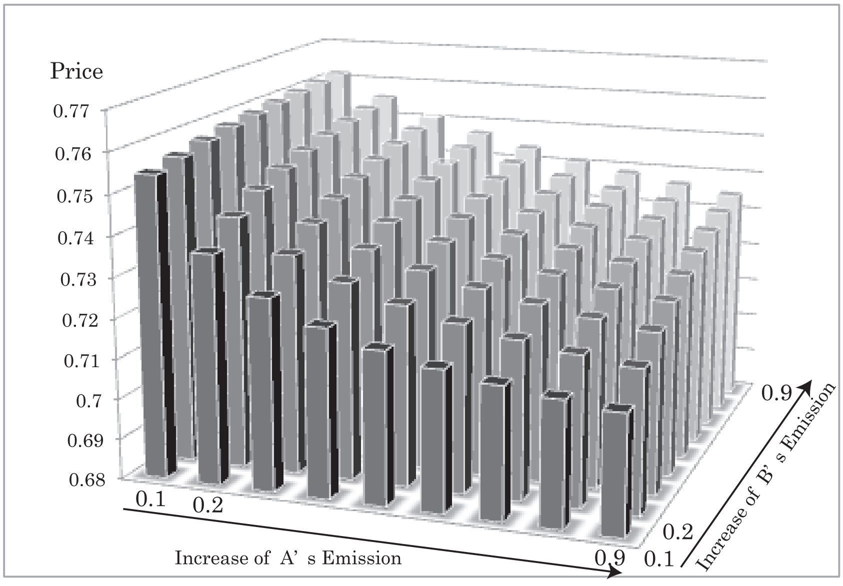

図 4: 排出係数 β_a, β_b の変化に対する均衡価格 P の反応

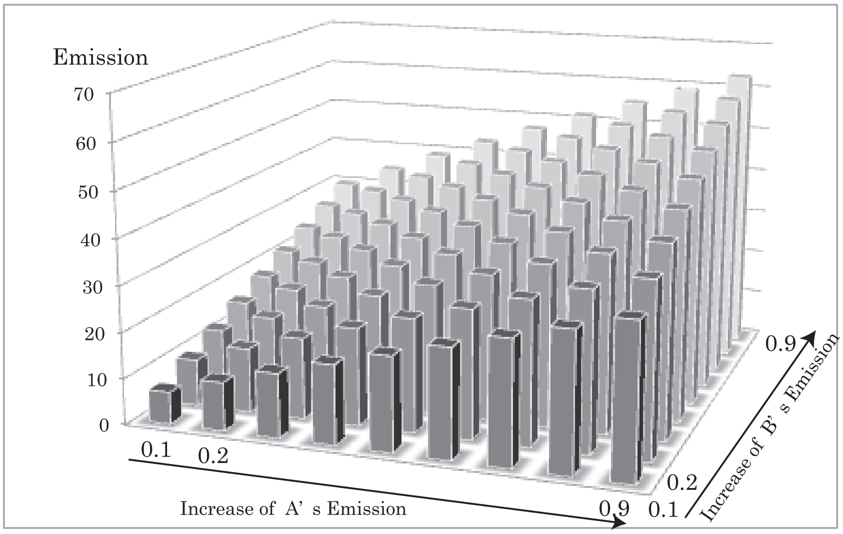

図 5: 排出係数 β_a, β_b の変化に対する総排出量 E の反応

から 0.75 の範囲となり、比較的安定している。数値は、第 2 財で測った第 1 財の価格である。傾向としては、地域 A の排出量の増加は、第 1 財の価格を下げ、逆に地域 B の排出量の増加は価格を増大させる。これには、初期賦存量の非対称性が効いていると思われるが、よく考察できていない。

次に、総排出量 E についてみてみる。図 5 にあるように、結果は明瞭である。いずれの地域の排出係数の増加も、総排出を増加させる。

次に、A, B それぞれの地域の排出係数 β_a, β_b、したがってまた両地域の戦略の変化に対するそれぞれの地域の効用水準（ゲーム論的な意味で「利得」）の状況を見てみよう。図 6 に A 地域の効用水準の結果を示した。全体としての傾向は、相手方である B 地域が排出係数を増加させればさせるほど、A 地域の効用水準は低下する。一方で、B 地域がいかなる排出係数を選択しようと、ほとんどの場合において、A 地域は、排出量を増加させた方が自らの効用水準を増加させることができる。ただし、表 2 にあるように、相手の地域 B が、きわめて小さい排出係数 0.1 を戦略として選んでいるときは、A の最適戦略は排出係数で 0.5 を選択することが最適となる。微妙な値だが。

次に、それぞれの地域の排出係数選択に対する B の効用水準の値をみてみよう。すると、この場合も、相手地域の A の排出係数の増加は、B の効用水準の低下を一般にもたらすが、A がいずれの排出係数を選択しようと、ほとんどの場合、B の最適戦略は最大排出係数を選択することである。ただし、例外があり、それは A が 0.1 という少ない排出水準を選択しているときは、B の最適戦略は 0.6 を選択することである。

以上の考察から、それぞれの地域の、相手地域の戦略に対する最適反応を示す反応関数（Reaction Function）を図 8 で示すことができる。ただし、本来シミュレーションでは、不連続な点のみでしか示せていないのだが、わかりやすいようにれ属的な千として反応関数を描いている。二つの地域の反応関数の交点がナッシュ均衡であるから、ナッシュ均衡点は、それぞれが最大排出係数を選択する点である。

したがって、このナッシュ均衡点は、一つの典型的な「囚人のジレンマゲーム」の均衡点となっていることがわかる。

以上の結果を踏まえて、理論編で示した図 3 に対応する図、すなわち、両者の実現可能な効用水準を描いた図を図 9 に示す。

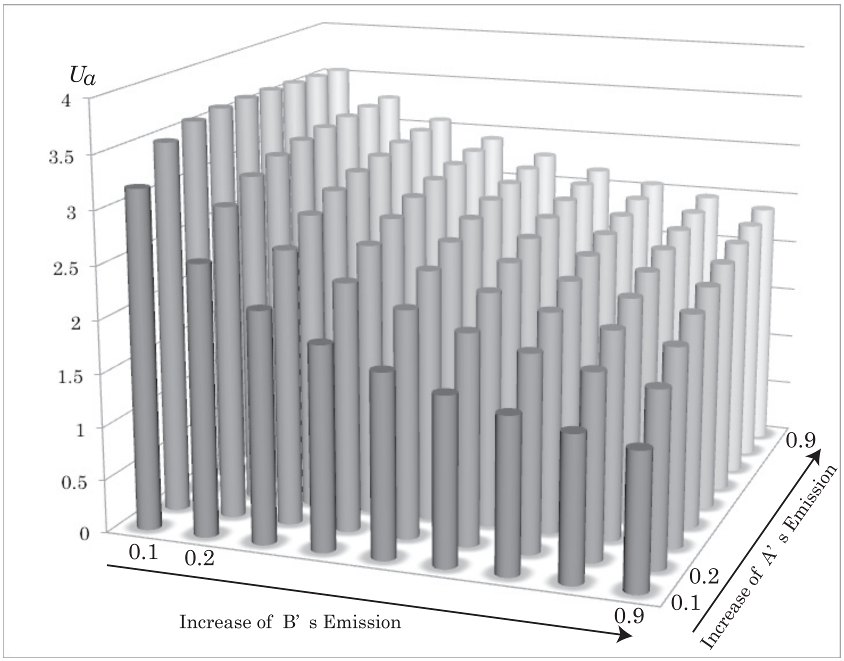

図 6: 排出係数 β_a, β_b の変化に対する A の効用水準 U_a の反応

表 2: A の効用水準

		β_a								
		0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
β_b	0.1	3.187	3.498	3.593	3.621	3.623	3.613	3.596	3.575	3.554
	0.2	2.554	2.947	3.114	3.200	3.247	3.272	3.285	3.291	3.291
	0.3	2.180	2.595	2.794	2.907	2.978	3.024	3.055	3.075	3.088
	0.4	1.925	2.342	2.555	2.685	2.770	2.829	2.871	2.902	2.924
	0.5	1.735	2.147	2.368	2.507	2.601	2.669	2.719	2.757	2.787
	0.6	1.588	1.991	2.214	2.359	2.460	2.534	2.590	2.634	2.668
	0.7	1.469	1.862	2.086	2.234	2.339	2.418	2.478	2.526	2.564
	0.8	1.371	1.753	1.976	2.126	2.234	2.316	2.379	2.430	2.472
	0.9	1.288	1.659	1.880	2.031	2.141	2.225	2.292	2.345	2.389

実現した効用水準が、菱形の点で描かれている。ナッシュ均衡は、図の点 N である。既に述べたように、このとき、両者の排出係数はともに最大となっている。両者の効用水準に関するフロンティアは赤線で描かれている。そのフロンティア上で、両端の数点をのぞく、その他のすべての領域がパレート最適である。ナッシュ均衡 N は、両者が全く協力しないときの均衡であるが、少なくともそれぞれの効用水準はこの点のレベルでは確保できるので、効用フロンティア上で、いずれかの効用水準が、ナッシュ均衡水準を下回る効用の組み合わせでの協力は実現不可能である。協力が意味ある領域は、CNC^* の、北東領域に含まれるフロンティアである。Incentive Compatible Domain（ICD）である。

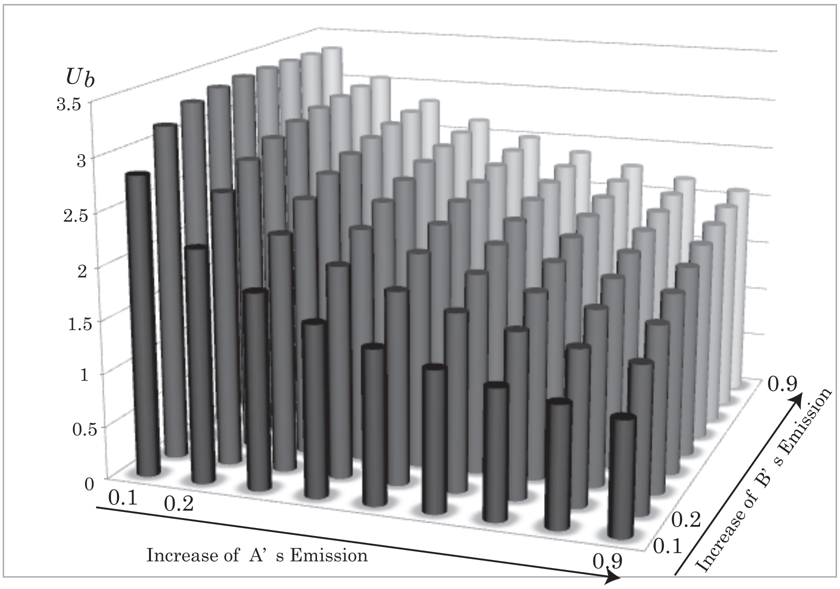

図 7: 排出係数 β_a, β_b の変化に対する B の効用水準 U_b の反応

表 3: B の効用水準

		β_a								
		0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
β_b	0.1	2.827	2.200	1.850	1.619	1.451	1.323	1.220	1.136	1.066
	0.2	3.168	2.596	2.247	2.005	1.824	1.681	1.565	1.468	1.386
	0.3	3.294	2.784	2.456	2.219	2.038	1.893	1.773	1.672	1.586
	0.4	3.346	2.891	2.584	2.358	2.181	2.037	1.918	1.816	1.728
	0.5	3.366	2.956	2.670	2.454	2.283	2.143	2.025	1.923	1.835
	0.6	3.368	2.997	2.730	2.525	2.360	2.224	2.108	2.008	1.920
	0.7	3.362	3.022	2.773	2.578	2.420	2.287	2.174	2.076	1.989
	0.8	3.351	3.038	2.804	2.619	2.466	2.338	2.228	2.132	2.047
	0.9	3.336	3.048	2.827	2.651	2.504	2.380	2.273	2.179	2.095

このシミュレーションでは、排出係数が 0.1 刻みでしか動かしていないので、離散的な点となっているが、フロンティアは連続的なものとして成立しうる。このシミュレーションの離散的な解において、ICD 上にある点は、3 点で、2 の点が、双方の排出係数がともに 0.1 である場合の解であり、1 と 3 の点は、それぞれ B がその状態から 0.1 だけ排出係数を増加させた状態である。

ゲーム論的には、どのようなプロセスで協力が成立するか、協力が成立する場合、この ICD 上のどの点がどのような理由で選択されるか、選択された点ではどのような経済的一般均衡が成立し、また、それぞれの地域にどのような経済的影響をもたらしているかを調べることが課題となる。

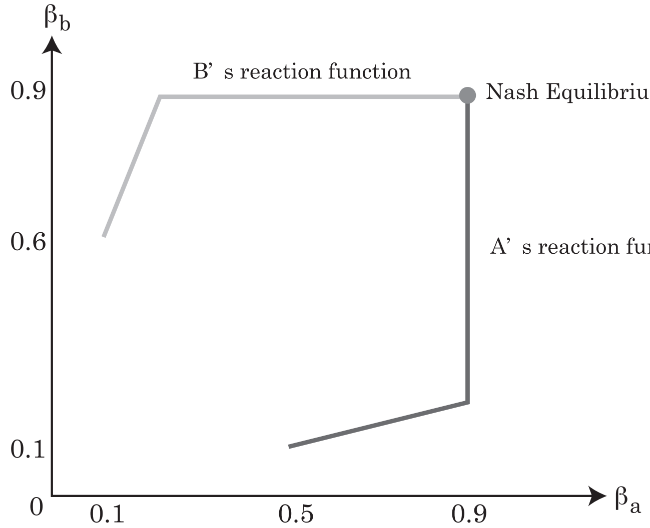

図 8: 反応関数（赤：A 地域、青：B 地域）

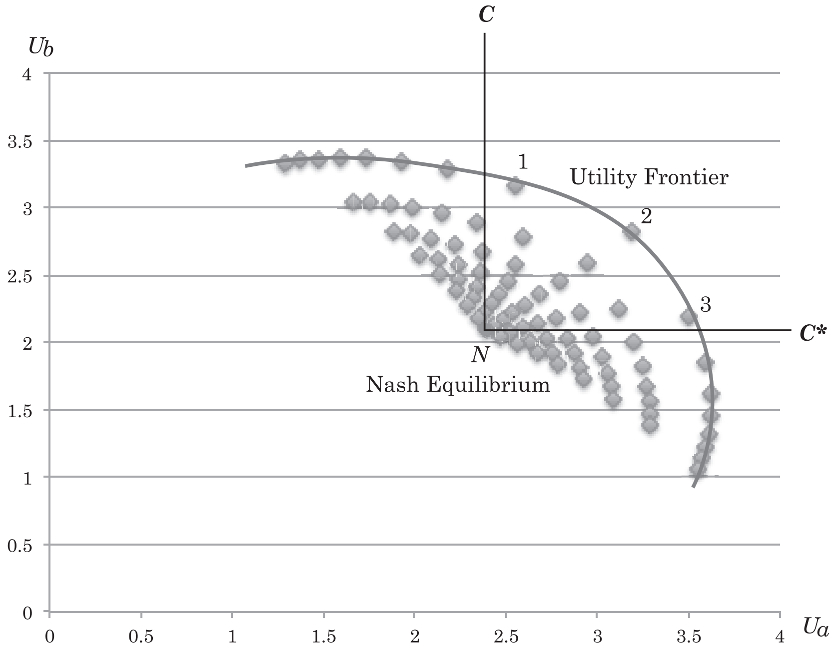

図 9: 実現可能な A, B の効用水準 U_a, U_b とナッシュ均衡 N

7　まとめ

これまでの議論から、一般均衡と環境ゲームとの関係、とくに同じモデルで一般均衡とゲームをともに表現できることを示すことができたはずである。ただ、環境問題は常に多期間に渡る問題として現れる。[1] も、動学モデルとなっている。動学モデルとなった場合の問題については、同論文を直接参照していただきたい。

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研究ノート

ラムサール条約における持続可能な観光に関する一考察

鈴木詩衣菜*

概要

「観光」は、多分野において経済成長、雇用創出、貧困撲滅、環境保全、相互理解を促進する役割を担い、最終的には平和に繋がるツールとしてその効果が期待されている。国際環境法においては、2000年代以降、観光と環境に関する議論が積極的に行われるようになってきた。

国際環境法上、観光を直接対象とする条約は存在しないが、環境諸条約は、観光に関連する条文を有している。本稿は、環境条約の中でも特に湿地保全に関するラムサール条約に焦点を当て、条約のもとで採択されたガイドラインが観光事業と環境保全の両立を図っていることを整理し、地元共同体の積極的な参加が、より好ましい観光の在り方へ導く役割を担うことを検討した。さらに、持続可能な観光を促進するための法的制度として、地理的表示制度についても若干の考察を加えた。

A Study on Sustainable Tourism in Ramsar Convention

Shiina Suzuki

Abstract

"Tourism" plays a role of promoting economic growth, employment creation, poverty eradication, environmental conservation, mutual understanding in multiple fields, and ultimately it is expected to be effective as a tool leading to peace. The discussions on tourism and environment have being carried out actively in the international environmental law since the 2000s.

Under the international environmental law, there are no treaties directly targeting tourism, but environmental treaties have provisions related to tourism. This paper focused on the Ramsar Convention on Wetland Conservation and the resolutions adopted under the Convention, which are compatible with tourism projects and environmental conservation to examine that active participation of local communities play a role in leading to more desirable tourism. In addition, this paper also added some consideration to the geographical indication system to promote sustainable tourism from legal aspects.

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ラムサール条約における持続可能な観光に関する一考察

1. はじめに

「観光」は、経済成長、雇用創出、貧困撲滅、環境保全、相互理解を促進する役割を担い、最終的には平和に繋がるツールとして多分野でその効果が期待されている。国際環境法の分野でもまた、観光は環境問題を捉えるうえで必要不可欠な要素のひとつである。

国際社会における観光への関心は、1925年に、観光分野における国際協力の促進することを目的に設立された官設観光機関国際同盟（International Union of Official Travel Organizations）にみることができる。同同盟は1975年に世界観光機関（World Tourism Organization）に改組され、2003年には、国際連合の専門機関（World Tourism Organization of the United Nations :UNWTO）となった。

また、国際連合は、2002年を「エコツーリズムの国際年」、2017年を「開発のための持続可能な観光の国際年」と位置づけた。2017年の第69回国連総会において、エコツーリズムを含む持続可能な観光の促進、貧困撲滅および環境保護の促進に関する決議69/233が採択された。

本稿は、「持続可能な観光」という軸のもとで、特に湿地保全との関係おいて、「特に水鳥にとって重要な生息地の保全に関するラムサール条約」（**The Ramsar Convention on Wetlands of International Importanceespecially as Waterfowl Habitat:**ラムサール条約）が「観光」をどのように認識し、それにどのように対応しているかを整理し、法的検討を試みるものである。

2. 湿地と観光

環境問題に対する国際合意が多く締結される中で、環境条約などで観光に関する議論がなされたのは2000年代に入ってからである。国際環境法上、観光を直接対象とする条約は存在しないが、環境諸条約には、観光に関連する条文を有しているものが存在する。当該条文を具体化するために、「観光」（tourism）、「エコツーリズム」（eco-tourism）、「レクリエーション」（recreation）などの用語を用いて、関連するガイドラインを採択し、観光事業と環境保全の両立を図っている。ガイドラインの適用にあたっては、「自然」、「経済」、「社会」、「文化」といった側面に適切なバランスをとることが求められている。

近年の「湿地」と「持続可能な観光」の関わりについての関心の高まりは、ラムサール条約の締約国会議（Contracting of Parties: COP）で採択された決議にみることができる。例えば、2008年に開催されたCOP 10では、決議Ⅹ.1「第三次戦略計画」や決議Ⅹ.3「人と湿地」が採択された。前者は、湿地サービスを分野横断的に認識することの重要性を掲げた戦略1.4において、賢明な利用を達成するための方法論を開発、普及することで観光に果たす湿地の重要性について触れており、後者は、湿地が人間の健康上の利益のために必要不可欠であり、また観光などの目的で訪問できる場所として重要であることを確認した。

2012年に開催されたCOP 11のもとで採択された決議Ⅺ.7「観光、レクリエーションおよび湿地」は、持続可能な観光の機会や魅力が、ラムサール条約登録湿地の重要性の国際的認識を通じて提供されることを確認した。同決議は、締約国に対し、湿地の生態系維持と観光のバランスに関する枠組を考えるよう要請した。なお、同決議は、UNWTOの持続可能な観光の定義が、ラムサール条約の賢明な利用の定義と

一致していることを確認した。（しかしながら、同決議の持続可能な観光の中には、エコツーリズムは含まれていないことは留意が必要である。同決議の草案段階では「エコツーリズム」が含まれていたものの、採択時には削除されている。一方で草案段階では「レクリエーション」の用語については含まれていなかったが、採択時には追記された。）また同決議附属書2は、「持続可能な観光と湿地周辺のレクリエーションを実現するための利害関係者の課題」に対するガイドラインとなっている。同附属書では、観光や土地利用を担当する行政部門や保護区域の管理を担当者、観光開発に関わる投資家や開発者、ガイド業など地元観光業従事者、NGOなどを含むラムサール条約登録湿地の管理者に対し、それぞれに確保すべき事項（モニタリング、評価、管理、訪問者が得る経験、訪問者による影響の軽減など）が示されている。

2015年に開催されたCOP 12では決議Ⅻ.2「第四次戦略計画（2016–2024）」が採択され、すべての湿地の賢明な利用のために、強化すべき持続可能な要素のひとつとして、観光が取り上げられた（目的13）。なお、2010年に、ラムサール条約事務局およびUNWTOは、持続可能な観光と持続可能な湿地管理・保全が表裏一体であることを認識し、湿地と持続可能な観光に関する文書を共同策定した。本文書は、湿地と観光に関わるガイドライン的役割を担い、持続可能な観光のために、組織間の協力強化、訪問者の管理や提供すべき事柄、地元共同体に対する経済的利益や雇用創出の向上といったことを念頭に置いたプロジェクトの実施などを提案した。

以上のように、ラムサール条約は、湿地に関する効果的な持続可能な観光の実施を確保するために、また湿地の生態系を維持するための必要なセーフガードのために、国家に対し、湿地の価値や湿地の賢明な利用の改善を観光およびレクリエーションに関する国内戦略、政策、計画に含めることを奨励している。

なお、2015年9月にラムサール文化調整チームにより、ラムサール文化ネットワークにおいて「観光」がテーマ別グループとして発足した。同グループは、湿地における持続可能なエコツーリズムの文化的側面に関心を寄せている。そのほかにも、2017年4月に世界旅行ツーリズム協議会（World Travel Tourism Council）は、持続可能な観光を実施した事例として、ボツワナのラムサール条約の登録湿地であるOkavango Deltaを「魅力的な渡航先賞」（Destination Award）に選出した。地元住民に最大限の利益を保証すると同時に絶滅のおそれのある種の保全および湿地への悪影響を最小限に留めたという点が評価された。また、2017年11月10日にアジア湿地シンポジウムで採択された佐賀ステートメントは、第5宣言において、地元の経済発展と湿地保全の両立を実現した事例（チリカ湖・インドやスンチョン・韓国）を評価し、湿地生態系の保全こそが、責任のある持続可能な観光の推進に寄与することを確認した。

3．ラムサール条約における持続可能な観光

ラムサール条約は、湿地を対象とし、これを保全するために、これら自然、経済、社会、文化のすべての側面を考慮することを締約国に推奨しており、地元共同体（local community）と政府、企業、旅行者、研究者などといった部外者（outsider）を繋げる役割を果たしている。そのため、各側面を個別で捉えるのではなく、湿地が有する自然、経済、社会、文化を統合的に捉える必要がある。このような認識は、欧州景観条約（European Landscape Convention）や社会のための文化遺産の価値に関するファロ条約（Faro Convention）など欧州の地域条約にみられるが、最近では、環境諸条約だけではなく各国の国内法などでも注目されている。（例えば、我が国では、自然公園法や文化財保護法にみられる。前者は、風

致や景観の維持および保護を含めた自然公園法の運用を検討した。後者は、改正に向けて、文化的景観だけでなく文化財の周辺環境の保全にも対応することが議論されている（本稿執筆現在））。自然、経済、社会、文化の要素がすべて合わさることにより、その区域固有の価値が生み出され、その価値を維持するために、地元共同体の役割が重視されてきている。

その例として、観光における湿地の位置づけとの関係が挙げられる。湿地がラムサール条約登録湿地である場合は、条約に基づく必要な保全管理が各国国内法に基づいて実施される。同条約の非登録湿地であっても、国は、条約に基づいて、必要に応じて当該湿地の保全管理を実施しなければならない。しかしながら、非登録湿地で湿地生態系に悪影響を生じさせる観光行為が存在する場合、国による保全管理が行き届かないことが生じうる。このような場合は、どのような観光行為が湿地生態系に悪影響を与えるかを知る地元共同体の意見や経験は、湿地保全だけではなく、持続可能な観光を実施する上でも必要不可欠である。具体的には、地元共同体からその国の政府に対し、適切な規制管理をするべきであるという発信をすることが可能となる。国は地元共同体からの意見を聞くことにより、国が取り組むべき優先順位の変更や保全措置を講じるための諸手続きを迅速に開始する判断などをとることが可能となる。

このように地元共同体は、より好ましい観光の在り方へ導く役割を担う。なお、地元共同体は、観光分野にも貢献するという点について、ラムサール条約は「コミュニケーション、教育、参加、認識」（Communication, Education, Participation, Awareness）のメカニズムのもとで対応し、実現している。

以上のように、持続可能な観光を実施するためには、観光資源となる湿地を統合的に把握し、地元共同体が湿地管理に積極的に関わる／関わっていける環境を整備していくことが必要不可欠である。

4. 持続可能な観光を促進するための法的制度

持続可能な観光のためには、その地域固有の特産物やその地域でしか見られない景色やそこでしか行うことができない体験などを通じて、訪問者（visitors）に満足を与えられるかということが求められている。それはこれまでも確認してきたように、地元共同体をはじめとする多様なアクターの積極的な関わりと強化が不可欠であるが、それだけではなく、経済的側面の支援も必要である。この点については、いかに地元の産品を有効活用し、付加価値をつけるかということが関わってくる。

地元の産品には、景色や景観（静的産品）や地場野菜や地酒などの特産物（動的産品）などが考えられる。前者については、条約登録地や保護区域などに指定することにより貴重な自然的、文化的価値を高めることが期待される。後者については、動的産品を対外的にその区域固有の価値を示す「地理的表示」（geographical indication）を利用することが、持続可能な観光を後押しする有効な制度のひとつであると考えられる。

国内法上、地理的表示制度が認められている場合には、同制度は、生態的・環境的・伝統的な知識に基づいたその生産地特有の伝統的な産品を商標登録することにより、それら産品に対し付加価値を生み出すことが期待されている。そのため同制度は、経済の拡大効果を有し、地元生産者の生産基盤の強化および利益の拡大に繋がり、地元共同体の生活環境の向上に貢献する。仮に、地理的表示制度が国内法によって認められていないとしても、地元産品の使い道を最もよく知る地元共同体の経験を生かすことにより、当該産品の特徴をいかに引き出し、また付加価値を高め、地理的表示制度と同等の効果を得ることが期待できる。

しかしながら、地理的表示については、持続可能な観光のために地理的表示が認められた産品をどのように扱うかという課題が残る。地理的表示が認められている伝統食材には、環境的、文化的、経済的価値が付与され、当該価値それ自体が観光の目的のひとつに据えられる。そういった場合、積極的に地理的表示を行い、動的産品を地元以外の場所で販売することが考えられる。一方で、地理的表示がされているものはその区域（area）でしか購入できないようにして、訪問者を増やす考え方も存在する。どちらの立場が持続可能な観光に合致するかについては、明確な判断基準が存在しない。

この点については、ラムサール条約が想定している持続可能な観光のために必要な要素として、「訪問者へ有益な経験をもたらすこと」が含まれていることに鑑み、やはり地理的表示を含む産品や観光地固有の価値が一体として提供される後者が、より持続可能な観光であると考えられる。

5. おわりに

持続可能な観光は、ラムサール条約だけではなく、他の環境条約（世界遺産条約、生物多様性条約、気候変動枠組条約）においても注目されている。例えば、世界遺産条約では、世界遺産登録地における観光管理マニュアルが策定されており、また生物多様性条約では、生物多様性の主流化を観光分野においても実施できるように締約国会議で決定が採択されている。さらに気候変動枠組条約では観光客の移動手段に際し、温室効果ガスの排出が懸念されている。環境条約間で協力していくことの重要性は、多々言及されており、持続可能な開発の一要素を担う持続可能な観光を実現するためには、環境条約間の単なる協力ではなく、連携の強化が今後の課題と考えられる。本稿では十分に触れることはできなかったが、特に、環境資源の最適な利用と持続可能な観光は、先住民族の文化的・歴史的側面をも十分に考慮して実施されなければならない。つまり、持続可能な観光のためには、その観光それ自体の意思決定や、観光開発計画および管理、キャパシティービルディングのための金銭的財源のルール作りなどが統合的に考えられる必要があり、先住民を含めた地元共同体をはじめとする多様な主体の積極的な参加が不可欠である。これらの課題が、各環境条約のもとで、持続可能な観光にどのように対応しているか今後検討していきたい。

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