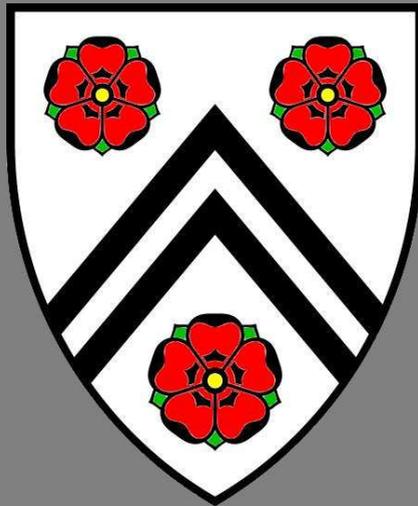


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The New Collection

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Editorial Welcome

Welcome to the eighth edition of the New Collection! With an MCR of over 350 members, this volume is a sample of just some of the diverse academic research within New College. Each article has been written by a specialist in their field, with the intention of being accessible to a broad readership. The authors have received extensive feedback from both their MCR peers and members of the SCR. It is easy to become absorbed in our own individual and specific projects, we therefore hope you take the chance to explore some of the new and unfamiliar subjects you might find in this journal.

The New Collection is now a firmly established part of the MCR and we are always looking out for new people to get involved, whether as an editor, author or typesetter. It is an excellent opportunity to experience the peer review process early on in our academic careers. Please get in touch if you are interested in contributing to the next volume; submission guidelines can be found at the back of the journal.

We would like to thank everyone without whom this volume of the New Collection would not have been possible, from the authors themselves to the team of volunteer editors and typesetters. Special thanks also to the SCR members who reviewed the articles and the Warden and Tutor for Graduates for their help and support. Finally, we would like to thank college for the continuing financial assistance.

We hope you all enjoy reading the 2012/2013 New Collection!

Kate Reynolds, Editor-in-chief

Alex Lucas, Publisher

MCR President's Foreword

The New Collection, a termly academic journal written and produced by members of the college MCR, is one of the key aspects of graduate life at New College. The journal offers a fantastic opportunity to showcase the depth and variety of interesting research being done by MCR members and acts as a complement to the regular MCR colloquia. It is the only academic journal published by an Oxbridge common room, making New College unique. The work in this edition will be preserved through the copy held and maintained in the Bodleian Library; an inspiring and intimidating prospect for our authors!

Whatever your interests, from the social impacts of disasters to mimicking plants in order to solve the global energy problem, I am sure you will find something written by your peers to engage or challenge you within these pages. Above all, the New Collection is a great celebration of the talents and ambitions of this dynamic MCR.

I hope you enjoy reading the issue.

Richard Millar
MCR President 2013

The Warden's Foreword

With the publication of this eighth volume, one can safely say that The New Collection is no flash-in-the-pan. Changing editors and indeed editorial teams nearly every year, it has maintained a consistently high standard and is testament to a vibrant and industrious MCR at New College. Once again, we find a wide variety of articles from different disciplines which should nevertheless appeal to a general academic readership. But I would challenge our pure mathematicians and theoretical physicists to contribute similarly accessible articles to future issues. Then The New Collection would be truly representative of the MCR.

The following articles are all single-authored, a growing rarity in an academic world in which the humanities and social sciences are following the sciences in collaborative research. But let's not get ahead of ourselves. The contributors to this volume are research students, and theses and dissertations are still generally the work of one person, depending of course on the extent to which one's supervisor is involved! Yet every article ought in effect to be co-authored, in that it might be shaped, corrected and improved by others. Those submitting their first article to a major referred journal are sometimes shocked by the severity of anonymous criticism and the necessity to re-write, indeed sometimes re-think. But almost every article can benefit from scrutiny by a second pair of eyes and be improved by editing, whilst learning how and when to cut one's own writing is essential.

The authors of this volume have similarly benefitted from help and advice offered by senior members of the College, with the editorial team providing the peer review. I congratulate the editors and commend this issue to a wide and curious readership. Now, in anticipation of the ninth volume of The New Collection, I am off to learn quantum mechanics.

Curtis Price
Warden

Article Summaries

Gender and Disaster Studies

Evgenia Ivanova

Reading, listening or watching the news may make one believe that the modern world is a world of disasters. ‘Natural’ or ‘man-made’, disasters seem to equally affect anybody who happens to be in a wrong place at a wrong time. This paper argues that disaster is a social phenomenon, its effects are not random, and they impact unevenly on different social groups. Drawing attention to the connection between vulnerability to disasters and age, race and class, this essay particularly focuses on the significance of gender in how disasters impact individuals and communities. Finally, it is suggested that disaster studies is a valuable approach and context for understanding how a particular society works and that, despite being incredibly destructive, disasters can create a space for positive social and political changes.

Putting the Tryst on Trial: An analysis of the lovers’ relationship in Bérroul’s *Le Roman de Tristan* after the elapsing of the love potion

Alice McCallum

The folkloric tale of Tristan and Yseut was recounted in different ways in the French literature of the 12th century. In this paper, I outline Broul’s presentation of the lovers in *Le Roman de Tristan*, in order to examine the debates surrounding their relationship, which mainly centre around the extent to which they are exculpated (or not) by the influence of the love potion, or lovendrins.

A Regional Approach to a Global Challenge

Benjamin Merle

Over the last decade academics publishing on economic impacts of climate change have engaged in a vigorous discourse on the appropriate discount rate

(indicates the time value of money). The models are highly sensitive to the rate and any choice implies a stance on issues of inter- and intra-generational justice. Most studies have based their cost-benefit-analyses on the assumption of a global discount rate. As more funds become available for regional adaptation or mitigation projects, the question arises whether the notion of a global rate results in the most realistic representation of regional costs and benefits. This essay argues that applying regional discount rates can lead to a more efficient allocation of funds among regions. The UNFCCC Green Climate Fund is presented as an example of this issue's relevance to policy-makers. Based on the Ramsey equation, the essay argues for regional discount rates and methods for their implementation into the Green Climate Fund framework.

Artificial Photosynthesis: Creating Fuel from Sunlight

Bhavin Siritanaratkul

There is an urgent need to secure an energy source that is both renewable and clean. Solar energy can potentially satisfy all of our energy needs, but current solar cell technologies face the problem of electricity storage. An alternative is to use solar energy to create fuel directly by mimicking nature's photosynthesis. Our main target is the water-splitting reaction, producing hydrogen and oxygen in a clean process involving only water, sunlight, and materials called photocatalysts. This article covers the principles of artificial photosynthesis on semiconductor photocatalysts, various research directions, and the outlook of the field.

Gender and Disaster Studies

Evgenia Ivanova*

Faculty of Politics and International Relations

Reading, listening or watching the news may make one believe that the modern world is a world of disasters. 'Natural' or 'man-made', disasters seem to equally affect anybody who happens to be in a wrong place at a wrong time. This paper argues that disaster is a social phenomenon, its effects are not random, and they impact unevenly on different social groups. Drawing attention to the connection between vulnerability to disasters and age, race and class, this essay particularly focuses on the significance of gender in how disasters impact individuals and communities. Finally, it is suggested that disaster studies is a valuable approach and context for understanding how a particular society works and that, despite being incredibly destructive, disasters can create a space for positive social and political changes.

What is disaster?

Disasters exist only where people are: a hurricane racing across the Atlantic or a tsunami engulfing small islands go unnoticed if they do not cause a direct or indirect harm to humankind. At the same time a regular rainstorm may cause a dramatic disaster if its impacts are floods that destroy bridges, houses and power lines, forcing families to leave behind their homes and their familiar stable life, resulting in grief, fear and anxiety.

Disaster is an event of a natural or technological nature and the following processes of recovery and reconstruction. Disaster is what is perceived and defined as such by people and communities; therefore it is a social construct and may vary in different times and places. Some researchers suggest using a disaster approach for the research and understanding of conflicts, wars and genocide as

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they also cause community-wide crises. As an area of research and (or) as an approach, disaster studies on one hand looks at preparedness, mitigation, response and recovery of affected territories, they on the other hand is interested in what, and how, events are defined as a “disaster” and how a disaster is contextualised in and by social, cultural and political contexts.

Being a fairly new field, disaster studies is an intrinsically multidisciplinary area which employs methods from sociology, anthropology, history, cultural and media studies, etc. The specificity of the subject allows a fruitful exchange between theoreticians and practitioners: all data for disaster studies is taken from real life and analysed in order to contribute to policy making, risk prevention and disaster management. Moreover, as a disaster is seen not just as an event but as a process, it involves very different groups of people, from survivors to policy formulators. This creates a space for different perspectives on the interactions between individuals, society and the state, and on issues of justice and governmentality.

The most crucial feature of disaster studies is to see disaster as a social phenomenon. As Ronald Perry notes “There is wide agreement... that disasters are social, that they are understood in human interactions”.¹ It is also widely accepted that disasters are rooted in social structures and therefore reveal certain social relationships, unmask the distribution of power in the society, demonstrate social and cultural rules that are not obvious in “normal” life, intensify hidden conflicts, and give opportunities for social changes. That is why some researchers think that disaster studies (with people and social relationships as their focus) give a very unique perspective on the society’s social structure and social changes that cannot be grasped in “normal” conditions.²

Disasters occur as physical, biological and socio-cultural events and processes. They create a unique and complex context where various actors³ construct, interpret and experience the disaster differently. That in its turn produces multiple disaster projects that may have various political, cultural,

¹Perry, R. W. What is disaster? In *Handbook of Disaster Research*. Eds. by Havidán Rodríguez, Enrico Louis Quarantelli, Russell Rowe Dynes. 2006. P.12

²Perry, R. W. What is disaster? In *Handbook of Disaster Research*. Eds. by Havidán Rodríguez, Enrico Louis Quarantelli, Russell Rowe Dynes. 2006; Garcia-Acosta, Virginia. *Historical Disaster Research/ In Catastrophe and Culture: the anthropology of disaster*. Eds. by Susanna M. Hoffman and Anthony Oliver-Smith. Sante Fe: School of American Research Press; Oxford: James Currey, 2002; Oliver-Smith, Anthony; Hoffman, Susanna M. *Why Anthropologists Should Study Disasters/ In Catastrophe and Culture: the anthropology of disaster (2002)*; Fritz, Charles. E. *Disaster/ In Contemporary social Problems*. Eds. by R.K. Merton and R.A. Nisbet. New York: Harcourt, Brace, and World, 1961.

³Social actors are participants in social actions and processes, normally ascribed agency to act; that is, to take part in social relations and be responsible and accountable.

social and economic agendas and impacts. Anthony Oliver-Smith describes this complexity in the following manner:

“... [D]isasters focus in... the widest possible variety of intersecting... processes and events of social, environmental, cultural, political, physical, and technological natures. As disasters develop and occur, all dimensions of a social structural formation and the totality of its relations with the environment become involved, affected, and focused. In disasters are expressed continuity and contradiction, cooperation and conflict, power and resistance. All are articulated through the operation of physical, biological, and social systems and their interactions among populations, institutions, and practices.”⁴

This complex mixture of contradictory elements does not mean, however, that effects of disasters are random. Similarly, physical objectivity of an event does not mean that vulnerability is distributed equally. Even when caused by natural forces, disasters impact unevenly on different segments of the population: that is, certain individuals and groups are more likely to become victims or to be affected than others. As human actions and decisions along with civil conflicts are at the heart of any disaster, it generates (or reveals) the vulnerabilities of different groups and – ultimately – inequality. For instance, the earthquake casualties might be heavier in poor regions which can not afford to build earthquake-proof housing or provide organised evacuation from the dangerous zones. Foreigners, or outsiders, may be caught in a hurricane if they do not have access to the information sources and networks. Old and sick people may not be physically able to move away when a warning about tsunami is issued or indeed some may just have nowhere to go. Poor, overcrowded neighbourhoods can be a dangerous place to live just by virtue of being overpopulated, where even a minor accident can rapidly propagate and affect a vast population. Colonisers bringing a new “advanced” technology to the local population of seismically-active areas may endanger the latter by forcing them to live in heavy, concrete, blocks of houses instead of light traditional dwellings. Similarly, foreign developers may open a building site in places traditionally avoided for risk of landslides.

Mary Anderson suggests that vulnerability to disasters can be analysed in three categories: physical vulnerability, social vulnerability (marginalisation or exclusion from political processes), and psychological vulnerability (victimisa-

⁴Oliver-Smith, Anthony. *Theorizing Disasters: Nature, Power and Culture* / In *Catastrophe and Culture: the anthropology of disaster*. Ed. by Susanna M. Hoffman and Anthony Oliver-Smith. Sante Fe: School of American Research Press; Oxford: James Currey, 2002. P.26

Age	%
0-9	0.3
10-19	1.1
20-29	1.1
30-39	3.0
40-49	8.6
50-59	14.2
60-69	14.1
70-79	24.6
80-89	24.9
90-	8.0

Table 1: Age distribution of 729 victims, 21 December 2005

tion, disempowerment, deprivation).⁵ All three categories are – to a lesser or greater extent – rooted in socioeconomic structures and embedded in ideological systems; “vulnerability” is therefore socially framed and determined. It is widely acknowledged that the poor are almost always the group that are most heavily impacted by disasters; and it has also begun to be recognised that race, along with gender and age, make a significant difference.⁶

Hurricane Katrina alone can provide a good example of how vulnerability, even when physical, is socioeconomically shaped. Public housing that was constructed in the most undesirable areas was home to mostly black and poor populations which in addition to the location disadvantage had reduced access to health care, goods, services, emergency response personnel, capital, and political representation.⁷ Some neighbourhoods like Violet, Louisiana – a small African American community in the East of New Orleans – were not affected by Katrina directly, but destroyed by waters released by the floodgates to save other more important areas. Given a few minutes between a warning and water bursting through their homes, only those quick and strong enough had a chance to survive and help others. Having small children to save, being old, sick or physically weak was a clear disadvantage – often a lethal one. That is what one can gather from

⁵Anderson, Mary B. Understanding the disaster-development continuum: gender analysis is the essential tool. /In *Women and Emergencies*. Ed by Bridget Walker. Oxford: Oxfam, 1994. P.8

⁶Farber, Daniel A. *Disaster Law and Inequality: Law & inequality*, vol:25, 2007; *Women and Emergencies*. Ed by Bridget Walker. Oxford: Oxfam, 1994; *Hurricane Andrew: ethnicity, gender, and the sociology of disasters*. noEds. by Walter Gillis Peacock; Betty Hearn Morrow; Hugh Gladwin. London: Routledge, 1997.

⁷Cutter, Susan. *The Geography of Social Vulnerability: Race, Class, and Catastrophe*.

the stories of the survivors.⁸ Looking at the age distribution of the survivors tells one more story of social vulnerability, the story of age (see Table 1).⁹

The factors causing this disproportion, yet again, are a mixture of the physical and social. They are illness and mobility problems, attitudes of “I grew up with hurricanes. I’m used to them” and ageist policies and attitudes from those responsible for evacuation and other disaster related responses.¹⁰

Despite the acceptance of a disaster approach many authors admit there is still “much sociological ground to cover” in disaster studies¹¹ and that the relationship between disasters and social disadvantage needs further study from social scientists.¹²

Gender and Disaster

There is a growing body of literature documenting that gender, for instance, noticeably influences vulnerability in disasters.¹³ Gender differences were observed during the floods that occurred in Scotland during December 1994,¹⁴ the earthquake in India in 1993,¹⁵ floods in Bangladesh and many other disasters. Different gender groups may rely on different sources to get information about the disaster or the relief. Different social and family roles ascribed to individuals impact how they meet the social and cultural expectations and fulfil their duties in the disaster context. For instance, if there are no schools, nurseries and hospitals available after a disaster, and women are the primary care takers, they have to spend time taking care of the family members and possibly abandon their jobs. If

⁸Bergin, Kathleen. *Witness; Hurricane Andrew: ethnicity, gender, and the sociology of disasters*. Eds. by Walter Gillis Peacock; Betty Hearn Morrow; Hugh Gladwin. London: Routledge, 1997

⁹Bytheway, Bill. *The Evacuation of Older People: The Case of Hurricane Katrina*. Published on: Mar 15, 2007. <http://understandingkatrina.ssrc.org/Bytheway/printable.html>

¹⁰See more detailed in Bytheway, Bill. *The Evacuation of Older People: The Case of Hurricane Katrina*. Published on: Mar 15, 2007. <http://understandingkatrina.ssrc.org/Bytheway/printable.html>

¹¹Fothergill, Alice. *The Neglect of Gender in Disaster Work: An Overview of the Literature*. /In *The Gendered Terrain of Disaster: Through Women’s Eyes*. Eds Elaine Enarson, Betty Hearn Morrow. Praeger Publishers: Westport, CT. 1998

¹²Farber, Daniel A. *Disaster Law and Inequality //Law & inequality, vol:25, 2007*

¹³The Gendered Terrain of Disaster: Through Women’s Eyes. Eds. Elaine Enarson, Betty Hearn Morrow. Praeger Publishers: Westport, CT. 1998; Rivers, J.P.W. *Women and Children Last: An Essay on Sex Discrimination in Disasters*.// *Disasters*, 6(4): 1982, pp. 256-67; etc.

¹⁴Fordham, Maureen H. *Making Women Visible in Disasters: Problematising the Private Domain*.// *Disasters*, 22(2), 1998, pp. 126-143; Lovekamp, William E. *Gender and Disaster: A Synthesis of Flood Research in Bangladesh/ In Women and Disasters*. From Theory to Practice, ed. Brenda D. Phillips and Betty Hearn Morrow. Philadelphia: Xlibris, 2008.

¹⁵*Women and Emergencies*. Ed by Bridget Walker. Oxford: Oxfam, 1994; *Hurricane Andrew: ethnicity, gender, and the sociology of disasters*. Eds. by Walter Gillis Peacock; Betty Hearn Morrow; Hugh Gladwin. London: Routledge, 1997

women are responsible for cooking food they may have to travel long distances to gather fuel supplies, food and water within the conflict or disaster zone, which may further endanger their lives. On the other hand, differences in socializations can result in specific coping strategies and responses to disasters. For example, the Chicago Heat Wave of 1995 had a dramatic impact on elderly single men. One of the reasons for the vulnerability of this particular group was their social isolation. In this context, social networking skills (along with the ability to ask for help) were significant for survival; and what was lacking in this group was due to gender socialisation.

Along with the significance of gender vulnerability in disaster events, processes and responses, some gender injustices during the disasters were also noticed. For instance it was noticed that women played crucial public and private roles during Hurricane Andrew, but their voices and experience were silenced in community policy-making.¹⁶ Similar claims were made in regard to many other disasters.¹⁷ Even though almost all practitioners and researchers who draw public attention to gender and disaster issues prove that gender is a crucial variable for the study of exposure to risks, perception of risks and disasters, preparedness behaviour, warning communication and response, physical impacts, psychological impacts, emergency response, recovery, and reconstruction,¹⁸ they still argue that there has been a persistent “gender silence” in mainstream disaster work. Gender is still an often overlooked factor and an underdeveloped dimension in disaster research¹⁹ and the impact of gender discrimination in disasters is “one

¹⁶Enarson, Elaine; Morrow, Betty Hearn. A gendered perspective: the voices of women./ In Hurricane Andrew: Race, Gender and the Sociology of Disaster. Eds. by Walter Gillis Peacock, Betty Hearn Morrow, and Hugh Gladwin. London: Routledge, 1997. Pp. 116-140

¹⁷Scanlon, Joseph. The perspective of Gender: a missing element in disaster response./ In The Gendered Terrain of Disaster: Through Women’s Eyes. Eds. by Elaine Enarson, Betty Hearn Morrow. Praeger Publishers: Westport, CT. 1998; Women and Emergencies. Ed by Bridget Walker. Oxford: Oxfam, 1994; Cox, H. Women in bushfire territory/ In The Gendered Terrain of Disaster: Through Women’s Eyes (1998); Fothergill, Alice. Heads Above Water: Gender, Class And Family In The Grand Forks Flood, SUNY Press, 2004; Enarson, Elaine. What women do: gendered labor in the Red River Valley flood // Global Environmental Change Part B: Environmental Hazards, Volume 3, Issue 1, March 2001, pp. 1-18; etc.

¹⁸Fothergill, Alice. The Neglect of Gender in Disaster Work: An Overview of the Literature/ In The Gendered Terrain of Disaster: Through Women’s Eyes. Eds. by Elaine Enarson, Betty Hearn Morrow . Praeger Publishers: Westport, CT. 1998; Lovekamp, William E. Gender and Disaster: A Synthesis of Flood Research in Bangladesh./ In Women and Disasters. From Theory to Practice, ed. Brenda D. Phillips and Betty Hearn Morrow. Philadelphia: Xlibris, 2008.

¹⁹See for instance Enarson, Elaine; Fothergill, Alice; Peek, Lori. Gender and Disaster: Foundations and Directions/ In Handbook of Disaster Research. Eds. Havidán Rodríguez; Enrico L. Quarantelli; Russell R. Dynes. New York, 2007; Women and Emergencies. Ed by Bridget Walker. Oxford: Oxfam, 1994; Scanlon, Joseph. The perspective of Gender: a missing element in disaster response./ In The Gendered Terrain of Disaster: Through Women’s Eyes. Eds. by Elaine Enarson, Betty Hearn Morrow.

of those topics in Emergency Management that isn't widely known and discussed even less".²⁰ Enarson and Morrow – who are among the leading US researchers in the field of gender and disaster – had to come to the conclusion that “theory and research in disaster studies have generally failed to acknowledge the myriad, but not always obvious, ways in which gender bias is sometimes attached to disaster research. This results in programs which do not adequately reflect an understanding of female victims’ daily lives and which fail to utilize effectively the knowledge and skills of over half of the population”.²¹

Nonetheless, despite all the difficulties, gender analysis is emerging as an (alternative) paradigm in disaster research.²² Yet the context in which this gendered disaster analysis has occurred, and the objectives it has pursued, have determined the specificity of this theoretical approach and established certain limitations.

This approach started to appear in the late 80's and became more visible in the mid 90's. Initially it emerged and took its theoretical background from the field of gender and development and was advocated, first of all, by practitioners and activists. At that time the main goal of this approach was to draw attention to women's and girls' vulnerability in disasters and to provide concrete and effective relief to those in need. For instance, it was necessary to make sure that girls have enough food and water if families prioritised the health of boys as a part of the survival strategy for parents and agricultural communities. Protecting women from the sexual violence that tends to increase in social chaos and crises was another issue. Some women got trapped in the traditional norms of their culture making them dependent on the families of their dead husbands. One of the important issues raised at this time was to bring attention to gender unfriendliness in post-conflict and post-disaster environments. For example, refugee camps can be detrimental to women's health; in some cases, the toilet facilities are outside the camp and women would need to cover quite some distance to use them. As it was unsafe (or seemed unsafe) for them to travel alone several times a day, they would try to minimize these trips or go in groups and therefore be dependent on when the group went. Women were not only constantly stressed but also developed

Praeger Publishers: Westport, CT. 1998, etc.

²⁰Lucus, Valerie. Review of Women, Gender and Disaster: Global Issues and Initiatives//Journal of Homeland Security and Emergency Management: Vol. 7: Iss. 1, Article 27, 2010.

²¹Enarson, Elaine; Morrow, Betty Hearn. A gendered perspective: the voices of women./ In Hurricane Andrew: Race, Gender and the Sociology of Disaster. Eds. by Walter Gillis Peacock, Betty Hearn Morrow, and Hugh Gladwin. London: Routledge, 1997. Pp. 116-140

²²Enarson, Elaine; Morrow, Betty Hearn. Conclusion: Toward Gendered Disaster Policy, Practice, and Research./ In The Gendered Terrain of Disaster: Through Women's Eyes. Eds. by Elaine Enarson, Betty Hearn Morrow. Praeger Publishers: Westport, CT. 1998

diseases of the urogenital system.

As most field work was done in developing countries where gender roles were rather rigid, and cultural and religious norms dominated peoples' lives, the main stress in the literature on gender and disasters was assumed to be the socially constructed nature of gender, gender roles and gender behaviour. For instance, it was important to demonstrate that women are vulnerable not because of their physical weakness or nature but because of the social arrangements that cause poverty, dependency and deprivation, all of which are caused by human actions and attitudes.²³ Issues at stake include the gender division of labour, access to resources, social and cultural roles, gender stereotypes, social and economic status of women, women's domestic responsibilities and women's empowerment. After several serious disasters occurred in countries considered to be democratic (hurricanes Andrew, Katrina, and Rita in the US and floods in Scotland amongst others) researchers, activists and journalists began to question democracy in their countries and address issues of gender, class, race and age in their societies. Some new issues were brought into the centre of the research and practical agenda; among them were the experience of the poor and other disadvantaged groups, making women's voices heard and their roles in disaster processes visible, women's participation in decision-making, and issues of power distribution in society. The research approach was widened as well: not only the development paradigm, but anthropologists and social scientists came into the field too.

Conclusion

Even admitting the importance of this scholarship, it still contains some limitations and gaps. First of all, it has to be noted that a significant amount of literature, despite mentioning gender and the gender approach, is primarily concerned with women's issues and treats "gender" and "women" as synonyms. Although the experiences of different male groups and the tensions between social constructs of masculinity and disasters are mentioned in some studies, male disaster experience is rarely addressed or problematized. Moreover, most studies operate only by categories of men and women, ignoring the variety of other gender-related identities and issues. For instance, issues of gender identity, sexuality or trans-gender issues are almost completely ignored. This creates a feeling that gender is an objective tangible reality (a simple social or cultural twin of biological sex) rather than a useful category of analysis of the social order.

²³See for instance, Scanlon, Joseph. *The perspective of Gender: a missing element in disaster response.* In *The Gendered Terrain of Disaster: Through Women's Eyes*. Eds. by Elaine Enarson, Betty Hearn Morrow. Praeger Publishers: Westport, CT. 1998

Another academic “dissatisfaction” with the scholarship on disaster research comes from an interest in social and political theory. As the primary interest of the gender and disaster field has been oriented towards disaster relief practice, theoretically it seems to be less elaborated from a the perspective of social science in general and political science in particular seems to have been less developed. Although lots of analysis has been performed within the frameworks of disaster management or disaster response, there is little political theory produced that explains the relationship between politics and gender in a disaster context and not many theoretical models have been suggested to explain the interaction between different political actors involved in disaster processes from a gender perspective.

Disaster studies appears to be a valuable approach and context for understanding how a particular society works. Disasters are unique moments when stable and familiar reality breaks, revealing hidden mechanisms and structures of the social, political and cultural fabric. As with any dramatic time, disasters provide a chance to question the ordinary order of things and revise our presumptions and understanding. They also present an opportunity to be critical and creative, offering a space for changes and contributions so that the society can become a better place for people to be.

Putting the Tryst on Trial: An analysis of the lovers' relationship in Bérout's *Le Roman de Tristan* after the elapsing of the love potion

Alice McCallum*

Faculty of Medieval and Modern Languages

The folkloric tale of Tristan and Yseut was recounted in different ways in the French literature of the 12th century. This paper will focus on the version told by Bérout, a brief (and partial) summary of which is as follows:

A Cornish knight, Tristan, is sent to Ireland to fetch Yseut so that she may marry his king, Marc. On the journey, however, the two of them drink a potion which causes them to fall deeply in love; as a result, although Yseut does marry the king, she and Tristan are compelled to have an adulterous relationship as they cannot resist their desire for one another. The lovers are accused of adultery several times, but each time they manage to convince the king of their innocence, until a wicked dwarf and three barons finally prove their guilt. The pair run away and live together in a forest, until the love potion elapses (three years after it was imbibed), after which point they return to the court to make their peace with the king.¹

In this paper, I outline Bérout's presentation of the lovers in *Le Roman de Tristan*, in order to examine the debates surrounding their relationship, which mainly centre around the extent to which they are exculpated (or not) by the influence of the love potion, or '*lovendrins*'.

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¹Only fragments remain of the Bérout version of the story, which begins *in medias res* after one of Marc's accusations, and ends with the barons attempting to catch out Tristan and Yseut after their return to the court.

As the driving force behind the main plot of the traditional story of *Tristan*, the wrongly-administered love potion takes on an even more significant role in Bérout's version of the tale. Unlike the tale told by Thomas,² in which the potion's effects last indefinitely, the love potion ('*lovedrins*'³) in Bérout's recounting is given a life-span of only three years before wearing off and further complicating the situation of the lovers. To some extent, the poet's intention may have been to endow the plot with more depth and complexity, to encourage his readers to consider the implications of love and to examine 'the struggle between love and social laws' on which the 'fascination'⁴ of the narrative relies. Indeed, debate surrounds any analysis of this work; critics not only disagree on whether the behaviour of Tristan and Yseut was justifiable, both before and after the elapsing of the love potion, but they also argue over whether Bérout intended to put across a moral message or whether he merely wished to incite such discussions. Without doubt, any examination of the status of the lovers' relationship after the elapsing of the love potion must first take into account its status before the aforementioned elapsing; it is only by comparing the behaviour of the lovers at different points in the poem that one is able to make an informed decision about the matter. The purpose of this paper is, therefore, to outline the various debates which surround the poem, examine the points in each of the arguments, and draw a conclusion as to whether the relationship of the two protagonists is immoral, or merely amoral.

Bérout - moralist or spectator?

Throughout the poem the narrator makes his presence felt. Bérout references his own name only twice in the work, but his frequent exclamations and direct addresses to the audience serve not only to remind the readers of his story-telling presence, but also to give them an indication of where their sympathies should lie. For example, when the dwarf Frocin comes up with a plan to catch Tristan in bed with Yseut, instead of praising the ingenuity which may help the king to realise that one of his vassals is doing him wrong by having a sexual relationship with his wife, the narrator exclaims to the reader 'Hah! Listen to the betrayal and treachery that the dwarf Frocin suggested to the king! May all these augurs be cursed!' ('*Ha! Or oiez qel traïson / Et confaite seducion / A dit au roi cil nain Frocin! / Dehé aient tuit cil devin!*'⁵). This direct and emotive address to the reader encourages him or her to take the side of the two protagonists, in the face

²Thomas of Britain wrote his own version of the tale in Anglo-Norman French.

³Bérout, *Le Roman de Tristan* (Librairie Générale Française, 1989) 120 (line 2138)

⁴Varvaro, A. *Bérout's Romance of Tristan* (Manchester University Press, 1972) 73

⁵Bérout, 52 (lines 643-646)

of ‘this dwarf who is cursed by God’ (*cist nain, qui Dez maudie*⁶). Evidently, Bérout does not want the lovers to be condemned because of their actions, even though these actions could theoretically be seen as transgressive. It is perhaps for this reason that some critics have argued that the poet is not moralising within the work, for he is clearly supporting two characters whose actions are supposedly condemnable. Elizabeth Bik comments that he ‘barely moralises [and he] gives [his] reflections the form of a general truth’ (*moralise à peine [et qu’il] donne à [ses] reflexions la forme d’une vérité générale*⁷), perhaps basing her argument on the lovers’ behaviour in the face of the ‘moral’ figure of Ogrin who ‘advises them to repent’ (*du repentir conseil lor done*⁸), while Tristan states that ‘the decision is irrevocable’ (*de tot an est li conseil pris*⁹). Similarly, Janet Caulkins states that ‘questions of morality are not of prime concern even in [Tristan and Yseut’s] encounters with Ogrin’¹⁰ and that Bérout may have described himself as ‘an observer and not a moralist’ (*observateur et non moraliste*¹¹), outlining the actions of his protagonists without passing comment on them.

However, the interest which the poet appears to show in the two characters’ behaviour and well-being would suggest that both of these comments are missing the point, to some degree. Even before the elapsing of the love potion, both are adamant that their love is not to be regretted: in the aforementioned discussion with Ogrin, Tristan claims that Yseut ‘loves me in good faith’ (*m’aime en bone foi*¹²), which she echoes later in the poem, stating that ‘I love him with a good love’ (*je [...] l’aim de bone amor*¹³). Although one may expect the narrator to be critical of the two lovers – as Thomas was in his heavily moralistic recounting of the tale – it is not true that Bérout is not moralistic because he does not criticise them; indeed, his support of the pair is unwavering throughout the poem, which seems rather to suggest that he is moralising in *their* favour. This idea is supported (or at least, the possibility of its legitimacy is proffered) by Barbara Sargent-Baur in her examination of ‘*La dimension morale*’ within the poem. Sargent-Baur does not dismiss the possibility that the work could contain ‘an intentional moral dimension and even teachings about the behaviour of human beings, and judgements of this’ (*une dimension morale consciemment voulue et même un*

⁶Ibid. (line 648)

⁷Bik, E. “Les Interventions d’auteur dans le Tristan de Bérout” *Neophilologus* 56 (1972) 35

⁸Bérout, 86 (line 1394)

⁹Ibid. (line 1403)

¹⁰Caulkins, J. “The meaning of *pechié* in the *Romance of Tristan* by Bérout” *Romance Notes* 13 (1971-2) 548

¹¹Ibid. 549

¹²Bérout, 86 (line 1382)

¹³Ibid. 128 (line 1327)

enseignement à propos de la conduite des êtres humains et des jugements à y apporter'¹⁴); if this is the case, she remarks, 'Béroul would be not only a storyteller but also a moralist' ('*Béroul serait non seulement un conteur, mais aussi un moraliste*'¹⁵).

The issue of whether Béroul is a moralist or not is particularly pertinent when it comes to any analysis of the lovers' relationship both before and after the elapsing of the 'lovendrins'. If one views Béroul as a mere storyteller looking impassively at the actions of his protagonists while his narrator merely *claims* to support them in their actions, then it is justifiable to suggest that their behaviour is contemptible throughout the poem, and the only question is whether their behaviour becomes *even more* contemptible after the elapsing of the love potion. If, by contrast, one believes that Béroul's apparent lack of impartiality is intended to show his unequivocal support for the behaviour of Tristan and Yseut, rather than simply being a story-telling device, then it could be argued that either he believes that the love potion exculpates the lovers entirely, or he thinks that it exculpates them until it elapses, after which point their behaviour is still reasonable. If it is in fact the case that the poet supports their actions, one must examine his reasons for doing so.

The ambiguity of the lovers' repentance

In general, most criticism of Tristan and Yseut stems not from the fact that they have an adulterous relationship behind the king's back – for many critics argue that the presence of the love potion in the story exonerates them from this – but from the fact that they seem to show no repentance after the potion expires. In fact, by adding a time limit to the potion in his version of the tale, Béroul has entirely changed the way in which the reader could potentially view the two lovers (it is interesting that Thomas, even in his version of the story in which the potion's effects never wear off, seems more critical of the pair than Béroul is). Notably, when the potion expires for Béroul's protagonists, their thoughts are not of shame at the way they have treated the cuckolded king, but rather of regret that they have wasted so much of their lives in suffering. Tristan bewails the fact that he has lost his skills and pride as a knight, 'I have forgotten chivalry, the ways of the court and of barons [...] I am no longer at court with the knights' ('*Oublié ai chevalerie, / A seure cort et baronie [...] / Ne sui a cort a chevaliers*'¹⁶) while Yseut, in a speech which has made her the target of much criticism by scholars, focuses on

¹⁴Sargent-Baur, B. "La dimension morale dans le *Roman de Tristan* de Béroul" (Unknown) 49

¹⁵Ibid.

¹⁶Béroul, 122 (lines 2165-6, line 2169)

the wealth and comfort she has foregone, before placing the blame entirely upon Brangien, her maidservant, who mistakenly gave the lovers the potion:

‘Poor woman, unhappy woman, / what have you done with your youth? / You are in the woods like any other slave, / barely anyone is here to serve you. / I am queen, but that title / I have lost thanks to the potion / which we drank at sea. / Brangien should be on her guard.’

*(‘Lasse, dolente,
Porquoi eüstes vos jovente?
En bois estes com autre serve,
Petit trovez qui ci vos serve.
Je suis roïne, mais le non
En ai perdu par la poison
Que nos beümes en la mer.
Ce fist Brengain, qu’i dut garder’¹⁷)*

Yseut is, understandably, described as ‘ambiguously penitent’¹⁸ by Roger Pensom. Sargent-Baur is even more critical of her, noting the absence of any form of repentance with regard to the way she treated her husband, and concluding that ‘it becomes clear that Bérout is creating for us a portrait of a couple who lack any sense of morality’ (*‘il ressort que Bérout nous fait le portrait d’un couple à qui manque tout sens moral’*¹⁹). Indeed, it is true that Yseut’s self-pitying switching between first and second person in the previously-quoted lament does show that she is very much her own focus, and that her misery is almost exclusively linked to how the potion has affected her, and her place in the social hierarchy, as seen in her contrast between the words ‘servant’ (*‘serve’*) and ‘queen’ (*‘roïne’*). Nonetheless, the critical comments of Pensom and Sargent-Baur are only justifiable if one believes that the queen’s behaviour, while under the influence of the potion, was reprehensible.

As previously stated, both she and Tristan think of their love as pure and good, something for which they should have no regrets; indeed, their very dissimulation could be said to support this. The fragment of the poem which we still have opens with the pair seemingly having a ‘private’ conversation while fully aware that the king is listening to every word; Yseut makes the factually correct statement, ‘may my body be cursed if any man other than he who took my

¹⁷Ibid. 124 (lines 2201-2208)

¹⁸Pensom, R. *Reading Bérout’s Tristan* (Peter Lang, 1995) 66

¹⁹Sargent-Baur, B. 54

virginity were to be my lover' (*'Qui sor mon cors mete flaele, / S'onques fors cil qui m'ot pucele / Out m'amistié encore nul jor'*²⁰), which the king will think is referring to him, but which is in fact a reference to Tristan, who is the only man to take her virginity and to have her 'love' (*'amistié'*). While it is true that the couple was committing adultery and repeatedly dissembling to trick the king, it could be argued that their adultery is purely on account of the love potion, which exculpates them, and that their trickery is merely a means of reducing the shame the love potion's consequences would bring upon the king. Many critics have discussed the theory that any sin is discounted by the fact that the lovers have no control over their feelings; Tony Hunt, famously, stated that 'neither the love of Tristan and Iseut nor their action, would, in the Abelardian view, constitute sin',²¹ for the strength of their feelings is entirely out of their control, as is their compulsion to act on them. Thanks to the influence of the '*lovedrins*', Tristan and Yseut are exonerated. However, Simon Gaunt, by contrast, seems somewhat critical of this 'excuse' for the lovers' behaviour. He comments that 'with deft, even dodgy logic, Bérout uses the magic potion [...] to exculpate the lovers',²² suggesting that the potion is being used to explain away behaviour which is fundamentally wrong, both in the context of the feudal system (Tristan is betraying his king) and that of marriage (Yseut is betraying her husband). It seems unfair to reduce Bérout's support of the couple to a mere product of 'dodgy logic', as this sweeps aside the complex moral issues raised by the text. Such criticism becomes even less appropriate when one takes into account Bérout's continued support of the lovers even after the potion's effects have worn off, even though, as many critics argue, they still maintain an intense love for one another.

How does the elapsing of the potion change the lovers' behaviour?

The status and morality of their love after the love potion wears off is another highly debated aspect of the poem, and one which is contingent on the extent to which their indiscretions continue after this event. That so many critics can have such polarised views on this matter reflects the often ambiguous and allusive depictions of the couple's interaction: Sargent-Baur claims that the lovers 'show no change, whether in their feelings or in their actions' (*'ne font prevue d'aucun changement, que ce soit dans leurs sentiments ou leurs actions'*²³), and that Tristan 'continues to see the queen in secret, not just for a mere visit'

²⁰Bérout, 24 (lines 23-25)

²¹Hunt, T. "Abelardian Ethics and Bérout's *Tristan*" *Romania* 98 (1977) 511

²²Gaunt, S. *Retelling the Tale* (Duckworth, 2001) 131

²³Sargent-Baur, B. 54

(*'continue [...] à venir voir clandestinement la reine, et ce non pas pour une simple visite'*²⁴). Both statements, however, seem unfounded if one examines the text itself. Certainly, it is true that Tristan and Yseut continue to have a strong emotional attachment to one another even after the potion elapses. Tristan says 'noble queen, wherever I am I will always proclaim that I am yours' (*'Roïne franche, ou que je soie, / Vostre tos jorz me clamerioie'*²⁵), promising her his enduring love and services, and, when he goes to deliver the letter of explanation to King Marc, the queen suffers greatly, crying and worrying about his safety. However, does this necessarily mean that their relationship has not changed in any way, and that it is still sexual in nature? A contrasting view is that of Alberto Varvaro, who clearly views the status of the lovers' feelings towards one another, before and after the elapsing of the love potion, as two extremes. Varvaro claims that Béroul 'forcibly juxtaposes two diametrically opposed emotional conditions, indifference and irrevocable love, between which the only hinge is the potion';²⁶ by this logic, Tristan's claim to be 'always yours' (*'vostre tos jorz'*) is a sign of indifference, an argument which is difficult to support. To view it in either way (that the lovers continue their sexual relations, or become entirely indifferent to one another) seems somewhat simplistic. There is evidently a change in the feelings and behaviour of the two lovers after the potion elapses – their willingness (albeit grudging) to part in order to restore the natural order of society is a testament to this – but this by no means constitutes 'indifference'. Indeed, Yseut's tears when Tristan leaves give a clear indication of the remaining emotional attachment that binds them, which the expiry of the potion has only served to turn into a surmountable issue, rather than something which is all-consuming and uncontrollable.

There is little doubt, given what has been outlined in this paper, that the expiry of the potion leads to a change in love, rather than to its entire disappearance. While some critics have claimed that the sexual adultery continues, there is no evidence for this in the text; the subsequent meetings between the queen and Tristan make no reference to sexual interaction. Nonetheless, the question is still raised as to whether the lovers' feelings towards one another, once the justification given by the existence of the love potion is no longer relevant, continue to be disrespectful to the king, and to threaten the feudal system by demonstrating a vassal who has chosen love over his duties to his lord. Certainly, it could still be the case that any sort of emotion between a man and a woman who are not married (whether sexual or not) is meant to be understood as contemptible. If this is the

²⁴Ibid.

²⁵Béroul 126 (lines 2249-2250)

²⁶Varvaro, A. 75

case, however, why does Béroul not criticise Tristan and the queen, choosing rather to display his supposed enmity towards those – for example, Frocin and the barons – who try to bring harm to them? One response, which may have been eschewed by critics due to it endowing Béroul with a degree of emotion and personal history which is necessarily unverifiable, is that Béroul favours lovers because he is a lover himself, or is merely sympathetic to their plight. Indeed, his tender descriptions of the queen and Tristan interlaced in the bed – ‘listen to how they are lying: she has put her arm round Tristan’s neck, and she has rested the other on top of him; she holds him tightly to her, and he has his arms wrapped around her’ (*‘Oez com il se sont couchiez: / Desoz le col Tristan a mis/ Son braz, et l’autre [...] / Li out par dedesus geté; / Estroitement l’ot acolé, / Et il la rot de ses braz çainte’*²⁷) – seem to be the work of someone who has either experienced such bliss in the arms of the person one loves, or who has an exceedingly good imagination. Quoting Curtis’s argument, Hunt summarises this situation perfectly, stating that ‘the power of [the lovers’] magically inspired love is replaced by the frailty of human passion’.²⁸ It seems that Béroul did not want to suggest that love can disappear instantaneously, leaving no trace; instead, he opted for a more realistic rendering of the lovers’ situation, in which the only effect of the potion elapsing was that it enabled them to do what they knew they should, even though they still wanted to be together, and even though they still loved each other. If it is true that Béroul was writing about love, inspired by his own experience of it, then it is unsurprising that he condones the behaviour of the lovers, even though their actions may be seen as immoral to those who do not agree that the power of the love potion is a sufficient justification.

Conclusion

In a work as morally complex as *Le Roman de Tristan*, it is almost impossible to give any firm answers to the various questions which are raised within the text. The pivotal analysis remains focused on the status of the lovers’ relationship before and after the elapsing of the love potion, and, as this paper has sought to demonstrate, the question of this status is contentious. However, whether or not Béroul was merely playing devil’s advocate and courting debate by supporting the lovers, there is no doubt that his support endows them with a kind of justification which is lacking in Thomas’s version of the tale. Without the exculpation provided by the potion, their adultery and love would simply be seen as an

²⁷Béroul 106 (lines 1816-1821)

²⁸Hunt, T. 513

immoral betrayal of the queen's husband, and the knight's king. However, given that the love was initiated by the potion, Bérout seems to imply that its continuation is innocent (and even realistic) as long as they do not act on it once they have the power to resist. In summary, the potion renders amoral a situation which would otherwise be immoral, and while one could doubtless argue that the lovers' relationship becomes inappropriate with the disappearance of its catalyst, it appears that Bérout's continued support for the pair would suggest otherwise, unless he – like his characters – has had his views of morality blinded by the power of all-consuming love.

A Regional Approach to a Global Challenge

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Over the last decade academics publishing on economic impacts of climate change have engaged in a vigorous discourse on the appropriate discount rate. The models are highly sensitive to the rate and any choice implies a stance on issues of inter- and intra-generational justice. Most studies have based their cost-benefit-analyses on the assumption of a global discount rate. As more funds become available for regional adaptation or mitigation projects, the question arises whether the notion of a global rate results in the most realistic representation of regional costs and benefits. This essay argues that applying regional discount rates can lead to a more efficient allocation of funds among regions. The UNFCCC Green Climate Fund is presented as an example of this issue's relevance to policy-makers. Based on the Ramsey equation, the essay argues for regional discount rates and methods for their implementation into the Green Climate Fund framework.

Introduction - A New Policy Challenge

Since 1992 the United Nation Framework Convention on Climate Change (UNFCCC) has functioned as an international negotiation platform for emissions targets, transfer payments and green technology transfer. One of the achievements of the negotiations in Cancun (COP 16) is the foundation of the \$100bn Green Climate Fund (GCFund). Under the agreements of UNFCCC COP 16, developed nations agreed to provide \$100bn per year by 2020 to finance mitigation and adaptation¹ efforts in developing countries (UNFCCC, 2011). The actual source

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¹Mitigation refers to projects directed at the prevention of climate change. Usually this involves either emission reductions or capturing already emitted CO₂, for example by means of reforestation. Adaption project are directed at reducing vulnerability towards climate change impacts.

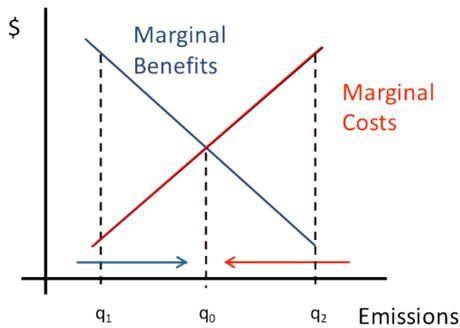


Figure 1: Schematic cost-benefit graph. Source: created by author

of these funds and allocation of the burden among developed countries still remain to be negotiated. This is the first considerable international climate change fund that aims at a transfer from countries that contributed the most to the current carbon stock in the atmosphere (Page, 2012) to countries with highest potential negative impact of climate change (Mendelsohn, 2006).

To ensure continued funding, the GCFund bears the burden to prove that it can allocate money efficiently among climate change adaptation and mitigation projects. This essay focuses on “efficiency” in a purely economic sense. This means it is assumed that developed countries are trying to maximise their return on the funds committed to GCFund. In this case the return is defined as benefits in terms of avoided future damage associated with climate change. To maximise these returns GCFund should fund projects in order of their “marginal benefits-marginal costs” and should not fund any project where marginal costs of abatement exceed marginal benefits.

Figure 1 shows an example of a marginal benefit and marginal cost function of a mitigation project. Reducing emissions by an additional ton of carbon at q_1 is relatively cheap and bears high benefits. This is because clean up costs for the first tons is likely to be lower, as there is still a wide variety of abatement options (e.g. efficiency increases) available. At q_2 most measures of reducing CO₂ emissions have already been put into place, which makes it more expensive to abate another ton of carbon emission. However, cleaning up these last tons also bear little benefits, as the climate is resilient against a certain oscillation in CO₂ concentration. The figure shows that the optimal amount of emission reduction/abatement is at the point where marginal benefits equal marginal costs.

In order to evaluate a project according to these criteria, economists use cost-benefit-analyses (CBA). A CBA calculates the net present value (NPV) of a project by discounting the difference of future benefits (B) and costs (C) to current dollar values (Equation 1) (Boadway, 1984). B_t and C_t are the benefits and costs in period t , respectively. The discount rate (r) is the percentage by which money in period $t + 1$ is worth less than in period t . This notion of time-value of money is explained in more detail in a subsequent section.

$$\text{NPV} = \sum_{t=0}^{t=\infty} \frac{B_t - C_t}{(1+r)^t} \quad (1)$$

It will be assumed that nations have to submit project proposals to the GCFund as part of an application process for funds. In order to ensure transparency, the evaluation and decision on a proposal is most likely going to be a deterministic process defined by preset rules. This leaves the board member with the power to set the rules. As previously argued, the CBA should be the main criterion for investment decisions; thus a first rule should require parties to include detailed CBAs in their proposals. A second rule should determine a generic framework for using CBAs in order to ensure minimal administrative work, comparability and transparency. To set the content of this framework one has to understand the main drivers of CBAs. Many previous authors have shown that, over a long time period, CBAs are most sensitive to a change in the discount rate (r) (e.g. Weitzman, 2007; Dasgupta 2007; Nordhaus, 2007).

Figure 2 shows the impact of different discount rates on future cash flows. In $t = 1$, \$100 are worth exactly \$100; while a cash flow of \$100, will at $t = 10$ have a current value of only \$57 to \$0.2, depending on the discount rate. The higher the discount rate, the more the value of money depreciates from period to period. It is important to note that even at the discount rate of 1% a cash flow at $t = 30$ is only worth 1% compared to its current value. In the context of climate change mitigation or adaptation problems this poses the issue that benefits that will arise in the far future only have a marginal impact on the overall evaluation of the project. Therefore, this essay argues that one of the most important set of rules the GCFund has to define is the choice of an appropriate discount rate.

This introduction was aimed at familiarizing the reader with three concepts (1) it described a new policy challenge, namely the efficient distribution of investments from the GCFund; (2) it introduced the reader to the dominant concept of project appraisal in welfare economics, CBA; (3) it argued that the discount rate is the main driver for the outcome of any long-term CBA and therefore should receive adequate attention when designing the funding rules. The

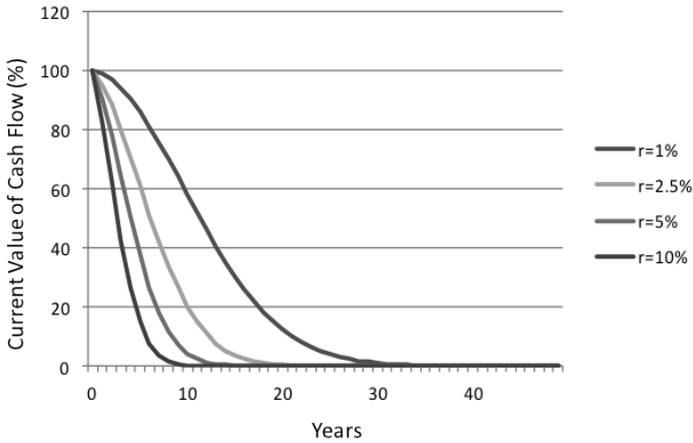


Figure 2: Current value of a discounted cash flow for four different discount rates (r)

essay continues with a discourse analysis on discount rates in a climate change context. Equipped with this knowledge two arguments will be discussed on the issue of global versus regional discount rates. The essay will be concluded by relating the discussion back to possible implications for the GCFund.

Discourse Analysis Discount Rates in Climate Change Economics

The idea that future goods are worth less than current goods and should therefore be discounted goes back to Menger (1871) an influential member of the Austrian School of Economics. In this essay the discussion will be limited to discounting in the context of climate change economics. The dominant discourse during the last thirty years is rooted in a paper by Ramsey: A Mathematical Theory of Savings (1928). Ramsey proved that based on welfare economic theory the discount rate should be determined by Equation 2:

$$r = \delta + \eta \times g(c) \quad (2)$$

This equation underlies the notion of a single planner or society with an infinite lifetime attempting to maximise the level of consumption over a long time horizon (Ramsey, 1928). We learn that the discount rate consists of three components. δ (delta) describes the pure time preference. It has often been

described as the impatience of individuals to consume today rather than tomorrow (Nordhaus, 2007).

η (eta) is the elasticity of marginal utility, and $g(c)$ is the long-term growth rate of consumption. The marginal utility is the first derivative of the utility function. The utility function shows the utility one receives from a certain level of consumption. The elasticity of marginal utility indicates how responsive the marginal utility function is to a marginal change in consumption. The more responsive the marginal utility is to a marginal change in consumption, the more weight the growth rate of consumption has on the discount rate. For example if the economy grows steadily at 3% p.a. the next generation (thirty years in the future) will be almost two and a half times as rich as the current generation.² Let us assume that this translates one to one in a higher level of consumption. As long as the elasticity of marginal utility is bigger than zero, the future generation gains utility from this increase in consumption. If society assumes that it will be richer in the future and receive more utility from this, it is less likely to accept a decrease in consumption today to avoid a decrease in consumption for the more rich generation tomorrow.

The dominant discourse will be divided into three periods: (1) pre 2006, where the discourse on discount rates was simply a byproduct of the general discourse around the early integrated assessment models (IAM). (2) The post Stern period from 2006 onwards, as discount rates became the focal point of discussions. (3) From 2010 onwards, an increasing number of economists move away from Ramsey's traditional infinitely-lived agent model towards new approaches.

Throughout period (1) and (2) there is a strong consensus that δ and η in Equation 2 are ethical parameters, meaning that any decision on those values implies ethical stances on consumer preferences and intergenerational justice (Ramsey, 1928; Stern, 2006; Nordhaus, 2007; Weitzman, 2007; Dasgupta, 2007). Therefore, most of the discussions are based around these two parameters while the question about the adequate growth rate of consumption has attracted less attention. Table 1 summarises the chosen variables of the most influential authors over all three periods. Period (1) has been dominated by the first assessments of economics impact of climate change by Cline (1992) and Nordhaus's DICE model (1992). Cline (1992) chose relatively low values; thereby following the original reasoning of Ramsey who wrote that discounting the well-being of future generations "*is ethically indefensible and arises merely from the weakness of the imagination*" (Ramsey, 1928:261). In his original paper on the DICE model,

² $(1 + 0.03)^{30} = 2.428$

Nordhaus (1992) disagreed with this position, arguing that the discount rate ought to reflect observed behaviour in the market.

Publication	Delta (δ)	Eta (η)	Consumption growth (g(C))	Scope
Cline (1992)	3%	1	1.5%	Global
Nordhaus (1992) - DICE	3%	1	2-3%	Global
Norhaus (1996) - RICE	3%	1	Varying	Regional
Stern (2006)	0.1%	1	1.3%	Global
Weitzman (2007)	2%	2	2%	Global
Dasgupta (2007)	< 2%	2-4	Not specified	Global

Table 1: Variables and scope chosen by influential climate economists; source: compiled by author.

Although these disagreements arose early on it took the publication of the Stern Review (Stern, 2006) to move the discount rate into the focus of the discourse. Stern (2006) stipulated that δ should be close to zero, following the reasoning on intergenerational justice by Cline (1992) and Ramsey (1928). Using these parameters the Stern review estimates the social cost of emissions to be \$350 per ton of C (Stern, 2006). This triggered a new wave in the discourse as the result is approximately ten times the price Nordhaus's DICE model predicts (Nordhaus, 2007). In his review of the Stern review, Nordhaus showed that the main difference between the two estimates is not the model but merely the difference between a 5.5% and a 1.4% discount rate.

In hindsight, the dominant academics during period (2) can be divided into two camps, namely supporters of the positive and the normative approach. Supporters of the positive approach, such as Nordhaus and Weitzman, make three basic arguments. (a) δ (delta) and η (eta) must be rooted in observed consumer choice and therefore in market rates. (b) The authors argue that Stern's normatively chosen parameters of δ and η lead to unrealistic high saving rates and low real return rates when applied to standard economic welfare models (Dasgupta, 2007; Nordhaus, 2007; Weitzman, 2007). (c) Further it is stipulated that intergenerational justice is not obtained by an artificially low discount rate, as future generations are likely to be richer and therefore better able to cope with the impact. One could argue that this is based upon an interpretation of Rawls' Theory of Justice (1971):

“Social and economic inequalities are to be arranged so that they are to be of the greatest benefit of the least-advantaged members of society,[...].” (Rawls, 1971, p.302)

In this case the “least-advantaged members of society” are the current generation, based on the notion that consumption will continue to grow.

Supporters of the normative approach, such as Cline and Stern, have argued that one should value damage and benefits of future generations as equal as possible to the current generations. Furthermore, they point out that the current market rates are inadequate for climate change CBAs as they do not account for GHG externalities (Traeger, 2012). Analysing their ethical stance, Hepburn (2007) argues that it is a narrow view on intergenerational justice which disregards other philosophical schools such as Hume’s agent-relative ethics. The disagreements between the two camps have not been resolved; however, in the last couple of years a third phase of the discourse seems to be emerging. Traeger (2012) argues that the infinitely-lived agent model of Ramsey is “*not able to disentangle a social planner’s discounting of future generations from an individual’s discounting of his own future*”. Therefore, they suggest an overlapping generation approach.

This essay does not aim at deriving a novel approach for discounting in climate change economics, it rather intends to draw attention to the fact that the vast majority of the discourse focuses on a global discount rate. This is also reflected in the calibration of most integrated assessment models (Tol, 1998). As Table 1 shows, Nordhaus RICE model (1996) assumes regional discount rates. This paper is the great exception, but even here one neither finds the exact values for the regional differences nor a detailed discussion on why there should be differences. This phenomenon can partially be explained by the fact that economists commonly base their theoretical arguments on the assumption of perfectly integrated capital markets. While this simplification is useful to test and derive theories it is not necessarily adequate to guide policy on an issue such as efficient allocation of funds among regions where markets are not perfectly integrated. Therefore, this essay will analyse the argument of how regional discount rates can lead to a more realistic representation of the actual costs and benefits. The discussion focus on the Ramsey equation rather than on a more novel approach which is based on the notion that policy makers are risk averse and thus likely to apply the most established method.

Regional differences in discount rates

When regional long-term growth rates of consumption are taken into account, the Ramsey equation will yield significantly differing regional discount rates. This argument is only valid under two conditions: (a) the discount rate is sensitive to the growth rate of consumption (b) the long-term growth rate of consumption $g(C)$ can significantly differ between regions. (a) Equation 2 shows that as long as η is > 0 the rate is sensitive to $g(C)$. Moreover, the higher η and the lower δ , the more sensitive the rate is to a change in the growth rate of consumption. (b) For the second condition there are two questions that need to be considered. (1) Are there significant regional differences in growth rates? (2) If so, are these likely to be sustained in the long-term?

Growth Quartile	Average GDP Growth per year and Capita 2010-17 (PPP)
Lowest	-3.74%
1st Quartile	3.09%
2nd Quartile	4.30%
3rd Quartile	5.78%
Highest	15.73%

Table 2: Average GDP growth of 183 countries; source: calculated by author based on IMF data (2012).

The most recent World Economic Outlook report (IMF, 2012) provides evidence that growth rates, measured as an average change in GDP per capita over seven years, vary significantly between countries, ranging from -3.74% to 15.73% with a median of 4.30%. It is notable that the majority of nations in the second and third quartile are developing or emerging countries (IMF, 2012). On the other hand half of the fifteen nations with an average growth rate below 2% are developing as well, while the rest are European states troubled by the sovereign debt crisis. Just based on this data, the majority of developing countries would have to apply higher discount rates than developed countries. Although the data shows an estimated average over seven years, it does not provide an insight into the development of growth rates over decades or even centuries.

Assuming that over such time periods markets further integrate, reducing inequality gaps and smoothing differences in growth rate, one has to ask what other factors might account for varying growth rates? From Mendelsohn (2006) we learn that climate change itself may be responsible for long-term regional

differences in economic growth rates. The authors compared the economic impact of climate change on different regions of the world. He found a highly unequal distribution of climate change damages with the absolute and relative majority of the damage taking place in developing countries. Mendelsohn's analysis provides reasonable ground to argue that even if markets integrate over time, the significantly unequally distributed long-term impact of climate change damage can result in varying regional growth rates.

		<i>Impacts by climate predictions</i>					
		PCM		CCSR		CGCMI	
Income Group		Cross Section	Experimental	Cross Section	Experimental	Cross Section	Experimental
Poorest Quartile	Impact	-1.2	-8.0	-4.8	-69.4	-6.9	-140.7
	%GDP	-0.2	-1.4	-0.8	-11.8	-1.2	-23.8
Second Quartile	Impact	4.5	19.7	-5.6	-30.2	-9.5	-92.0
	%GDP	-0.4	1.6	-0.5	-2.4	-0.8	-7.4
Third Quartile	Impact	21.8	56.6	-0.7	-7.1	-4.5	-64.1
	%GDP	0.8	2.1	0.0	0.3	0.2	2.4
Richest Quartile	Impact	38.8	148.7	-11.7	13.2	1.8	23.5
	%GDP	0.2	0.9	-0.1	0.1	0.0	0.1

Table 3: Market impacts in 2100 by income (Billions USD/yr); source: Mendelsohn, 2006. "Cross section" and "experimental" refer to two different methodologies. Cross section values are based on observed data from different regions around the world. Experimental values are based on controlled experiments, which isolate the effect but often fail to account for adaptation measures.

This finding implies lower discount rates for developing countries, which stands in contrast to the short-term data. One interpretation is that there are two other offsetting effects. On the one hand, developing and emerging economies show higher growth rates than developed economies; on the other hand, they will suffer higher impact from climate change. Given this effect, one would find three groups: (1) additional economic growth outweighs climate change damage; (2) additional growth is equal to climate change damage; (3) additional growth is less than climate change impact. The Ramsey equation yields higher than global average discount rates for the first group, approximately average for the second and below average discount rates for nations in the third group.

Interesting cases arise at the peripheries. For example, a nation that faces climate change impact severe enough to result in a long-term shrinking of $g(C)$

would yield a negative discount rate (depending on δ), implying that more money should be spent today to avoid a lesser amount of future climate damage. This could be the case for certain island states that are threatened by rising sea levels. While those cases are debatable, in general this approach makes economic sense for the distribution of funds, such as the GCFund, as these discount rates reduce the likelihood of funds being allocated to nations that in the future will possess the economic ability to cope with the impact themselves.

While a detailed analysis of the magnitude of each effect is outside of the scope of this paper, Table 4 provides an overview of the possible spread in discount rates, based on estimated climate impact and growth rates. Mendelsohn's (2006) analysis has been used to estimate the climate change impact. The medium and high impact scenarios represent the arithmetic average of Mendelsohn's medium and high impact scenarios, respectively.³ The discount rate has been calculated based on the Ramsey equation, assuming η and δ are set to 2 as discussed previously.

Discount rate based on Ramsey Equation			
	<i>Climate Change Impact (% of GDP)</i>		
GDP growth per year	No impact (0%)	Medium impact (-0.7%)	High impact (-2.5%)
Low growth (1%)	4	2.6	-1.1
Medium growth (3%)	8	6.6	2.9
High growth (5%)	12	10.6	6.9

Table 4: Discount rate based on Ramsey equation under different growth rates (η and δ are 2 for all cases); source: calculated by author

This rather simplified analysis offers some insight into the possible magnitude of the effect, with discount rates ranging from -1.1% to 12%. It is interesting to note that under these assumptions a medium growth, medium impact country (potentially the EU) should apply a lower discount rate than a high growth, high impact country (e.g. Brazil). This shows how important the long-term growth rate is. This section has argued that there are arguments supporting the notion of varying long-term growth rates. In addition it showed the significance of this effect on the discount rate.

The arguments provided some evidence that, based on the dominant paradigm, significant differences in regional discount rates do exist. It is important to notice

³The highest and lowest of the six scenarios has been treated as outliers and thus been excluded from the average.

that this does not imply that using global discount rates is wrong, it merely means that using regional discount rates may result in a more realistic representation of costs and benefits and therefore in a more efficient allocation of funds.

Based on the previous discussion three main questions arise: (1) how relevant are the findings in the context of the GCFund; (2) how can regional discount rates be implemented in this context; (3) what are the main omissions the reader should keep in mind when interpreting the arguments?

1. As previously argued, if regional differences exist, allocation of funds would be more efficient if they are taken into account. To implement the approach discussed above, one would have to estimate long-term growth rates for each nation. This could either be done by a central agency or by the countries themselves. The decentralized approach potentially leads to a higher level of support as nations are self-responsible. However, each nation has an incentive to underestimate their long-term growth rate as this yields a lower discount rate. Yet such an underestimation would be punished by the market if it stands in contrast to the expectations of international investors. Such a feedback loop would function as a self-monitoring system by creating a disincentive for unrealistic estimates.
2. As previously assumed, the GCFund has the power to create the rules under which nations will have to apply for funds. As a first step, in order to implement the bottom-up approach, the board should require nations to base their discount rate calculations on the Ramsey function. The second condition is that all nations use the same values for η and δ to avoid tweaking the rate by different assumptions of time preference or marginal utility functions. Finally, nations will have to make estimates for their long-term growth rates. The rationale for those estimates should be publicly available to increase the efficiency of the previously described self-monitoring system. A great advantage of this approach is that, if correctly designed, it requires relatively little additional information and therefore keeps extra costs at a minimum.
3. Due to space constraints and the complexity of this issue, this essay had to make certain omissions. In the author's opinion the following four issues should be explicitly mentioned to allow proper interpretation of the results and encourage further research:
 - (a) There are more factors than pure economic reasoning that will drive the allocation of funds like the GCFund. Some of them are:

equal and fair distribution of funds, considerations of human rights, incentivising democratic processes, level of corruption etc. Those should certainly be taken into consideration.

- (b) This essay does not explicitly enter the discussion of regionally varying δ and η . The dominant economic theory suggests that poorer countries generally have a higher value for time preference; however recent studies have shown that empirical evidence is suggesting rather the opposite (Moseley, 2001). This field requires further research.
- (c) This essay did not discuss the cultural dependency of discount rates. As mentioned in the first argument, a normative approach to regional discount rates would require an in-depth analysis of the individual cultural context. The method of discounting itself is a man-made construct which is only valid in certain socio-economic system. This becomes evident when comparing the current western socio-economic system with other systems. For example the medieval European church did not allow the taking of interest, based on the Bible (Book of Deuteronomy, 23, 20-21). Even nowadays, in the Islamic world taking interest is considered against Shariah law. Jobst (2007) argues that discounting is often considered as interest taking and therefore is not common place in the Islamic world. This cultural dependency of discounting is an additional challenge when attempting to design an international framework. However it is questionable if this would have an impact on the GCFund, as all donor countries are part of the western socio-economic system.
- (d) This essay does not differentiate between adaptation and mitigation projects, although it is quite intuitive that these issues should be dealt with separately. For example adaptation projects protect against local damage while mitigation projects yield global benefits. Thus, one could argue that global discount rates should be used for mitigation projects. However, this argument would require more detailed analysis.

Taking those additional issues into consideration, it might be difficult to imagine how significantly a decision will actually be influenced by the pure economic reasoning presented in this essay. In this context it is important to keep in mind that it is still better to get it half right than exactly wrong. Regional discount rates can definitely provide an improvement to current models; therefore they should be a part of the discussion for allocating international funds such as the GCFund.

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Artificial Photosynthesis: Creating Fuel from Sunlight

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There is an urgent need to secure an energy source that is both renewable and clean. Solar energy can potentially satisfy all of our energy needs, but current solar cell technologies face the problem of electricity storage. An alternative is to use solar energy to create fuel directly by mimicking nature's photosynthesis. Our main target is the water-splitting reaction, producing hydrogen and oxygen in a clean process involving only water, sunlight, and materials called photocatalysts. This article covers the principles of artificial photosynthesis on semiconductor photocatalysts, various research directions, and the outlook of the field.

Every time you eat a piece of bread, you are in essence consuming a form of captured sunlight. The carbohydrates in the bread are the products of photosynthesis: a wonderful process by which plants create fuel from carbon dioxide, water and sunlight. Each year, plants and algae create more than 100 billion tons of carbohydrates, a process comparable to the production of more than the weight of an aircraft carrier every minute.

Can we create fuel from sunlight as well? And why should we?

Introduction

Civilization has always been reliant on energy. From wood-burning in ancient times to modern nuclear generators, these sources of energy fulfill our needs for warmth, transport, technology and much more. At present, 81% of our energy demands are satisfied by fossil fuels, i.e. coal, gas and oil.^[1] This practice is

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unsustainable for two reasons: the limited amount of available fossil fuels and the global warming resulting from burning these fuels. Given the amount of proven reserves and rate of annual consumption, fossil fuels are expected to run out in 40 to 120 years.^[2] (Although if new reserves are taken into account, coal may last for several centuries more.) Combustion of fossil fuels produces carbon dioxide which contributes to the greenhouse effect, trapping heat within the atmosphere and raising the average global temperature.^[3] These reasons compel us to find new sources of energy that are both renewable and clean.

Solar energy is an attractive candidate. An oft-cited statistic is that the energy in sunlight that reaches the earth in one hour is roughly the same as the global energy demand in one year.^[4] But sunlight in its original form is not very useful for modern civilization, which is why we need solar energy conversion technologies.

Solar energy conversion and storage

A well-developed technology already exists: solar cells. The latest panels have reached 15 - 25% solar-to-electricity conversion efficiency.^[5] However, solar cells alone cannot satisfy all our energy requirements, because sunlight is intermittent. Energy production is impossible at night, and during daytime the amount of sunlight we receive is out of our control. We therefore need energy storage as well as energy production.

There are many ways to store electricity. A convenient method is to use batteries, which is therefore one of the most active research fields at the moment. Unfortunately, batteries have low energy density, i.e. they can only store a limited amount of energy per kilogram. Another method is to store electricity in the form of mechanical energy. This is used in hydroelectric power plants. During night time when electricity usage is lower, excess electricity is used to power pumps to move water uphill, so it can be discharged later to generate electricity when needed. This process is not suitable for short-cycle operations and only viable for large-scale, stationary systems.^[4]

An attractive solution is to create fuels, whether it be in gaseous or liquid form. The advantage of fuels is their high energy density compared to other storage methods. The energy densities of liquid fuels (ca.50 MJ/kg) and hydrogen (140 MJ/kg) dwarf those of batteries (0.1 - 0.5 MJ/kg) by a hundred times or more.^[4] Currently, we mostly generate hydrogen from natural gas in the steam reforming process, which produces carbon dioxide as an undesired product. This process must be replaced by one that is clean and does not rely on fossil fuels and this is where artificial photosynthesis comes in.

Artificial photosynthesis using semiconductors

In my research, I am interested in water splitting, the simplest fuel generating process. Using solar energy, water (H_2O) can be split into hydrogen (H_2) and oxygen (O_2) gases. Hydrogen can then be used as fuel in fuel cells, and also as chemical feedstock for industrial chemicals such as ammonia. Since water is transparent to a large part of sunlight, water by itself cannot absorb and utilize the necessary energy for the reaction. Some other material is required to absorb light and use its energy to power the water-splitting reaction.

My work is focused on a branch of solar fuel production that uses semiconductor particles suspended in water. This process is also called *photocatalytic water splitting*. Catalysts are materials that promote a specific reaction without themselves being consumed, and photocatalysts are catalysts that are driven by light. In recent review articles,^[6, 7] more than 400 materials and combinations of materials have been reported as photocatalysts for water splitting. The following paragraphs describe how the water splitting reaction occurs on a semiconductor.

One way to look at the water splitting process is to see it as a combination of the light-harvesting step (by the semiconductor) and the chemical reaction step (on surface active sites). In the initial step, sunlight must be absorbed by the semiconductor and converted into *electrons* and *holes* that are necessary for hydrogen and oxygen production.

Electrons in materials can exist only at certain energy levels. Try to picture a vertical stack of shelves, with a box on each shelf. You have a certain number of marbles (here, representing electrons) on hand, and you have to fill in the boxes, starting from the bottom. The vertical position of the box signifies its energy; marbles in higher boxes have more energy. Sometimes, you run out of marbles in the middle of a box, leaving it half-filled. Other times, you finish just as you top up a box, leaving the next one above it completely empty.

For most of the time, we are interested in the topmost box with the marbles. Materials with a half-filled top box are called metals, which have the important property of electrical conduction. This means that marbles in the top box can move around within the box quite easily. Semiconductors, on the other hand, have an empty top box with a completely filled box below. The ‘technical terms’ are the *conduction band* (the top box), *valence band* (the box below the top box) and *band gap* (the energy difference between them). Insulators are similar to semiconductors, but they have a much larger band gap. Figure 1 (a) shows the band structures as described above.

Electrons in the filled valence band cannot move around, but they can jump up into the conduction band by absorbing energy, as shown in Figure 1 (b). This

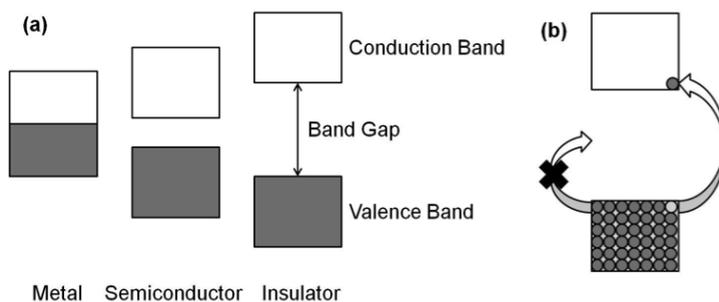


Figure 1: (a) Electronic band structures of metals, semiconductors and insulators. Shaded areas (bands) are filled (partially or completely) with electrons, while white areas are empty. (b) Electron excitation from the valence band to the conduction band

process is called *excitation* (i.e. excited electrons have more energy). Since electrons can exist in the bands but not in the band gap in between, the size of the band gap governs the light energy that the semiconductor can absorb. The incoming light must have energy at least as large as the band gap in order to propel an electron across the gap.

Once an electron is excited into the conduction band, a hole is left behind where it used to be. In many cases it is convenient to think of the hole as another particle, with exactly the opposite charge of an electron. These photo-generated electrons and holes must migrate from inside the bulk to the surface of the semiconductor particle where they can cause reactions.

In the hydrogen production reaction, protons (H^+) react with electrons (e^-), turning into H_2 . There must be a specific place for the protons (supplied by water) and electrons (supplied by the semiconductor) to meet each other. Such places on the semiconductor surface are called *active sites*. First, the proton must become attached to an active site on the surface of the semiconductor and receive an electron, thus becoming a hydrogen atom (H). This process is called *adsorption*. Then the H atom can react with another similarly adsorbed H to form H_2 . The process is shown in Figure 2.

To help this process, another material can be loaded onto the semiconductor to act as a catalyst, providing “anchoring” sites for the H atoms and thus accelerating the reaction rate. Noble metals such as platinum and rhodium work well in this role, due to an interesting property: they adsorb H *moderately* well. Most semiconductors adsorb H poorly, so not enough H is on the surface to

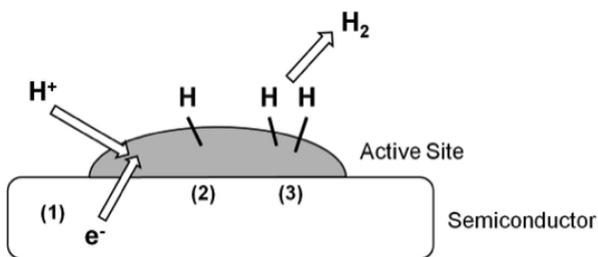


Figure 2: Steps involved in the hydrogen production reaction: (1) A proton receives an electron from the semiconductor. (2) The proton becomes adsorbed onto the active site as an H atom. (3) Two adsorbed H atoms combine to produce hydrogen gas (H_2).

produce the desired H_2 . On the other hand, some metals like molybdenum adsorb H too strongly, and H refuses to leave the surface as H_2 . The effectiveness of adsorption in moderation has been generalized as Sabatier's principle, which states that the optimum attachment of a material to a surface must be strong enough for the reaction to start, but weak enough for the products to be released.

The oxygen production reaction is similar, but it involves electrons going in the opposite direction. Water (H_2O) is adsorbed onto the semiconductor surface, then it releases electrons which are taken up by holes from the semiconductor. H_2O is gradually broken down to an oxygen atom (O), which then combines with another adsorbed O or an O from another H_2O molecule to form oxygen gas (O_2). The total photocatalytic water splitting process is summarized in Figure 3.

To reiterate the water splitting process explained above, three steps are required for the reaction to proceed:

1. Light absorption and electron-hole creation
2. Electron-hole migration to the surface
3. Reaction at surface active sites

Improvements can be made at each step to increase the photocatalytic activity, and I will describe some examples in the following sections.

Visible light absorption

The sunlight that reaches the Earth's surface has a large range of wavelengths. The wavelength is a property of light which indicates its energy. Light with a long wavelength has lower energy, and light with a short wavelength has higher energy.

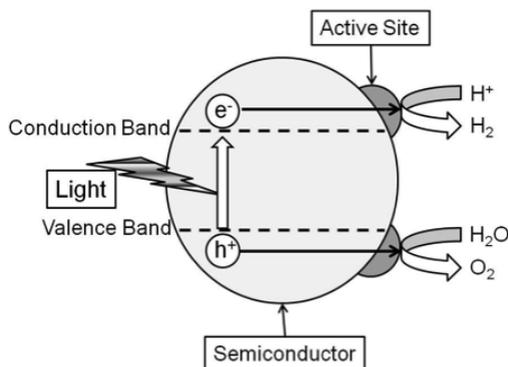


Figure 3: Water splitting reaction on a semiconductor particle under light irradiation (h^+ represents a hole, e^- an electron)

Looking at the intensity of the spectrum of solar energy that reaches the Earth's surface, we can see that a small part lies within 300 - 400 nm (UV region), rises to a peak between 400 - 800 nm (visible region), and gradually decreases upwards of 800 nm (infrared region).

The band gap energy of semiconductors is one of their most important properties, because a semiconductor can only absorb light with energy equal to or larger than its band gap. Since sunlight comes with a wide range of energies, a smaller band gap would lead to absorbing a larger portion of sunlight. However, there is also a lower limit, as the water splitting reaction requires a certain minimum amount of energy input. Theoretically, sunlight from 300 - 1000 nm is usable for water splitting.

Most compounds studied so far as prospective photocatalysts are oxides, with titanium dioxide (TiO_2) being the most frequently used material since the first report in 1972.^[8] The advantages of oxides are their stability and straightforward synthesis. However, their band gaps are quite large, which means they can only absorb UV light. Since UV light comprises only 4% of the whole solar spectrum, we need materials with smaller band gaps in order to utilize a larger part of solar energy.

In my previous work with Professor Kazunari Domen's group at the University of Tokyo, I synthesized a group of compounds called niobium oxynitrides, specifically $CaNbO_2N$ and $SrNbO_2N$.^[9] Oxynitrides are synthesized by introducing nitrogen atoms into an oxide, usually by putting an oxide into a flow

of ammonia at high temperature. This synthesis process is called nitridation or ammonolysis. For example, $\text{Ca}_2\text{Nb}_2\text{O}_7$ (an oxide precursor material) is converted to CaNbO_2N (the desired oxynitride material) under ammonia at $750\text{ }^\circ\text{C}$. The presence of nitrogen decreases the band gap, thus increasing the absorption limit from 300 nm (in $\text{Ca}_2\text{Nb}_2\text{O}_7$) to 600 nm (in CaNbO_2N), well into the visible region. This corresponds to absorption of 31% of the solar spectrum, a substantial increase compared to oxide materials. The band gap change is noticeable to the naked eye, as the sample changes color from white (i.e. no visible light absorption) to yellow-brown after nitridation.

CaNbO_2N is just one member of a growing library of materials that absorb visible light. The Domen group has contributed more than a dozen materials, mostly oxynitrides and oxysulfides.^[10] Most recently, a $\text{BaZrO}_3/\text{BaTaO}_2\text{N}$ solid solution^[11] has been reported to work with light up to 660 nm , a new record for visible light absorbing photocatalysts.

Reducing the recombination rate

This section deals with an undesirable process at step 2 in the water splitting process, namely electron-hole migration to the surface. Instead of moving separately to the surface, some of the generated electrons and holes recombine before they can reach the surface. When electrons and holes recombine, they cancel each other out and lead to no reaction. Obviously, this pathway results in a loss of usable electrons, and controlling the semiconductor particle's size and shape can help mitigate this problem. Smaller particles mean that the electrons and holes have a shorter distance to travel to reach the surface. This would make a surface reaction more likely and recombination less likely. In addition, special particle shapes that help separate the hydrogen production (electron consuming) and oxygen production (hole consuming) reactions would also lessen recombination.

There is a well-known example in the literature. The material NaTaO_3 , when mixed with a small amount of lanthanum (La), has almost 10 times the water-splitting activity of the pure material.^[12] The addition of a small foreign component is called doping. Upon observation with an electron microscope, it was found that La-doping created a smaller particle as well as nano-sized steps on the particle surface. H_2 -production was occurring on the tips of the steps, while O_2 -production was occurring at the valleys. This separation of reaction areas led to a lower electron-hole recombination rate and consequently higher activity.

The presence of impurities in the semiconductor can also lower the activity because the impurity can act as a recombination site for electrons and holes. I

focused on decreasing the impurities in a specific material, CaNbO_2N , in my bachelor degree's thesis.^[9] I synthesized CaNbO_2N by nitridation under different temperatures, from 700 - 950 °C. At temperatures lower than 750 °C, the desired material (CaNbO_2N) was not fully formed, and the resulting material was barely active under visible light irradiation. The activity reached a peak for the sample obtained at 750 °C then decreased with the increasing nitridation temperature. Analysis of the material showed increasing impurity levels with higher synthesis temperature. The conclusion is that the synthesis temperature has to be in the "sweet spot" to strike a balance for production of the desired material to complete, but before impurity production begins.

Semiconductor-enzyme composites

Here in Oxford, in Professor Armstrong's group in the Inorganic Chemistry Laboratory, I am working on modifying the surface of semiconductors (step 3 in the above explanation) with enzymes.^[13] Enzymes are nature's excellent catalysts, exquisitely tailored for its own specific reaction. For example, many bacteria possess a class of enzymes called hydrogenases which promote the production and consumption of hydrogen. By attaching such enzymes to the semiconductor surface, I aim to use them as active sites to produce hydrogen.

The advantages of using enzymes are their specificity and high activity. However, this comes with the disadvantage of the large molecule size (compared to nanometer-scaled noble metals). Moreover, the effort required in purifying large amounts of enzymes precludes their use in large scale applications. The usage of enzymes is expected to yield insights about the mechanism of the reaction, leading to design of new active sites.

A previous member of the group has published a report on a hydrogenase- TiO_2 system.^[14] Since TiO_2 only absorbs UV light, a photosensitizer (a ruthenium trisbipyridyl complex) was also attached to TiO_2 to create visible light absorption. The resulting three-component system (photosensitizer-semiconductor-enzyme) was shown to function under visible light. My current research is focused on replacing TiO_2 with semiconductors that can absorb longer wavelengths, thereby eliminating the need for a photosensitizer and simplifying the system to two components. I also plan to explore the interaction between the semiconductor and the enzyme, and improve the electron transfer between them.

Current state and outlook of the field

Since work started in this field 40 years ago, artificial photosynthesis has made steady progress. We have shown that it is indeed possible to emulate nature and produce fuel from sunlight. But is the process efficient enough for us to make the leap from the laboratory scale to the industrialized production scale? Unfortunately, the answer is “not yet”. For the process to be viable on a large scale, it will have to meet the tentative goal of 10% solar-to-fuel efficiency.^[10]

Our benchmarks have yet to reach that level of efficiency. For example, a recent compound (ZrO₂-TaON/WO₃ tandem system) was reported by the Domen group with the limit of light absorption at 500 nm, leading to approximately 1% solar-to-fuel efficiency under sunlight.^[15] Using earth-abundant materials (silicon, cobalt, phosphorus), the Nocera group at MIT reported the construction of an “artificial leaf”, with 3 - 5% efficiency.^[16]

Efficiency is not the only concern, as large scale implementation also requires us to consider the lifetime and cost of the materials. Most photocatalysts are tested for their activity over a 5-hour period, and “long-term” operation often means a testing period between a few days and a week. The longest reported testing time is 6 months, with the activity dropping to half that of the fresh material.^[17] This result is exceptional compared to the rest of the field, but even this is not enough. Many solar cell manufacturers guarantee their efficiency for 10 years or more, and solar fuel materials have to match this scale in the long term. Moreover, many of the best-performing materials still rely on rare metals, such as gallium, indium, ruthenium and rhodium. Platinum is also a popular choice, as it acts as an excellent hydrogen production co-catalyst. Replacement of these rare metals with cheaper materials is one of the imperatives of solar fuel research.

Although we have not reached our goal, it is within sight. With the discovery of novel materials, larger absorption of the solar spectrum and new surface modifications, I hope that artificial photosynthesis will become a realistic energy production route over the next 40 years.

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