UNIVERSITÉ DU QUÉBEC À RIMOUSKI

RENEWABLE NORTH: POLICY CONSIDERATIONS FOR WIND-DIESEL SYSTEMS IN REMOTE CANADA

LE NORD RENOUVELABLE : CONSIDÉRATIONS POLITIQUES POUR LES SYSTÈMES ÉOLIEN-DIESEL DANS LES SITES ISOLÉS AU CANADA

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SOMMAIRE

Les systèmes hybrides éolien-diesel représentent une solution pour réduire la dépendance des combustibles fossiles dans les réseaux électriques des communautés isolées. Au cours des deux dernières décennies, il y a eu un taux d'installation accéléré des éoliennes de grande taille, sous forme de grands parcs connectés aux systèmes électriques provinciaux ou nationaux. Les coûts pour ces grandes éoliennes ont diminué jusqu'au point où ils commencent à être comparables aux technologies traditionnelles de génération de l'électricité. Le marché pour les éoliennes à grande échelle a dépassé considérablement celui des éoliennes de taille moyenne – la taille appropriée pour la plupart des communautés isolées au Canada qui peuvent être les candidates pour l'implantation des systèmes éolien-diesel. Toutefois, l'éloignement de ces communautés, l'emplacement de certaines d'entre eux dans des zones moins venteuses, les hauteurs limitées des tours d'éoliennes à cause de l'absence d'équipements de levage adéquats, les coûts de transport très élevées et les difficultés associées aves l'opération et la maintenance conduisent à des frais plus élevés pour l'électricité produite par les éoliennes en régions isolées. Pour ces raisons, les systèmes hybrides utilisant l'énergie éolienne ont eu des difficultés à concurrencer les systèmes diesel traditionnels, même si les coûts de génération avec diesel peuvent être cinq à dix fois plus élevés que ceux des centrales conventionnelles, connectées au réseau de distribution dans le sud du pays.

Il y a plus de 200 000 canadiens et canadiennes qui vivent dans environ 300 communautés isolées, qui ne sont pas connectées aux réseaux électriques provinciaux ou territoriaux (Ah-You et Leng, 1999). Beaucoup d'entre eux utilisent les générateurs électriques diesel pour leur alimentation en électricité. Les frais de carburant diesel, la dégradation de la qualité de l'air, les risques de déversement de carburant et la problématique du développement durable sont souvent cités comme motifs pour ces communautés à rechercher des solutions alternatives. Entre-temps, les compagnies ou gouvernements qui sont responsables à fournir l'électricité pour ces communautés opèrent avec un déficit (Reid et Laflamme, 1995) ou font passer le coût élevé de production à leurs clients, ou une combinaison des deux (Pinard et Weis, 2003). Il n'y a pas beaucoup d'alternatives pour la plupart de ces communautés à cause du fait que les coûts prohibitifs peuvent limiter rapidement l'étendue du réseau de transport d'électricité qui peut être construit pour récolter une ressource renouvelable locale si il y en a. Ainsi, les communautés dans l'extrême Nord ont un accès limité à nombreuses ressources renouvelables comme l'énergie solaire, la biomasse ou même celles à un stade expérimental comme les technologies hydroliennes qui utilisent les vagues ou les marées.

L'option d'utiliser les éoliennes a été perçue comme une alternative viable dans ces communautés pour quelques décennies ; en fait, le premier projet de recherche éolien-diesel a commencé au Canada en 1978 (Chappell, 1986). Il y a eu plus de dix projets de démonstration du jumelage éolien-diesel au Canada essayés par les compagnies électriques ou les gouvernements depuis ce temps. Aussi, quelques entreprises commerciales ou des producteurs indépendants d'énergie ont négocié l'opportunité de vendre l'énergie générée par les éoliennes aux compagnies électriques qui servent les communautés isolées (Weis et Ilinca, 2007). La plupart de ces projets n'ont pas eu beaucoup de succès. Certains d'entre eux avaient fait face à des problèmes mécaniques qui ont augmenté les coûts d'opération comme fût le cas de Sachs Harbour, dans les territoires du Nord-Ouest et Big Trout Lake, en Ontario. Les budgets initiaux dépassés, ces projets ont été abandonnés. Pour d'autres, comme les projets à Kasabonica Lake, en Ontario, Rankin Inlet, Nunavut et Cambridge Bay, dans les Territoires du Nord-Ouest, le manque de maintenance adéquate a contribué à l'échec après quelques années d'opération. Finalement, les éoliennes à Kugluktuk, dans les Territoires du Nord-Ouest ont subi des accidents non-prévus (frappées par la foudre). Dans tous les cas, ça a été jugé que les économies de carburant diesel n'étaient pas suffisamment importantes pour justifier le reconditionnement ou la réparation des éoliennes après l'essai pilote initial. Alors que les défaillances mécaniques font partie du fonctionnement normal de toute machine tournante, y compris des moteurs diesel, les éoliennes, particulièrement dans les régions isolées, n'ont pas bénéficié de la même disponibilité de composantes pour faire les réparations, ni de techniciens sur place ayant une formation adéquate. En conséquence, vers la fin des années 1990, beaucoup de l'intérêt initial dans les systèmes éolien-diesel avait diminué au Canada au point que, depuis l'an 2000, un seul de ces systèmes a été installé au Canada.

Aujourd'hui, il y a plusieurs projets éolien-diesel qui fonctionnent en Alaska avec beaucoup de succès, ce qui démontre que la technologie éolien-diesel peut fonctionner dans les climats difficiles et les sites isolés (AWEA, 2007). Ces projets réussis ont renouvelé l'intérêt dans les systèmes éolien-diesel au Canada ces dernières années, fait illustré par l'installation, dans plus de dix communautés isolées, des stations météorologiques pour évaluer le potentiel de développement des systèmes d'énergie éolienne. Aussi, le gouvernement des Territoires du Nord-Ouest, a promis de développer un système éolien-diesel durant l'année 2009 (G.T.N, 2007). Ce projet a été retardé de deux ans, mais un projet pilote initié par la Communauté de Tuktoyaktuk était en construction au moment de la rédaction de cette thèse.

Il existe de nombreux obstacles communs à tous les systèmes d'énergies renouvelables, incluant les systèmes éolien-diesel. En même temps, il y a eu certains programmes incitatifs mis en place par les pouvoirs politiques et qui ont été testées pour surmonter ces obstacles, notamment financés soit par l'ensemble des payeurs des taxes ou par les clients bénéficiant de l'énergie électrique ou bien des réglementations politiques qui ne nécessitent pas de financement direct. Les programmes incitatifs pour le développement des projets d'énergie renouvelable peuvent être classés, de façon générale, dans les catégories suivantes: financement du coût en capital, incitatif basé sur la production d'énergie, la formation et l'information technique et l'imposition d'un pourcentage minimum de production par des énergies renouvelables. Une autre option a été d'ajouter un surcoût relié à la pollution aux coûts de l'énergie produite par des diesels. Cependant, une des raisons principales pour développer les systèmes éolien-diesel, celle de réduire les coûts de l'énergie à long terme pour les communautés isolées, n'a jamais été considéré dans l'élaboration de ces programmes. Une synthèse de ces programmes est présentée dans le tableau suivant :

Politiques et programmes gouvernementaux pour supporter les systèmes éolien-diesel (adapté de Bailie, et al., 2007)

Instrument	Source de financement	Exigences de la politique
Incitatifs basés sur le financement des coûts en capital		
Remises ou subventions	Taxe de base ou taux au kW	Établir les technologies qui sont éligibles au programme de subvention
Crédit de taxe foncière ou d'impôt sur le revenu	Taxe de base	Modifications de règles fiscales (crédit limité au taux de taxation)
Remise de la taxe de vente	Taxe de base	Aucun
Support du financement	Taxe de base	Ententes avec les institutions financières
Incitatifs basés sur la production		
Tarif préférentiel d'achat du kWh	Taux au kWh	Règlements impliquant les opérateurs des réseaux

Encouragement de la production	Taxe de base	Établir des critères d'admissibilité
Formation et information		
Planification énergétique communautaire	Taxe de base	Aucun, bien que dans certaines juridictions est rendue une exigence préalable
Formation technique	Taxe de base	Aucun
Obligation de taux d'énergies renouvelables		
Taux d'énergies renouvelables	Taux d'énergies renouvelables	Lois provinciales pour définir les quotas et les règles de négociation
Réduction d'émissions de GES	Taux d'émissions	Législation pour définir les règles du marché

Les programmes de réduction du coût en capital aident les développeurs en fournissant des fonds pour commencer ou financer les projets. Ces programmes sont très intéressants puisque les projets d'énergies renouvelables, tels que les systèmes éolien-diesel, ont tendance d'avoir la plupart de leurs coûts au début du projet, et permettent d'éliminer cette barrière des coûts élevés en capital. Si les subventions sont suffisantes, elles peuvent aider de construire ces projets, bien qu'ils ne garantissent pas nécessairement que les projets fonctionnent à long terme. Les incitatifs à la production essayent également d'améliorer la rentabilité globale, mais en « récompensant » uniquement lorsque l'énergie est produite, pas uniquement à l'étape de l'investissement initial d'un projet. Cela vise à s'assurer que les projets fonctionneront correctement à longue terme, bien qu'ils ne règlent pas le problème des coûts initiaux, très élevés.

Les programmes de formation peuvent aider les projets en améliorant la capacité de la communauté locale à comprendre leurs problèmes en rapport au développement de l'énergie. Ces programmes peuvent être importants dans le processus de planification, de prise de décisions, ainsi qu'aider à long terme pour l'opération et l'entretien des installations, même s'ils ne changent pas les aspects économiques des projets. Enfin, les obligations de taux minimum d'énergies renouvelables dans le portefeuille énergétique sont basées sur des règlements adoptés par le gouvernement et qui requièrent une puissance ou un pourcentage spécifique d'énergie renouvelable dans l'approvisionnement énergétique total. Ces obligations sont souvent jumelées avec des programmes commerciaux pour échanger les crédits entre les compagnies qui ont eu plus ou moins de succès dans l'atteinte des objectifs (mécanisme similaire aux bourses de carbone).

Même si ces politiques peuvent aider à tracer la meilleure route à suivre, les communautés isolées ont certaines caractéristiques uniques et distinctes par rapport au développement énergétique dans les régions plus peuplées et plus facilement accessibles, notamment les frais très élevés de transport, la logistique difficile, les contraintes sur les capacités locales ainsi que des capacités économiques très limitées, non seulement pour les projets eux-mêmes, mais également pour le développement de l'industrie dans son ensemble.

Pour le succès des projets éolien-diesel dans les communautés isolées, il faut identifier les obstacles auxquels font face ces projets et trouver les solutions appropriées autant pour les aspects techniques qu'économiques. Les trois articles qui composent cette recherche discutent de ces trois questions consécutivement. Le premier article, présenté dans le chapitre 2, présente les résultats d'un sondage auprès des acteurs directement concernés par le marché éolien-diesel Canadien en examinant leur perception des principaux obstacles au déploiement des systèmes éolien-diesel. Cet article identifie les coûts en capital et les coûts d'entretien des systèmes comme les principaux obstacles au déploiement, ainsi que les capacités techniques et humaines limitées dans les communautés éloignées. Le deuxième article, présenté dans le chapitre 3, utilise une modélisation informatique originale pour déterminer comment améliorer les aspects économiques des systèmes éolien-diesel par l'ajout de solutions de stockage d'énergie. Le modèle examine les systèmes avec une « haute pénétration » de l'énergie éolienne (possibilité d'arrêt complet des diesels durant les périodes de fortes vitesses de vent) et comment les prix et l'efficacité des solutions de stockage influencent le prix global de l'énergie produite. Le dernier article, qui constitue le chapitre 4, illustre les résultats de l'implantation d'un programme incitatif fédéral pour prendre en charge un large déploiement des systèmes éolien-diesel au Canada. L'ensemble de cette recherche examine ainsi les aspects qui ralentissent le développement des systèmes éolien-diesel au Canada et analyse comment le développement technologique et les programmes incitatifs et politiques peuvent contribuer à surmonter ces obstacles.

Article 1: Obstacles aux systèmes éolien-diesel

Lundsager et al. (2004) a suggéré que l'identification des obstacles aux systèmes éolien-diesel « vise l'élimination de l'impasse selon lequel le marché de l'énergie éolienne dans les sites isolés ne s'est pas développé parce que le produit n'est pas là, et le produit n'est pas développé parce que le marché n'est pas suffisamment important ».

Ainsi, la recherche a commencé avec un examen des barrières et le premier article est intitulée « Opinion des acteurs sur les obstacles au déploiement des systèmes éoliens-diesel dans les sites isolés au Canada » (Energy Policy, Vol 36, numéro 5, Mai 2008, pages 1611-1621). Il caractérise et classifie les obstacles au développement dans les communautés isolées canadiennes selon le point de vue des intervenants qui étaient directement impliqués dans les projets éolien-diesel. Il est important de bien comprendre la perception de ces barrières par le gouvernement (fédéral, provincial et/ou territorial), ainsi que par les compagnies d'électricité puisque ces groupes sont inévitablement impliqués (décisionnels) dans les projets énergétiques des communautés isolées. Les obstacles perçus par ces groupes doivent être abordés de manière à ce que des politiques efficaces puissent être élaborées et implémentées.

L'enquête examine également les perceptions sur les politiques qui pourraient encourager le développement des systèmes éolien-diesel au Canada.

La recherche pour cet article comprend des sondages auprès des nombreux intervenants dans le développement de systèmes éolien-diesel, les manufacturiers, les promoteurs, les chercheurs, les employés du gouvernement et les employés des compagnies électriques. Apres avoir recueilli et catégorisé les différentes perceptions il devient possible de déterminer sur quels aspects il est important de concentrer les décisions et les politiques afin d'encourager une croissance à long terme, au lieu des projets pilotes sporadiques qui, à ce jour, ont été lancés au Canada.

Les coûts en capital et les frais d'entretien des systèmes ont été constamment cités comme les obstacles les plus importants, par toutes les catégories d'intervenants. Compte tenu des prix du carburant diesel économisé actuellement et sans mesures d'incitation pour les systèmes éoliens, ces perceptions sont bien fondées. Il est improbable que les fabricants soient en mesure de réduire les coûts grâce à une meilleure conception et des volumes de vente sans qu'il y ait un nombre important de ces systèmes installé dans les communautés isolées. Cependant, sans incitatif financier, il est peu probable de voir beaucoup de ces projets se réaliser dans le contexte économique actuel.

Même avec les coûts plus élevés de production, il est possible que les compagnies d'électricité soient encore intéressés à investir dans des projets éolien-diesel pour des

raisons telles que la réduction de la variabilité des prix, la réduction des gaz à effet de serre et autres émissions atmosphériques locales ou les économies sur le transport et le stockage de carburant sans oublier la diminution des risques de déversement. Toutefois, l'enquête a souligné que la majorité des répondants de ces compagnies n'a pas confiance dans la maturité technique des systèmes éolien-diesel. Cela aggrave encore l'obstacle des coûts. Il y avait un écart très important par rapport à la majorité des intervenants en dehors des compagnies d'électricité qui croient que les systèmes éolien-diesel sont techniquement matures pour le déploiement dans des sites isolés. Les intervenants reconnaissent le malaise des compagnies d'électricité à propos de la technologie éolienne et ils ont toujours identifié cette attitude comme une des plus importantes barrières en dehors des coûts en capitaux et des frais d'exploitation.

La capacité d'accéder à des équipements appropriés et de la main-d'œuvre qualifiée dans les communautés isolées a été également classée comme un obstacle important par tous les groupes d'intervenants. Beaucoup d'obstacles sont interdépendants, le manque d'accès à l'équipement et la main-d'œuvre localement, augmente significativement les coûts d'exploitation et entretien. Par exemple, si la main-d'œuvre qualifiée doit voyager des grandes distances pour installer ou réparer l'équipement, cela peut limiter la taille et ainsi les performances de l'équipement installé. Certains de ces obstacles sont intrinsèques aux petites communautés isolées et aux petits projets en particulier. Toutefois, si un nombre important de projets devait avoir lieu dans une région donnée, certains des compétences locales et des équipements pourraient être acquis et partagés entre communautés et parmi les projets. Ces impasses génèrent un cercle vicieux, ou la meilleure solution pour surmonter les obstacles à la mise en œuvre des projets est en fait le démarrage et la mise en œuvre des dits projets.

Globalement, la majorité des intervenants estime que les systèmes éolien-diesel sont prêts à être déployés dans les communautés canadiennes isolées, avec la plupart des répondants notant les projets menés avec succès dans d'autres pays et plus particulièrement en Alaska. Toutefois, parmi ces mêmes intervenants qui estimaient que les systèmes éolien-diesel sont technologiquement prêts, il n'y a pas beaucoup de confiance que les projets vont réussir sans incitatifs importants et à long terme.

Les résultats des sondages ont suggéré que les incitatifs financiers étaient susceptibles d'être les plus efficaces pour encourager le déploiement des systèmes éolien-diesel. Les programmes d'appui basés sur la production ont été légèrement favorisés par rapport aux subventions directes pour les coûts en capital. En fait, les deux approches ont été perçues comme des méthodes efficaces par une forte majorité des répondants. La mise en œuvre d'un pourcentage d'énergies renouvelables dans le portefeuille énergétique a été considérée comme la prochaine stratégie le plus acceptable, tandis que certains répondants ont également suggéré que les projets de démonstration et le renforcement de la formation serait efficaces. Les incitatifs fiscaux et les ventes des crédits de carbone n'étaient pas perçus comme étant efficaces pour les systèmes éolien-diesel.

Les résultats du sondage ont également souligné que des incitatifs financiers conçus pour surmonter les obstacles du coût doivent être associés à un développement stratégique des systèmes d'énergie éolienne de manière à mettre en place un modèle de développement durable pour favoriser la prise en charge des développements futurs.

Article 2: Le stockage d'énergie - solution technique pour améliorer l'efficacité économique des systèmes éolien-diesel

Le coût élevé de l'énergie, en particulier dans les communautés alimentées par des diesels, avec un objectif avéré d'autonomie énergétique, ont alimenté l'intérêt grandissant dans les systèmes éolien-diesel. En fait, la société d'énergie du Yukon a commencé à analyser les systèmes éoliens commerciaux, non pas pour leurs avantages environnementaux, mais comme une alternative économiquement intéressante à la production d'électricité à partir du diesel (Maissan, 2001).

La plupart des premiers systèmes expérimentaux éolien-diesel au Canada ont été développées comme des projets pilotes et, de cette manière, les coûts globaux ont été sous-estimés avec peu de fonds disponibles au-delà des frais d'acquisition et installation. En général, les coûts d'entretien des petites machines installées individuellement ont été souvent plus élevés que les économies de diesel réalisées.

En dépit des frais relativement élevés du carburant, les économies réalisées par une réduction de la consommation de fuel sont souvent de l'ordre de 30 % du coût final de l'électricité (G.T.N, 2007). Combiné avec les frais d'acquisition et d'entretien relativement élevés des systèmes éoliens, cela signifie que les économies à long terme ne sont pas aussi attrayantes qu'elles peuvent apparaître à première vue, en particulier si le pourcentage d'énergie éolienne dans le système est petit, ayant comme conséquence que des frais d'entretiens imprévus peuvent dépasser la valeur de la production éolienne.

Les systèmes de stockage d'énergie permettent d'augmenter la quantité d'énergie éolienne produite dans une configuration éolien-diesel à haute-pénétration. Il a été déterminé que divers facteurs, notamment la ressource éolienne locale, la valeur de la production d'électricité éolienne générée, l'efficacité globale d'un système de stockage d'énergie, la capacité de stockage et le coût, ont tous des répercussions majeures sur l'utilité d'un tel système.

Dans le contexte canadien, un système réaliste peut présumer d'avoir une efficacité globale de 75% avec un système de batterie-redresseur-onduleur qui pourraient avoir une efficacité de l'ordre de 90%. Aux prix courants du carburant diesel évités, la valeur de la production d'électricité éolienne généré est susceptible d'être de l'ordre de

0,30$/kWh (coût évité de la production diesel). Dans de tels cas, un régime de vent caractérisé par une vitesse moyenne annuelle de près de 7 m/s ou supérieure est nécessaire avant que les systèmes de stockage deviennent rentables, avec des coûts d'acquisition de l'ordre de 1 000$ par kW ou moins.

Le logiciel HOMER a été utilisé pour modéliser un système générique éolien-diesel avec stockage. HOMER modélise bien les performances globales du système en raison des pas de temps de 1 heure mais il ne tient pas compte comment le système de stockage se comporte lors des variations plus rapides comme les rafales de vent. Les données de vent sur le site sont indispensables à une bonne analyse de faisabilité de ces systèmes.

HOMER modélise adéquatement les systèmes de stockage de type batterie/convertisseur, ainsi que ceux basé sur l'utilisation de l'hydrogène (électrolyseur – pile à combustible). Dans cette recherche nous avons utilisé le modèle de l'hydrogène comme système générique de stockage. Le modèle de système de stockage générique utilisé permet d'illustrer ses avantages et ses limites pour fonctionner avec des générateurs éolien-diesel. Le modèle illustre également dans quelles conditions un système de stockage d'énergie devrait être considéré et quels sont les spécifications techniques et financières minimales qu'il doit respecter pour assurer la rentabilité.

Le modèle utilisé dans cette recherche ne tient pas compte de l'interaction possible entre le système de stockage et les génératrices diesel. En même temps, un système de stockage peut fonctionner de manière à améliorer et optimiser l'efficacité d'exploitation des diesels. Les systèmes avec un taux de pénétration plus élevé (pourcentage plus important d'énergie éolienne) ont l'inconvénient de forcer les diesels à fonctionner à des régimes moins efficaces. Tandis que le modèle représente bien ces effets de pertes d'efficacité des diesels à plus fables régimes, il ne tient pas compte de l'optimisation possible du contrôle des diesels permis par l'implantation d'un système de stockage. Ces aspects doivent être examinés afin de comprendre l'ensemble des impacts et avantages apportés par le stockage sur les petits diesels.

Il est important de noter qu'un développeur d'énergie éolienne ne peut-être pas toujours avoir accès au contrôle des diesels et c'est ce scénario qui est modélisé dans cette recherche. Dans ce cas, où la centrale d'énergie éolienne fonctionne comme une production électrique indépendante du diesel, le modèle utilisé est approprié du point de vue du développeur d'énergie éolienne sans qu'il y ait nécessairement une optimisation de l'ensemble du système. Il est donc logique que les systèmes haute-pénétration éolien-diesel, avec ou sans stockage, doivent être développés et conçus en partenariat afin de les intégrer directement dans les centrales diesel existantes au profit autant du promoteur éolien que de l'utilité.

Article 3: Modélisation de l'impact potentiel d'une politique d'incitatifs financiers

La volatilité des prix des carburants est une préoccupation majeure pour les collectivités Canadiennes vivant en sites isolés, bon nombre d'entre elles dépendent des générateurs diesel pour la production d'électricité. L'article intitulé « Évaluation d'un incitatif financier pour le développement de l'énergie éolienne dans les communautés éloignés au Canada » (Energy Policy, Volume 38, Issue 10, 2010, Pages 5504-5511) examine comment une vaste politique fédérale pourrait aider l'ajout des systèmes d'énergie éolienne pour diminuer la dépendance du diesel dans ces collectivités.

Des nombreuses communautés canadiennes isolées, particulièrement celles dans l'Arctique, s'appuient sur un seul voyage annuel de fournitures dans la communauté et, en conséquence, sont obligées d'acheter leur carburant diesel sur le marché spot. Cette incertitude complique à chaque année la planification financière et peut conduire à des prix très élevés de l'énergie, tel qu'en 2009 lorsque, malgré la baisse des prix du pétrole à l'échelle mondiale, les achats ont été faits à l'été 2008 lorsque le pétrole avait atteint des sommets. L'introduction d'alternatives énergétiques qui n'utilisent pas des carburants, comme l'énergie éolienne, peut non seulement réduire le niveau de pollution mais aussi stabiliser et réduire, à long terme, les coûts de l'énergie en réduisant la proportion du coût du diesel dans le prix total de l'énergie.

En dépit d'avoir été un pionnier dans la recherche et le développement des systèmes éolien-diesel et abriter pas moins de 5 manufacturiers de turbines éoliennes de dimensions adéquates pour les communautés isolées (Marbek and GPCo, 2005), le Canada a connu très peu de projets éolien-diesel couronnés de succès (Weis and Ilinca, 2007). Ailleurs dans le monde, depuis 2005, des nombreux systèmes éoliens-diesel ont été installés pour alimenter des communautés éloignées, notamment en Australie, Alaska et en Antarctique.

Pendant que les systèmes éolien-diesel présentent une opportunité intéressante pour des nombreuses communautés installées dans des sites éloignées, un régime de vent plus faible, des tours plus basses, des coûts de transport et opération plus importants représentent des barrières additionnelles par rapport aux projets similaires installés dans des régions facilement accessibles. Les résultats d'un sondage auprès des acteurs impliqués dans le développement des systèmes énergétiques au Canada (Weis, et al, 2008) ont identifié le besoin d'incitatifs gouvernementaux pour faciliter le déploiement des systèmes éolien-diesel. Les coûts d'acquisition, d'opération et d'entretien ont été identifiés comme les barrières les plus importantes à ce développement dans les communautés éloignées.

La réduction de la consommation de diesel dans les communautés éloignées a été identifiée comme un objectif par le département des Affaires Indiennes du Gouvernement du Canada dans le « Programme d'action des communautés autochtones et du Nord du Canada » (INAC 2007) et dans le « Programme ecoÉnergie pour des communautés autochtones et du Nord du Canada » lancés en 2007. À date, il n'y a jamais eu de programme à long terme ayant comme objectif directement les systèmes d'énergies renouvelables dans les communautés isolées du Canada et aucun des programmes existants n'a permis d'installer un seul système éolien-diesel au Canada.

L'instance la plus appropriée pour mettre en place un tel programme d'appui est le gouvernement fédéral, soit tout seul ou en partenariat avec des programmes provinciaux ou autochtones. Des communautés isolées se retrouvent dans les trois territoires et dans cinq des dix provinces canadiennes (NRCan, 1999) et ainsi, un programme fédéral aurait une couverture nationale. De plus, le gouvernement fédéral a des responsabilités spécifiques par rapport aux communautés autochtones partout au Canada ainsi qu'auprès des communautés autochtones et non-autochtones au Nord du 60ème parallèle.

Alors que la politique énergétique n'est pas du ressort du gouvernement fédéral au Canada, ils existent des précédents de programmes fédéraux de développement de l'énergie renouvelable, notamment le « Programme d'encouragement à la production d'énergie éolienne » (EPÉÉ) lancé en 2002 et sa continuation et expansion « Programme écoÉNERGIE pour le développement de l'énergie renouvelable » (eERP) lancé en 2007, qui soutient les systèmes de production d'énergie renouvelable à grande échelle avec une contribution de 1¢/kWh pour les dix premières années de production d'électricité. À la fin 2008, près de 90 % de la capacité d'énergie éolienne installée au Canada avait été développé sous l'un de ces deux programmes (Royer et Zborwoski, 2008), et le programme EPÉÉ a été un précurseur de tous les programmes provinciaux et territoriaux d'énergie renouvelable et de leurs objectifs. Aucun de ces programmes n'a entraîné l'installation de systèmes éolien-diesel dans des communautés isolées puisque la taille de ces systèmes était inférieure au minimum admissible dans les programmes. Aussi, l'incitatif de 1 ¢/kWh est totalement inadéquat et ne change pas la rentabilité des systèmes éolien-diesel puisque la génération d'électricité dans les communautés isolées peut coûter 40-100 ¢/kWh (Weis et Ilinca, 2007).

L'objectif de l'article n'est pas de faire une analyse de cas pour un programme incitatif particulier pour les systèmes éolien-diesel, mais plutôt d'examiner quels sont les facteurs qui doivent être considérés pour concevoir un programme couronné de succès au Canada sur une période de 10 ans. Le but de cette recherche est d'illustrer les effets possibles de l'aide directe aux projets éolien-diesel au Canada dans le but d'éclairer les décisions par rapport à une politique future.

Ce document décrit les impacts potentiels d'un programme incitatif spécifiquement conçu pour encourages la production par jumelage éolien-diesel dans les collectivités nordiques et isolées du Canada. La plupart de l'énergie éolienne à grande échelle du

Canada a été développé comme conséquence directe d'un incitatif fédéral de production mis en place en 2002, et la plupart des intervenants qui ont répondu à l'enquête sur les obstacles au systèmes éolien-diesel ont identifié un incitatif lié à la production comme étant potentiellement le meilleur outil du développement de tels systèmes. À l'aide de cette structure ayant montré du succès pour les projets à grande échelle, cet article explore comment un tel programme pourrait être adapté spécifiquement aux communautés isolées. Le programme faisant l'objet de l'analyse a été le « Programme d'aide pour le développement de l'énergie éolienne dans les communautés isolées » (*Remote Commununity Wind Incentive Program - ReCWIP*), qui a été conçu par le caucus en charge du développement du Nord du Canada de l'Association canadienne d'énergie éolienne, qui inclut l'auteur de ce travail et a été en partie basée sur la recherche de barrières illustrée au chapitre 2.

Les simulations logicielles ont mis en évidence que ce programme d'aide, conçu par l'Association canadienne d'énergie éolienne coûterait en moyenne 4.7 millions $Cdn par année et qu'il pouvait entraîner l'installation de projets de 14,5MW d'énergie éolienne dans des villages éloignés au Canada pendant une période de 10 ans.

S'il existe au moins 62 communautés qui seraient candidates pour des projets éolien-diesel si le montant incitatif était de 0,15 $Cdn/kWh, il y a des limites pratiques au déploiement de ces systèmes dues en grande partie à la capacité des ressources humaines ainsi qu'au délai nécessaire pour déployer les systèmes de mesure du potentiel éolien et d'autres étapes exploratoires. Lorsque des incitatifs attrayants sont en jeu, une croissance exponentielle des systèmes installés s'est avéré « normale », ce qui a été observé d'ailleurs pour l'énergie éolienne au Canada à grande échelle tel qu'illustré par Royer et Zborowski (2008). Il a été estimé qu'un seul projet pourrait être mis en œuvre dans la première année après le lancement d'un programme d'encouragement, après quoi un taux de croissance annuel de 20% des projets sur une période de dix ans, aurait pour résultat le déploiement de 31 projets pour un total de 14,5 MW de capacité installée, ce qui génère en moyenne 32 GWh d'électricité par an.

Le déploiement des systèmes éolien-diesel ne se ferait donc que dans la moitié des communautés qui ont été identifiées comme étant viables à court terme. À un taux incitatif de 0,15 $/kWh, un tel programme coûterait en moyenne de 4,7 millions $ par année et entraînerait une réduction annuelle des frais de carburant diesel de 11,5 millions $, en supposant une efficacité de conversion de l'électricité typique des moteurs diesel de 0,3 L/kWh. Cela permettrait également d'éviter l'émission de 7 600 tonnes équivalentes de CO_2 et réduire de 9,6 millions de litres la consommation de diesel, chaque année.

Conclusions

Etant donnée la compétence du gouvernement fédéral par rapport aux peuples autochtones et aux collectivités du Nord au Canada, il serait approprié qu'une politique fédérale soit développée pour les aider dans leur développement. Parmi les options politiques disponibles au gouvernement, une combinaison de subventions du coût en capital et des incitatifs de production peut répondre aux deux obstacles les plus importants au déploiement des systèmes éolien-diesel. Ces aides pour faire face aux coûts en capital et aux frais élevés d'opération et entretien doivent faire partie d'une approche plus large, visant à appuyer les collectivités à poursuivre le développement et l'appropriation de ces systèmes de production d'énergie. Ces dernières aides ne doivent pas nécessairement être au niveau fédéral, mais pourraient être régionales, provinciales ou territoriales comme la formation de la main d'œuvre. Cette recherche montre que même si les contraintes financières doivent être éliminées pour le développement des systèmes éolien-diesel au Canada, elles ne sont pas les seules barrières face à l'adoption de cette technologie dans les communautés isolées, et que bon nombre d'obstacles sont interconnectés. Comme tel, lors de l'élaboration des politiques il faut tenir compte que seulement accorder de l'argent à ces projets ne réussira probablement pas d'assurer le succès et la pérennité des projets éolien-diesel au Canada. Les exemples de réussite dans les autres pays qui ont soutenu l'énergie renouvelable dans les communautés hors-réseau et isolées, notamment en Australie et en Alaska, ont illustré l'importance de l'engagement et du soutien communautaire complet, en plus de la mise en place d'incitatifs monétaires.

Dans la mesure du possible, la politique d'appui des systèmes éolien-diesel partout au Canada devrait se faire de manière ouverte en s'assurant que les paramètres de conception, d'opération, les plans de maintenance et les performances des systèmes soient publiques pour constituer des exemples pour les projets à venir. Les défis d'un tel développement dans le plus de communautés sont assez importants pour que les réussites et les échecs soient bien documentés et que l'information circule de manière constructive.

Dans le cadre de cette recherche globale, j'ai travaillé étroitement avec la communauté de Tuktoyaktuk, qui, au moment de la rédaction de ce document, était en train de développer le premier nouveau système éolien-diesel au Canada dans près d'une décennie. Si ce projet est réussi, il constituera un excellent exemple à analyser autant pour ses aspects techniques que politiques. En outre, si le soutien du gouvernement pour le déploiement des systèmes éolien-diesel se concrétise dans le sillage de ce projet, il sera une nécessité, mais aussi une opportunité, d'encadrer ce support dans une stratégie de développement à plus long terme ainsi que dans une définition des priorités de recherche et développement.

Les problèmes techniques qui nécessitent des investigations portent sur nombreux aspects, des performances des fondations dans le pergélisol à l'impact de l'utilisation des éoliennes et des systèmes de stockage sur les performances des générateurs diesel. Des nombreuses études analytiques des systèmes hybrides éolien-diesel ne tiennent pas compte des changements dans la performance des générateurs diesel en raison de la présence des éoliennes, particulièrement à des fréquences d'échantillonnage élevées. Dans la mesure du possible, les données de performance des systèmes, en particulier lors du fonctionnement en conditions de températures froides ou givre devraient être rendues publiques afin de construire des modèles empiriques adéquats. L'implantation des modèles d'optimisation, ainsi que l'ajout de capacité de stockage pour améliorer la pénétration éolienne et la stabilité du réseau vont améliorer la conception des futurs systèmes.

La publication des performances aidera non seulement à la solution des problèmes techniques des projets actuels et futurs, mais aidera également à surmonter la sensibilité et la perception des risques techniques parmi les utilités et autres décideurs identifiés comme d'importants obstacles au déploiement. La disponibilité des informations est également importante pour l'élaboration de la planification financière des projets ou pour des études en lien avec les systèmes éolien-diesel.

Des aspects de la politique énergétique qui requièrent plus d'attention sont notamment comment les politiques actuelles de subvention de carburant peuvent être ajustées afin d'éviter les effets dissuasifs pervers au déploiement des solutions de rechange, tels que les systèmes éolien-diesel, autant au niveau national que provinciaux et territoriaux. Des modèles de mise en œuvre efficace et des stratégies régionales pour les systèmes éolien-diesel ou d'autres alternatives ont besoin d'être développés dans les communautés isolées afin de bénéficier d'économies d'échelle au cours de la mise en œuvre et des opérations. Ces plans devraient examiner plus que les options de déploiement dans la communauté, mais aussi des technologies allant de faible pénétration à haute pénétration, des systèmes avec stockage, ainsi que les stratégies de service régional. Cela peut aider à atténuer le potentiel significatif d'augmentation du prix des carburants tout en s'assurant que les projets soient déployés de telle façon que les promoteurs ont des ressources techniques suffisantes pour concevoir, construire, exploiter et maintenir des futurs projets.

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LIST OF ABBREVIATIONS USED

\$Cdn	Canadian dollars
AB	Alberta
AEA	Alaska Energy Authority
AUD	Australian dollars
BC	British Columbia
CanWEA	Canadian Wind Energy Association
CDM	Clean Development Mechanism
CO_2	Carbon Dioxide
CO_{2eq}	Carbon Dioxide Equivalent
eERP	ecoENERGY for Renewable Power
FIT	Feed-in Tariff
INAC	Indian and Northern Affairs Canada
kW	kilowatts
kWh	kilowatt-hours
GNWT	Government of the Northwest Territories
HOMER	Hybrid Optimization Model for Electric Renewables
MB	Manitoba
MW	megawatt
MWh	megawatt-hours
NL	Newfoundland and Labrador
NTPC	Northwest Territories Power Corporation
NRCan	Natural Resources Canada
NREL	National Renewable Energy Laboratory
NWT	Northwest Territories
NU	Nunavut
ON	Ontario

PEDOH	Power Equipment Department of Ontario Hydro
ReCWIP	Remote Community Wind Incentive Program
REGP	Renewable Energy Grant Program (Alaska)
RRPGP	Renewable Remote Power Generation Program (Australia)
RPS	Renewable Portfolio Standard
SCADA	Supervisory Control and Data Acquisition
t	tonne
USD	United States dollars
WPPI	Wind Power Production Incentive
YK	Yukon

ABSTRACT

Canada has over 200,000 citizens living in remote communities, many of whom rely on diesel generators for their electricity supply. Developing wind power may be one of the only options that many of them have for year-round locally sourced renewable energy. Canada has long explored the possibility of wind-diesel hybrid systems but actual projects are not happening at a significant pace to address even a fraction of these communities. This research takes a multidisciplinary approach to examining how the development of such systems could be facilitated by looking at social and economic barriers, to technical advances that could enable broader deployment and finished with an examination of how public policy could incent uptake.

The research begins with an examination of the history of wind-diesel projects in Canada, as well as selected projects from Alaska before discussing barriers to renewable energy projects in general, and policy options that have been used to overcome these barriers. A more detailed look at policies that are aimed at remote communities in Alaska as well as Australia illustrate how successful jurisdictions have been able to target remote communities for renewable power deployment.

A stakeholder survey is discussed in Chapter 2 as to their perceptions of the key barriers to wind-diesel systems in Canada. This analysis illustrates there is strong agreement that system costs both capital and operational continue to be perceived as the most significant, but not the only important barrier to wind-diesel systems in Canada. There is a notable disagreement between two groupings of stakeholders as to the technical maturity of wind-diesel systems, specifically utilities and governments who remain largely unconvinced the technology is ready in the Canadian context compared to manufacturers, developers and researchers who strongly believe it is.

Micropower simulators were developed to model energy storage systems could help to overcome financial barriers by improving the economics of wind-diesel systems. This approach models where the round-trip efficiency and the overall capital costs of any energy storage needs to be in order to make these systems useful in improving the performance of wind-diesel systems in Canada.

Finally the potential for a federal incentive to support broad deployment of wind-diesel systems in Canada is discussed. The design of this incentive was a result of barriers analysed in this research as well as models developed herein which examine its uptake. This incentive structure is based on the success of past Federal production incentives in Canada for large-scale wind power, and is tailored for the needs in remote communities. Chapter 4 discusses the uptake potential for such a policy and how it can result in a savings of 11.5 $Cdn million dollars in diesel costs annually,

displacing 7,600 tonnes of CO_{2eq} emissions and 9.6 million litres of diesel fuel every year.

RÉSUMÉ

Pour beaucoup de Canadiens qui vivent dans des communautés éloignées, l'énergie éolienne peut être une des seules options de production d'énergie renouvelable locale pendant toute l'année. Parmi les nombreux systèmes hybrides éolien-diesel installés au Canada dans les 20 dernières années, ils restent seulement deux encore en fonction. Dans cette recherche nous abordons, à l'aide d'une approche multidisciplinaire, comment le développement de ces systèmes pourrait être facilité en identifiant les obstacles sociaux et économiques et les progrès techniques requis pour le déploiement de ces systèmes. Nous faisons aussi un examen des politiques publiques qui pourraient encourager un développement plus rapide des énergies renouvelables et plus particulièrement de l'énergie éolienne dans le Nord du Canada.

La recherche commence par une analyse des réussites et échecs associés aux projets de couplage éolien-diesel au Canada et en Alaska. Cela est suivi par une discussion des obstacles auxquels font face les projets d'énergies renouvelables et les politiques utilisées pour surmonter ces obstacles. Nous examinons en détail les politiques énergétiques mises en place par l'Alaska et l'Australie et qui ont assuré le succès du déploiement des énergies renouvelables dans les communautés éloignées dans ces deux régions du monde présentant des similitudes avec le Canada.

Le deuxième chapitre présente les perceptions des obstacles rencontrés par le déploiement des systèmes éolien-diesel en Canada. Cette analyse est basée sur un sondage auprès des acteurs directement concernés par le développement des systèmes éolien-diesel dans les communautés nordiques. Elle illustre que le coût des systèmes est perçu comme la barrière la plus importante, mais pas la seule. Il y a un désaccord notable entre deux groupes de parties prenantes, d'une part les services publics et les gouvernements qui restent sceptiques sur la maturité technologique des systèmes éolien-diesel dans le contexte canadien, et d'autre part, les fabricants, développeurs et chercheurs qui croient fermement que la technologie est suffisamment mature.

Les simulations des bilans horaires de puissance ont été utilisées pour déterminer comment les systèmes de stockage d'énergie pourraient aider à surmonter les obstacles financiers des systèmes éolien-diesel. Cette approche examine comment l'efficacité globale et les coûts en capital des systèmes de stockage affectent la rentabilité économique des systèmes éolien-diesel en fonction des conditions particulières du site d'installation.

Finalement, le potentiel d'un incitatif fédéral pour les systèmes éolien-diesel est analysé. La structure du programme incitatif est basée sur les autres politiques fédérales appliquées avec succès, notamment celle pour l'énergie éolienne à grande

échelle. Il est examiné comment cette politique peut être adaptée pour répondre aux besoins des communautés éloignées et les obstacles dont il faut tenir compte dans son élaboration, les mêmes obstacles identifiés auprès des différents acteurs. Le chapitre 4 examine, à l'aide des modèles de simulation micro-puissance (bilan horaire des puissances produite et consommée) les effets économiques et environnementaux d'un tel incitatif. Les simulations indiquent que la mise en place de l'incitatif fédéral peut résulter, sur une base annuelle, dans une économie de 11,5 millions de dollars en coût de diesel, équivalent à 9,6 millions de litres de carburant et une réduction de 7600 tonnes d'émissions d'équivalent CO_2.

CHAPTER 1: INTRODUCTION

Abstract

Wind-diesel hybrid systems are one of the few renewable energy sources that many of Canada's remote communities might be able to take advantage of locally to reduce their dependence on diesel fuel imports. This chapter discusses the opportunity that the technology presents, as well as the history of failed projects that have stunted its progress in Canada. Barriers to the deployment of renewable energy systems are examined as well as policy tools that have been used to overcome barriers facing to renewable energy systems are potentially appropriate for wind-diesel systems in Canada. Particular attention is also given to policies that have been deployed in Alaska and Australia that are targeted at renewable energy in remote communities, which in Alaska in particular have led to significant development of wind-diesel systems in recent year.

1.1 Wind in remote communities

> *"Current energy production in remote First Nations are largely dependent upon systems using diesel or other types of fossil fuels. These systems depend upon resources that must be imported from out of the territory, over long distances. Millions of litres of diesel fuel a year are transported by air, barge, and tractor train into remote communities for existing diesel electric power plants. In addition to the air pollution that burning fossil fuels generate, the transportation of such large amounts of fossil fuel into a remote harsh environment, presents many opportunities for a major spill. In addition, the cost of purchasing fossil fuels, either directly or passed through the consumers via electricity rates, accounts for a significant drain of cash resources from already cash poor communities."*
>
> – *Mushkegowuk Council and Nishnawbe-Aski Nation press release Feb 5, 1997*

In many ways wind power in Canada began in remote communities. Decades before the first commercial wind farms were being built, wind turbines had been operating in remote Canadian communities from Northern Quebec to the Northwest Territories. The high costs of diesel power and the promise of local sustainability drew early government research and development in wind power, with the first wind-diesel research occurring on the Magdalene Islands in the 1970s (Chappell, 1986). By comparison, large-scale wind has averaged annual growth rates of new installations over 20 per cent since the first Federal production incentive was introduced in 2002. In 2010, commercial, utility-scale wind power installations had surpassed 4,000 MW of installed capacity, such that approximately 2 per cent of the overall national electricity supply is generated from the wind (CanWEA, 2010). Given its head-start, one might expect that remote communities would be well ahead of utility-scale turbines, but in fact this is not the case. In 2010, there were only two communities in

Canada operating wind-diesel hybrid systems; Rankin Inlet, Nunavut and Ramea, Newfoundland. The goal of this research is to examine the barriers that have restricted the growth of remote wind power in Canada and what policy and technology options may help to restart the stalled momentum.

Remote communities are generally considered as being those that are not connected to the North American electrical grid with at least 10 permanent residences (PEDOH, 1995). Canada has hundreds of remote sites ranging in size and population from unmanned telecom stations, to the Territorial capital cities with several thousand people. There are industrial sites including logging field camps, resource extraction mines and military outposts, as well as predominantly residential communities, the majority of which are Aboriginal. The number of sites fluctuates as industrial sites are being developed and decommissioned, some remote communities have been connected to provincial or territorial power grids, such as the connection of seven remote communities in Northern Manitoba in 1997 (AFN, 2005), and occasionally a new community is started.

Using the above definition, every community within the three Canadian territories would be considered to be remote, even though there are electrical grids in both Yukon and the Northwest Territories that connect several communities around the capital cities Whitehorse and Yellowknife. Remote communities are not limited to the Territories however, in fact six out of the ten Canadian provinces have at least one remote community, (Saskatchewan and the Maritimes do not), with British Columbia having more remote communities than any other Canadian jurisdiction. While the majority of remote communities are in the North, some are as far south as Vancouver Island. Compared to the overall populations and electrical demand within their respective provinces or territories, remote communities are most significant in the Northwest Territories and Nunavut, and as such much of the discussion of remote communities often focuses on the North. The social, technical and economic frameworks in small communities are very different from those in industrial sites or even large communities. This work focuses exclusively on the small, residential communities that use diesel generators at a single generating station as their primary source of electricity generation.

Even within the category of communities that would be broadly described as small and residential, there are significant differences amongst these communities, which compromise four major Aboriginal groups (First Nations, Inuit, Innu and Inuvialuit), as well as non-Aboriginal communities. Amongst the Aboriginal communities, there are varying degrees of self-governance, including the Inuvialuit, who since 1984 have major regional land ownership, to historical treaty zones to communities still undergoing land lengthy claim negotiations. The result of which means that electricity services and financial structure can be very different from community to community, even within the same jurisdiction. As an illustration, residents of Wapekeka First Nation in Northern Ontario which is serviced by Hydro One Remote Communities pay 0.105 $Cdn/kWh (Weis and Zarowny, 2006), while residents of Poplar Hill First Nation, which runs its own micro-utility pay a fixed monthly fee regardless of consumption (Cobb and Wong, 2009). Generation costs can also vary dramatically within the same region, as in the case of Northern Ontario where average generation costs in 2008 ranged from as low as 0.27 $Cdn/kWh in North Spirit Lake to 1.32 $Cdn/kWh in Wawakapewin (Cobb and Wong, 2009). These differences can have major impacts on the viability of alternatives such as wind power, as well as consumption patterns and the social motivation for changes.

The term 'wind-diesel' generally refers to a hybrid system that couples a wind generator into a diesel electric system, where the wind generator is sufficiently large to be significant to the diesel engines, although there is no strict definition of relative sizes. A 60 kW wind turbine installed on les Îles de la Madeleine, which has a 10,000 kW diesel system, for example, would not typically be considered a 'wind-diesel' system, whereas that same turbine installed in community such as Sachs Harbour which has a peak load of only 220 kW would be considered to be a 'wind-diesel' system. Wind-diesel hybrid systems use complex control systems to enable the integration of the variable output from a wind turbine into a diesel electric grid, while maintaining a high quality of power (voltage and frequency). Wind 'penetration' is the commonly used descriptor to describe the average relative outputs from the wind turbines compared to that of the diesel generators. A low-penetration system, for example, has little effect on the diesel generators and are sometimes described as 'negative loads', as the diesel generators' control system treat the presence electricity delivered from the wind turbines the same way they would if a major load, such as a large pump was shut off. Increased levels of penetration however cause much more direct interaction with the diesel control system and are therefore increasingly technically complex (Randall and Thompson, 2001). Again, there are no formal definitions, but generally the penetration classes can be described below in Table 1.

Table 1: Description of wind-diesel penetration levels (Baring-Gould, 2009)

Penetration Class	Operating Characteristics	Penetration	
		Instantaneous Peak	Annual Average
Low	• Diesel(s) run full time • Wind power reduces net load on diesel • All wind energy goes to primary load • No supervisory control system	< 50%	< 20%
Medium	• Diesel(s) run full time • At high wind power levels, secondary loads dispatched to ensure sufficient diesel loading or wind generation is curtailed • Requires relatively simple control system	50% - 100%	20% - 50%
High	• Diesel(s) may be shut down during high wind availability • Auxiliary components required to regulate voltage and frequency • Requires sophisticated control system	100% - 400%	50% - 150%

Higher levels of wind penetration can result in very significant diesel savings which can make them attractive as opportunities to help utilities reduce electricity costs, shelter the communities from fuel price volatility, increasing local sustainability as well as reducing fossil fuel use. In spite of the potential benefits, and the fact that electricity generation costs in remote communities can be five to ten times that of continental electricity grid prices, wind-diesel systems have had little success in Canada. To date there have been more than ten remote wind-diesel systems attempted in Canada, all have been pilot projects that were either launched by or in partnership with the local utility. Most projects were failures, few lasting more than a couple of years in operation. The only exceptions include Kuujjuaq, Quebec which operated for 8 years (Hydro-Quebec, 1996), Cambridge Bay, Nunavut which operated for 6 years (Pinard and Weis 2003) and Ramea, Newfoundland, which in 2009 was the only wind-diesel system operating in Canada since its installation in 2003 (Government of Newfoundland and Laborador 2007).

1.2 Research Approach

The work that was carried out for this research involved four major activities ranging from field work in remote communities, to developing computer models to assess policy options. The first activity was to examine historical projects that have been attempted in Canada, to learn about their approach, the challenges they encountered and the reasons for their success or failure. This was done through visiting many of these communities, speaking with individuals that were involved in the projects from both the community and utility sides, as well as organizing three conferences in Whitehorse (2003), Tuktoyaktuk (2007) and Ottawa (2009) bringing individuals from remote communities together with technical experts and policy makers to discuss historical and future challenges.

The second research activity that was part of this effort was to work directly in remote communities assessing energy demands, costs and options as well as community governance and structure. I installed wind energy monitoring equipment in four remote communities (Kyuquot, BC, Hesquiaht, BC, Sayisi Dene, MB and Shamattawa MB) and worked on assessing wind-diesel feasibility for these communities. I worked on community energy planning projects in Hartley Bay, BC, Kyuquot, BC, Hupacasath, BC. Wha Ti, NWT, Driftpile, AB and Little Red River Cree Nation, AB, not all of which were remote, nor focused exclusively on wind energy, but provided insight into common challenges and issues developing alternative energy projects in Aboriginal communities. I also assisted in wind-diesel analysis for Tuktoyaktuk, NWT, Sachs Harbour, NWT, Paulatuk, NWT, Uluhuktuk, NWT, Nemiah Valley, BC, Tsay Keh Dene, BC and Kasabonica Lake, ON.

Taking this experience in the field I worked on identifying the key obstacles to developing wind-diesel projects in Canada. This was accomplished by surveying many of the stakeholders with whom I had either worked directly with, knew through the networks that were developed during these projects, or knew of as a result of their work in the field either in Canada or abroad. The results of this survey informed Chapter 2 titled *Stakeholders' perspectives on barriers to remote wind-diesel power plants in Canada*, and was published in the journal Energy Policy in 2008 (Volume 36, Issue 5, May 2008, pages 1611-1621).

Finally, I concentrated on developing computer models that could be used to assess how some of the financial barriers could be overcome, firstly through changes in technology and then in changes in Federal policy in terms of developing an incentive. *The utility of energy storage to improve the economics of wind-diesel power plants in Canada*, was published in the journal Renewable Energy in 2008 (Volume 33, Issue 7, July 2008, pages 1544-1557), and *Assessing the potential for a wind power incentive for remote villages in Canada* was published in the journal Energy Policy in 2009 (Volume 38, October 2010, pages 5504–5511). These efforts combined with work done by John Maissan of Leading Edge Project, JP Pinard of JP Pinard

Consulting and Sean Whittaker of the Canadian Wind Energy Association, as well as work with Natural Resources Canada staff has lead directly to the development of a proposed Federal incentive for wind-diesel projects in Canada which has been adopted by several Federal political parties in their official platforms and has been submitted to the Federal finance committee for consideration.

In addition, as part of the effort during this work, members of the Inuvialuit leadership agreed that the community of Tuktoyaktuk should be chosen to lead the development of the first wind-diesel project in Canada's North in close to a decade. This project is currently underway as a result of significant support from the government of the Northwest Territories, particularly Wade Carpenter from the department of Environment and Natural Resources, and is expected to be completed by the summer of 2011.

This dissertation represents the culmination of these research activities that have ranged from direct engagement with communities on local wind-diesel projects to policy development and advocacy.

1.3 Recent wind-diesel projects in Canada

There are three wind turbines that are currently operating in Canada's North although none in wind-diesel configurations. Yukon Energy has operated two wind turbines (a 150 kW and a 660 kW machine) since the 1990s, both connected to the Whitehorse power grid (Maissan, 2001) which is predominantly hydro-electric. A single 50 kW wind turbine was installed in Rankin Inlet, Nunavut in the year 2000, after the planning and installation began in 1998. While Rankin Inlet's electricity supply source is diesel engines, its installed diesel capacity is over 4,000 kW (NRCan, 1999), such that the 50 kW turbine would have a negligible impact on the overall operation of the diesel system. Nonetheless, this turbine experienced major difficulties, largely due to operations and maintenance. It operated from November 2000 to December

2001 and producing power only 36% of the year due to malfunctions and insufficient winds (Nunavut Power, 2002). It was originally expected that this installation could produce 152,000 kWh annually, displacing 41,100 L of diesel although brake failures kept this turbine inoperational for many years before being repaired in 2008 (Giroux, 2009).

There have been many other wind-diesel projects attempted in Canada. The most recent wind-diesel projects include single turbines installed in Cambridge Bay and in Sachs Harbour, NWT, Kugluktuk, NU and Ramea, NL. These projects will be discussed briefly below.

1.3.1 Cambridge Bay, NWT

Nunavut Power (2002) described the installation of an 80 kW wind turbine in Cambridge Bay in 1994 by Dutch Industries Inc. The company, based in Regina, Saskatchewan signed an 8-year power purchase agreement with Northwest Territories Power Corporation (NTPC) for 0.20 $Cdn/kWh. At the time of signing the contract the displaced price of diesel fuel for NTPC was 0.17 $Cdn/kWh. The turbine operated with an average capacity factor of 20% for the period between September 1994 and August 1998 and sold an estimated 135,000 kWh to NTPC annually representing 2% of the annual total generation in the community. A 20% capacity factor is low by utility-scale wind turbine standards which often operate at capacity factors closer to 30%. By 1998, the displaced price of diesel fuel was 0.206 $Cdn/kWh, such that the purchase of wind power was a net savings for the utility. 135,000 kWh represents about 39,200 L of displace diesel fuel annually, saving a calculated 100 tonnes of CO_{2eq} per year, and 78 kg of particulate matter. The wind turbine collapsed in June 2002 for reasons that were never determined by the utility, and was not replaced.

1.3.2 Sachs Harbour, NWT

In 1998, a 65 kW wind turbine was installed in Sachs Harbour. Sachs Harbour is a small community with approximately 150 residents and an average load of only kW (Pinard and Weis, 2003). As such the 65 kW turbine caused voltage dips during start-up, which caused the machine to remain off-line until a soft-start connection was established in 2000. The turbine began operation in the late summer 2000, but only operated for approximately 6 weeks, when a tip break broke off and was not repaired until October 2000. Severe rime icing conditions in Sachs Harbour resulted in a loss of aerodynamics such that the machine would not self-start. The operators learned they could motor the turbine to get it started which would eventually throw the ice off the blades. However, this practice eventually resulted in a damaged gearbox that needed replacing. The turbine remained off-line, and was scheduled for repair the following summer. It was destroyed in 2001, as it was dropped in an attempt to lower the turbine to replace the gearbox and the project was abandoned. The project was projected to cost $Cdn 230,000 (3,540 $Cdn/kW) but ultimately cost over $Cdn 450,000 (6,920 $Cdn/kW).

1.3.3 Kugluktuk, Nunavut

Two 80 kW turbines were installed in 1997 in Kugluktuk. These were the first turbines installed in the NWT that were owned and operated by the NTPC. The installation of these turbines was fraught with difficulties and cost overruns and did not start regular operation until 1998 (Nunavut Power, 2002). The installed cost of the two turbines was $CDN 580,000 (3,625 $Cdn/kW) and resulted in $41,298 in fuel savings in the 24 months that they were operational. In July 2000, one of the turbines fell from its tower after several mounting bolts failed, and the other was hit by lightening earlier in the same month. A $110,500 quote was received to recondition the damaged turbine, but it has not been repaired, and both turbines have been abandoned.

1.3.4 Ramea, Newfoundland

In 2003, six 65 kW wind turbines were connected to the Newfoundland and Labrador Hydro utility diesel system in the fishing community of Ramea. The wind turbines are owned and operated by Frontier Power Systems, and represent the first "medium penetration" system in Canada. The objective of this research is to examine a variety of existing policies both in Canada and internationally that support the deployment of renewable energy technologies in rural and remote areas. The synthesis of the suite policies will aid in the strategic and targeted development of public policy tools in Canada that could overcome the barriers and facilitate the deployment of renewable technologies in and maximize the benefit to remote and rural communities. To meet this objective, existing policy approaches and tools were catalogued and assessed the relative merits of the policies.

Table 2: Summary of selected Canadian wind-diesel projects

Project	Start Date	End Date	Capacity (kW)	Relevant Cost Information
Cambridge Bay, NWT	1994	2002	160	0.2 $/kWh elec. sale price
Sachs Harbour, NWT	1998	2001	65	6,920 $/kW installed
Kugluktuk, NU	1998	2000	160	3,625 $/kW installed
Ramea, NL	2003	Still operational	390	n/a

1.4 Selected wind-diesel projects in Alaska

Alaska's first successful wind energy project began in Kotzebue, in 1999 and has steadily grown since then. According to the Renewable Energy Alaska Partnership (REAP, 2009) there are over 20 wind-diesel projects currently under development or already operating in Alaska. These projects have received significant support from either the state or national governments (or both) and the recently established "renewable energy fund" in Alaska will likely continue to foster the growth of this area well into the future. This section highlights several of these projects to illustrate performance and technology designs that are operational in the North American context.

There are currently 17 wind turbines installed in Kotzebue, a community located on the North coast of Alaska, the first three of which were commissioned in 1997. Kotzebue Electricity Association owns and operates all of the wind turbines which have a total capacity of over 1 MW, including fifteen 65 kW, one 100 kW turbine, in addition to a single 65 kW remanufactured turbine that originally operated commercially in California. These units currently supply about seven percent of Kotzebue's electrical requirements annually. In spite of its relatively large wind capacity, it is still a considered low-penetration system, delivering at most 36% of the community's power during low-load/high-wind periods (Global Energy Concepts, 2007).

In 1999, a high-penetration wind-diesel system was commissioned on St. Paul's Island using a single 225 kW turbine that also provides additional heating to the local school with the excess energy. By the year 2002, Wales, Alaska had installed two wind turbines in a high-penetration configuration and in 2004, Selawik, Alaska installed 150 kW of wind energy capacity onto their remote grid followed by high penetration systems in Toksook Bay and Kasigluk in 2006. In December 2008 the Banner Wind Project, a 1.17 MW project in Nome, came online. This project is estimated to offset almost 757,000 litres of diesel fuel for the city and nearly doubled the state's installed wind capacity.

Many of the early projects in Alaska benefitted from direct support from the United States' Federal government. When oil prices peaked in 2007-08, the Alaska State Legislators approved State fund to support the deployment of renewable energy technologies that targets $50M USD a year for 5 years. Additional details of the fund are as follows:

- Solicitation conducted in the fall of 2008 for round 1 and round 2 projects
- Projects reviewed by Alaska Energy Authority and selected by the Legislator

- Round 1 - Funding provided $47.7M USD for wind projects or development support for 21 wind projects, 18 of which were wind-diesel applications.
- Round 2 - Identified 14 additional wind projects for support, 13 off grid, totalling over $14.6M USD

1.5 Barriers to Renewable Energy in Remote Communities

In spite of their advantages, there are numerous barriers to the deployment of wind-diesel systems in remote communities. Numerous papers discuss barriers to renewable energy such as wind-diesel systems, a comprehensive summary is discussed by Martinot and McDoom (2000). This list is not specific to wind energy in particular, but rather to renewable energy in general. While there has been significant changes in utility-scale renewable energy markets since the year 2000, many of these barriers still remain equally relevant for wind-diesel systems as they are on the cusp of wide-spread market deployment in a similar way that large-scale renewable energy was a decade ago. These barriers, listed in Table 3 below, can be classified into broad categories of cost structures, risk and risk perceptions, technical issues, policy constraints and social obstacles.

Table 3: Common barriers to renewable energy projects

Barrier	Category
Subsidized or average cost energy prices	Cost
Lack of information	Social
Transaction costs	Cost
High front-end capital costs	Cost
Lack of credit	Cost
Perceived technology performance uncertainty and risk	Risk
Institutional mismatch of energy costs and capital costs	Cost/Policy
Lack of legal framework for independent power production	Policy
Lack of technical or commercial skills	Social
Lack of utility acceptance of technologies	Technical
Prejudice against a technology because of poor past performance	Risk
Difficulty of firm dispatch in utility grid operations	Technical
Technical limits to utility integration of intermittent sources	Technical
Competition for access to resources	Social
Restrictions on siting and construction	Policy
Lack of utility grid access to remote sites	Technical

Risks of permit process	Policy/Risk
Institutional mismatch of capital costs and fuel-price risks	Policy/Cost
Difficulty of quantifying environmental costs	Policy/Social
Lack of detailed geographic resource data	Technical
Lack of government support	Policy
Opposition of existing interest groups	Social
High costs of developing new infrastructure and market institutions	Cost

Painuly (2001) also suggests that environmental barriers can exist as well as inconsistency in policy or pricing structures. Not all barriers are present for any given project, and some may be more prevalent than others in a given jurisdiction and technology, particularly in the context of remote communities.

Subsidized or average cost energy prices. Subsidies to existing electricity costs is a notable barrier in the remote Canadian context. Many jurisdictions in Canada spread the costs of remote power generation across the broader rate base sheltering inhabitants of remote communities from the full exposure to their electricity costs (Cobb and Wong, 2009). Additional subsidies can exist in terms of grants or funds that given to building diesel plants as essential community infrastructure, as well as emergency support for price spikes. While this is a barrier to alternatives, it is also difficult to change, and living costs are very high in remote communities, and in many cases income opportunities are low, beyond subsistence hunting. As such, while wind energy systems could argue for similar or matching support, it is unlikely that such subsidies would be removed.

Lack of information. Lack of information can also be a key barrier in remote communities. It is difficult to expect remote communities to be able to devote time and money to stay on top of the most recent technical developments in energy alternatives. Many Aboriginal communities in Canada have election cycles as often as every two years making information continuity an on-going challenge (AFN 2005). Communities often rely on precedents set by other communities (Underwood et al, 2007), and so a lack of operating projects can produce a self-perpetuating cycle.

Community energy planning has often been cited as an opportunity for communities to overcome information gaps and promote renewable energy such as wind-diesel, although St. Denis and Parker (2008) suggest that such efforts are often beneficial in leading to improved energy efficiency, although this is laudable, community energy planning has rarely resulted in renewable energy projects in Canada. Information gaps do not only exist at the community level however, as utilities are also often not aware of the most recent advances renewable energy technology.

Transaction costs. The impact of transaction costs can be amplified in remote communities as a result of high transportation costs both of equipment and of skilled labour to install it. This can be a barrier to a project even started, but ultimately becomes of the high upfront costs of wind-diesel systems.

High front-end capital costs/Lack of credit. While high capital costs are a common barrier to renewable energy projects in general, the inability to access credit is a challenge for small communities, particularly Aboriginal one as lenders can be averse to working with these communities for they fear they be unable to seize assets to recover a defaulted loan (AFN 2005).

Perceived technology performance uncertainty and risk. The perception of risks remains a barrier to wind-diesel projects in Canada, largely as a result of the legacy of failed projects described earlier. Failed projects can have very long institutional memories, long after the specific reasons for failure have been forgotten. Martinot and McDoom (2000) identify this as a separate barrier, as the perception of risks can also include concerns that go beyond previous projects.

Institutional mismatch of energy costs and capital costs. An institutional mismatch or a lack of a legal framework for developers to be able to either develop or own a project, or sell the energy that is created, either in the form of electricity or in some cases heat, are both examples of regulatory barriers that are often the unintended consequences of rules drafted to deal with other legal issues. They can remain barriers as any attempt at their legal removal or removal is either challenging or perceived as insurmountable.

Lack of legal framework for independent power production. In the past some provinces and territories have had legal restrictions on who is able to sell electricity.

Lack of technical or commercial skills. The lack of technical skills to develop, construct and maintain new technologies in remote communities is not unique to wind-diesel projects. A lack of "critical mass for classroom training and the related costs" (ACCC, 2004) limits the ability for communities to develop the necessary skills required to develop a wind-diesel project locally. Compounding this problem is the ongoing challenge of retaining skills within a community, as inhabitants are often mobile between communities, or leave to larger centres looking for employment.

Lack of utility acceptance of technologies/ Prejudice against a technology because of poor past performance. Specific to wind-diesel systems, a lack of utility acceptance is often related to either the legacy of failed historic projects to the next barrier identified as the difficulty of dispatching or controlling the output of wind energy systems into the existing utility infrastructure (Weis et al, 2008). This can either be a perceived or a real limit due to the availability or cost of technologies such as flywheels or power electronics required to smooth variable power output. These barriers can in combined into the state of the technical maturity of the overall system including the wind turbines themselves, the control systems and the integration equipment. As discussed in section 1.3 there have been several unsuccessful wind-diesel projects in Canada which have in part lead to a lack of interest in further developments.

Competition for access to resources. Competition for access to resources is different in remote communities than in developing renewable energy projects in the "southern" context the latter typical involves alternate land uses such as agriculture or even preservation of viewscapes. The most common competition is ensuring sufficient distance from the local airstrip for safe take-off and landing. This is therefore very much related to the barrier of restrictions on sitting and construction. In both cases this is in effect a capital cost barrier, as the ability to extend power lines outside of the community would alleviate many of these constraints. This is in essence the same as the barrier identified as the lack of utility grid access to remote sites, which in the case of remote communities or large-scale utility development are both constrained by limits to the existing grid infrastructure.

Restrictions on siting and construction. One advantage that many Aboriginal communities have is some degree of autonomy over the development of projects on or close to their territories, be it reserve, treaty, or traditional lands. The risks of permitting are therefore typically less of an unknown than it would be to other utility-scale projects that are the focus of the Martinot and McDoom (2000) barriers compilation and discussion.

Lack of utility grid access to remote sites. In remote communities, it can be very expensive to build power lines very far outside of the community, and so wind energy projects restricted to close proximity to existing infrastructure (Maissan, 2006).

Risks of permit process. All wind energy projects in Canada require approval from Transport Canada and Navigation Canada as a result of potential interference with airport landing strips. In addition, any project that involve federal government support need to have a federal environmental assessment, which can require up to a year of monitoring for potentially impacted species (Carpenter, 2010).

Institutional mismatch of capital costs and fuel-price risks. In the context of remote communities, institutional mismatches between capital costs and fuel-prices can be the result of the fact that utilities are responsible to public utility boards that review annual rates based on current costs and whose mandate does not tend to look beyond the current year. Long-term potential savings that result in short-term price increases can be blocked by public utility boards even when a utility is interested in pursuing such alternative.

Difficulty of quantifying environmental costs. Environmental damage resulting from diesel fuel use is either externalized in the form of air emissions, while the remediation of contaminated soils as a result of diesel spills tends to be funded by INAC and not the local utility or fuel supplier. Although there are real costs that are borne by the community as a result of a spill including the loss of usable resources and land they are more difficult to quantify. Emission reductions resulting from small projects are also generally too small to overcome transaction costs that would make them marketable to voluntary or mandated offset markets.

Lack of detailed geographic resource data. Like almost all wind energy projects, the local wind speeds need to be measured, as the performance of a wind turbine is highly dependent on the characteristics of the local wind regime. One advantage that most remote communities in Canada have is that they frequently have local airports with anemometers. While this data is often not logged over long periods of time, it is not difficult to use the pre-existing equipment to start to track wind speeds and obtain a reasonable estimate of the quality of the local wind speeds before investing in additional monitoring equipment.

Lack of government support. While there has been government support programs in the past both a Federal, Provincial and Territorial levels in Canada, one of the difficulties with these programs has been the lack of long-term availability or predictability of such support mechanisms. While several pilot projects have been developed, a lack of long-term support has not created a long-term deployment strategy.

Opposition of existing interest groups. In some communities, there is a local fuel supplier who is independent of the electricity provider and stands to lose if an alternative is pursued. These interests can impede the development of renewable systems such as wind power if the fuel supplier is politically connected or is not a part of the new project.

High costs of developing new infrastructure and market institutions. Barnett (1990) suggests that new energy technologies are at a disadvantage as they do not have the volume of maintenance infrastructure and institutions making it difficult to compete and offer the same level of service as traditional technologies particularly in rural settings. For remote communities in Canada, this essentially becomes an operations and maintenance cost barrier, as well as a barrier due to a lack of local skilled labour that can easily be drawn upon.

Finally, one barrier that is not discussed by Martin and McDoom (2000) is cold weather, which is often raised as a potential impediment to wind-diesel systems in Canada. While cold-weather modifications need to be made to the turbines that operate in Northern Canada (Maissan, 2001) they have been demonstrated to be able to function in extreme cold temperatures as exemplified by the numerous turbines operating in Alaska discussed in section 1.4. Blade icing is also frequently cited as a potential danger, and while it is issue that needs to be considered when planning a project, by virtue of being in a cold climate does not necessarily pre-dispose a turbine to subject to frequent icing conditions, rather altitude and humidity and likelihood of freezing rain tend to have more of an impact and is not necessarily correlated with latitude (Laakso et al, 2003).

Distilling and combining these barriers in the context of remote Canadian communities, the ten that appear to be the most significant include an awareness amongst communities, awareness amongst utilities, capital costs, operational and maintenance costs, perceived technical risks, regulatory barriers, market failures, environmental issues, local access to equipment/labour and technology maturity. These barriers were put to stakeholders in Chapter 2.

1.6 Federal Support Opportunities for Remote Communities

Indian and Northern Affairs Canada (INAC) has the primary responsibility and authority to fulfil the Federal government's legal and treaty responsibilities Aboriginal and First Nation's communities. INAC provides funding for basic community infrastructure as well as operation and maintenance of this equipment (INAC, 2001). As such it is consistent to expect support for developing alternatives to also come from the Federal government as the vast majority of remote communities in Canada are either Aboriginal or Northern, or both.

There are numerous policy instruments that can be used to foster the deployment of renewable energy technologies. The remote nature of wind-diesel systems is somewhat unique however, and many policies that are already being used in Canada or elsewhere in the world tend to be directed at utility-scale, or grid-connected technologies may not be applicable in a remote context. Incentive options for renewable energy projects can be generally classified in the categories of lowering capital costs, providing a production-based incentive, developing capacity or technical training and mandating minimum generation portfolios mixes. "Polluter pays" options such as a carbon tax are also at the disposal of the Federal government, is a much broader national policy and not specific to remote communities. Other polluter pays options are difficult to justify politically on communities already facing the highest energy costs in the country. A summary of incentive options that are available to the Federal government are listed in Table 4 below:

Table 4: Common policies/programs govnernements use to support wind-diesel systems (adapted from Bailie, et al, 2007)

Instrument	Cost Recovery Source	Policy Requirements
Capital Cost Reductions		
Rebate or Grants	Tax Base or Rate Base	Establishment of qualifying technologies
Property or Income Tax Credit	Tax Base	Tax rule changes (credit limited to size of tax appetite)
Sales Tax Rebate	Tax Base	None
Financing Support	Tax Base	Agreements with financial institutions
Production Incentive		
Feed-in Tariff	Rate Base	Market system operator regulations
Production incentive	Tax Base	Establishing qualifying criteria
Capacity Development		
Community Energy Planning	Tax Base	None, although some jurisdictions are making it a requirement
Technical Training	Tax Base	None
Mandating Generation Portfolios		
Renewable Portfolio Standard	Rate Base	Provincial legislation to set quotas and rules for trading
Emissions Offsets	Rate Base	Legislation to set market rules

1.6.1 Rebates or grants

Reducing the capital cost for wind-diesel projects can be desirable as turbines and the required integration equipment typically make up the largest proportion of the overall project costs (Weis and Ilinca, 2008). This approach also has the advantage of potentially leveraging additional funds for communities that often have difficulty in accessing capital. This can be accomplished through direct rebates or refunds either as a fixed amount or as a proportion of system costs, or reducing other parts of capital expenses such as taxes or the cost of borrowing.

Rebate programs or grants can be attractive to policy makers for their relative simplicity, in that they either lower or refund the purchase price of a desired technology. They provide non-repayable financial support to projects if the project meets specific program criteria. Rebate programs can directly lowering the purchase and/or the installed cost of the system or a specific component of it. Grants can provide an additional benefit of being a "bankable" asset that project developers can use to leverage financing. Rebates are often administered directly from the tax base, and depending on the size or the rebate or the scope of the program objectives rebates can become expensive for the issuing government if they are not carefully designed. An alternative design can be set up a fund by charging a rate rider on the bills of consumers which is pooled into a renewable energy fund.

As a one-time transaction these types of programs are relatively easy to administer for governments, but do not necessarily result in on-going production once the project is built. Forced repayments, or "claw-backs" can be built into such grants to try to avoid program inefficiencies, but may be difficult to extract from a failed company or from a community, if it was the project proponent. In order to be economically efficient, any capital grants need to balance the need to make a project viable that would not be otherwise, compared to over-incenting projects thereby removing risks or the need for medium to long-term success.

1.6.2 Property or income tax credit

Tax credits operate in a similar fashion to grants, although they do not require direct public spending, rather they provides an exemption or refund on qualifying systems. As they do not require specific government spending, they can be attractive to policy makers, although drawbacks for project developers include the fact that tax rebates or credits are retroactive and still require that initial funds are available to build the project. In many cases for remote communities, the entity that may benefit from a government program may have little or no tax appetite to be able to take advantage of such programs.

Section 43.1 of Canadian Accelerated Capital Cost Allowance, is an example of such a program that already exists in Canada which allows for an "accelerated rate of write-off for certain capital expenditures" on alternative energy equipment (Industry Canada 2011).

1.6.3 Sales tax rebates

Sales tax rebates alleviate the need for the project proponent to pay government taxes on equipment that is purchased for the project. The Federal Goods and Services Tax in Canada is 5 per cent, which would therefore be the limit to the size of the support the Federal government could offer for these types of programs.

1.6.4 Financing support

Grant programs require the issuing body to regularly renew the available funds, typically through the annual fiscal budget. Repayable no- or low-interest loans can be a way of reducing the initial capital costs to project developers, while recycling the funds back for additional future projects. This structure is often called a revolving fund and can help to avoid the uncertainty around whether or not a program will be available for from year to the next (Lipp 2008). While there is still an initial capital requirement from the issuing body, with the exception of bad debts the fund is replenish from the projects that are repaying theirs.

This type of program can help proponents access sufficient funds to complete a project however it does not lower the costs of a project that would otherwise be uneconomic, but. Accessing capital can be a challenge for small projects even when the economics are otherwise favourable, as lending institutions may not be comfortable with small community based projects, small developers without significant credit ratings and/or a new technologies whose profitability and success rates they are unfamiliar with. Other options exist to help proponents access financing such as guaranteeing loans made by other financial institutions and may be offered in conjunction with them. Funds can be initially granted from a government, or can be raised by investors or private entities such as utilities. Iowa's Alternative Energy Revolving Loan Program, is an example of the latter.

1.6.5 Feed-in tariff

Feed-in tariffs (or FITs) are so named as they are structure to pay producers to "feed" renewable electricity into the system and are paid a fixed rate, or "tariff" to do so. Feed-in tariffs originated in the United States, but have become most widespread in Europe and are credited by many as being the most effective tool at deploying renewable energy (Mendonça 2007). A feed-in tariff offers a guaranteed power sale price while putting an obligation on utilities to purchase this power and distribute the cost amongst the rate-base. To be effective, the tariff must be a price that is set such that if the renewable energy system operates well it will ensure a modest profit for the power producer (Gipe 2007).

Key elements of a feed-in tariff policy include the right to connect a renewable energy system to the local grid, a fair price that allows for a decent business case for the project, additional premium for specific projects types are deemed desirable such a community owned projects, long-term and stable contacts for the developers and a periodic review of the program that adjusts prices to reflect changes in technology costs (Peters and Weis, 2008). As with any renewable energy policy, the grid is managed and balanced by utility operator.

In spite of their successes for grid-connected renewable power generation, feed-in tariffs have not been used to target remote communities. In the Canadian context, there are several complicating factors to developing such a policy for remote communities. As each remote community is unique and has limited local grid capacity, any renewable energy system needs to be considered on a case by case basis, such that enabling open access to renewable energy projects which is a hallmark of a feed-in tariff is not obvious. While the overall financial impact on the rate base as a result of premiums paid for remote renewable power in the provinces in Canada would be very small, the territorial rate bases are much smaller and would be impacted much more significantly by feed-in rates. Finally, many remote communities in Canada do not belong to larger utilities; – including many within provincial boundaries notably in Ontario and British Columbia – instead they operate, and are responsible for their own diesel systems independently, and therefore would not have a broader rate base to absorb price premiums. Other villages, particularly in the Northwest Territories have price regimes that are at least in part influenced by the local cost of electricity generation, and as such the benefits spreading costs amongst the overall rate base are lost.

The Northwest Territories Power Corporation issued a request for proposals for wind energy projects in 2008, which offered wind energy producers the avoided cost of diesel fuel for any electricity they could sell into selected communities (NTPC 2008). Unlike a feed-in tariff, this was a competitive bidding system and was only open for tenders for a year. However, broader standing offer of this nature would lay the groundwork for a feed-in tariff in these communities.

1.6.6 Production incentive

A production incentive is a top-up or a bonus that is provided to the proponent of a renewable energy project that is directly based on the amount of electricity that is generated by that project. There are many such examples in the North American context, notably in Canada the ecoENERGY for renewable power program (eERP) and its predecessor, the Wind Power Producer Incentive (WPPI) were both federal incentives that provided a producer with one cent per kWh for the first ten years of a project's life. A production tax credit does the same, but the incentive is provided as a credit against annual tax payments instead of as a direct incentive payment, and has been the hallmark federal incentive program for wind power in the United States since the late 1990s. In spite of their similarities, production tax credits can be of lesser use to smaller and community-owned projects as their utility is limited to proponents with substantial tax appetites to be able to benefit (Bolinger 2004).

Unlike a feed-in tariff which is supported through the utility rate base, a production incentive is funded through the tax base. This fact means that these programs not only require an initial commitment of government spending, but they also require a continued allocation of annual budgets to sustain them. As a result, production incentives have tended to be less stable than feed-in tariffs. In Canada, the WPPI was cancelled following the 2006 federal election, and while it was eventually replaced by the eERP which expanded its scope several months later, the latter also ended in 2010 (Weis 2009). This can lead to uncertainty as well as boom-bust cycles of development, which was acutely demonstrated in the case in the United States in the early 2000s (Wiser 2007).

Production incentives do have the advantage of being simple to calculate and their benefits are easy to predict for project developers and can provide the additional bridge towards making a project viable that would not be otherwise. One distinct advantage that a production incentive has in the context of the Canadian federal government is that they can be offered without interfering with provincial or territorial regulations, and furthermore can be complimentary to programs or incentives offered by the latter within their respective jurisdictions.

1.6.7 Community energy planning

The first capacity development tool discussed here is Community Energy Planning. Energy planning can be done by municipalities, regional districts and small communities. Energy planning includes collecting data on current energy demand and costs, and examining alternatives for demand side management as well as alternative options for energy supply.

Energy planning has been carried out for many remote communities in Canada (Denis and Parker 2008), as a first step in examining energy alternatives. Community energy plans typically involve estimates of economic environmental implications of the current energy choices in the community while examining the implications of other future energy options, and includes consultations with community members regarding local priorities to help inform decision-makers in making choices that best meet the goals of their communities. Communities in the Northwest Territories are required to complete an "Integrated Community Sustainability Plan" that must be submitted to a strategic environmental assessment in order that they receive federal government gasoline tax transfers (Government of Canada 2005). Energy plans can be useful for determining the potential for wind-diesel systems, while gauging the level of local support for such a project, and can be important steps in designing a project to help it succeed, but they do not change the economics of such a project.

1.6.8 Technical training

Having local skills to properly install and more importantly maintain wind energy equipment can be important to ensure that preventative maintenance occurs and that necessary repairs can be done in a timely fashion. The latter can become extremely expensive if individuals need to travel great distances into the community to service the equipment not only as a result the costs required for this travel, but also because of lost operation time that can be very significant. An audit of renewable energy systems in remote Australian communities in the year 2000 found that about one-third of the systems installed in these communities were not functional (Lloyd et al, 2000).

Ensuring that training for the proper maintenance of wind energy systems is done locally, as well as training on any specialized integration equipment with the diesel systems can help to ensure that installed equipment will operated as well as possible. This can be done by ensuring that experts who travel to install the systems also train local technicians, as well as programs that bring community members to centralized training facilities. This training is important to ensure that well projects operate as they are designed to do, and can significantly reduce ongoing costs. Such training can either be a part of the project itself, or as a component of another incentive program.

1.6.9 Renewable portfolio standard

A renewable portfolio standard (RPS) is a target for specified amount of renewable electricity to be delivered in a given jurisdiction. Targets can be voluntary was in the case of Alberta (CASA 2005) or legally binding with associated penalties for failure to comply, as was the case in Nova Scotia (Nova Scotia General Assembly 2007). The standard can be the minimum amount of electricity that must be provided as a portion of the total electricity sales or generation, or simply an installed capacity target (whether or not that capacity actually generates electricity). This approach is popular in the United States as well as in Australia. Jurisdictions often allow the trade renewable of credits such that companies who exceed their minimum requirements can choose to sell credits to companies that are below the standard that year.

For such a standard to work in remote Canadian communities, it would require that the quota be made specific to diesel-powered communities, as all provinces and territories with the exception of Nunavut have significant renewable energy systems (typically hydro), the production from which dwarfs the power consumed in remote communities, as such it would be difficult to set a target that would spur development in remote communities as very small changes in the larger systems could more easily and more economically meet the target.

1.6.10 Emissions Offsets

Similar to how utilities or other entities may want to trade credits in a renewable portfolio standard, emissions credits could also be traded as part of a broader emissions reduction program, either mandated or voluntary. The ability to sell the offsets essentially monetizes the value of reducing emissions, and effectively becomes a subsidy to the project helping to delineate the advantages of clean energy projects compared to those that pollute.

One difficulty that is particularly acute for the small populations and relatively small levels of overall pollution resulting from remote communities compared to large industries would be the relatively small amounts of credits that they could generate, and equally challenging would be the accounting and auditing of the credits themselves, which may outweigh the potential value of the credits themselves. One option that remote communities could pursue in such a system would be to bundle their respective credits in a similar way to what was allowed for small projects in the Kyoto Protocol's Clean Development Mechanism (Peters et al, 2002).

It is important to note that both an emissions offset program or a renewable portfolio standard for remote communities could mandate the development of wind-diesel systems or at least create a favourable market for them, although neither directly reduces the cost of their development. This could be a deterring factor for remote communities already facing acute electricity costs, although in the longer-term there may be cost savings for rate payers as diesel fuel prices increase, this prospect would need to be clearly communicated to potential host communities.

1.6.11 International wind-diesel programs

The policy options discussed above present various options that could be pursued by the government of Canada to encourage remote wind-diesel systems. Lipp (2007) argues that a "policy framed around specific goals and targets is more likely to achieve results than vague support" such as a government or utility goal for "more" renewable energy. This argument is supported by the fact that technology neutral programs such as the Aboriginal and Northern Climate Change Program Aboriginal (ANCCP) and the Northern Community Action Program (ANCAP) programs put in place by INAC between 2001-2007 resulted in no wind-diesel projects in Canada (INAC, 2004 and CIER 2010). This, combined with the fact that wind-diesel systems provide unique technological challenges, suggest that a program specific to remote wind energy is more likely to achieve results.

While both Mendonça et al (2009) and Sovacool (2009) examine large-scale renewable power deployment, a common point they both emphasize in successful jurisdictions is the importance of stability as well as a comprehensive design of a renewable energy policy. A federal program to encourage wind-diesel systems should therefore be not only targeted this technology but also needs address multiple barriers to their development and/or be a part of a broader framework of policies that does.

There are two international programs that are worth examining in the context of remote communities, notably the Renewable Energy Grant Program (REGP) in Alaska and the Bushlight program in Australia.

The Renewable Energy Grant Program was created in Alaska in 2008, and is administered by the Alaska Energy Authority (AEA 2008). This five year program is designed to allocate 50 million USD as grants for qualifying projects.

The REGP provides assistance to utilities, independent power producers, local governments, and tribal governments towards the development of renewable energy projects within the state of Alaska ranging from feasibility studies, energy resource monitoring, and design and construction of eligible facilities. The fund is not limited to wind-diesel projects and includes technology ranging from solar, to geothermal, to fuel cells that use hydrogen generated from an eligible renewable resource or natural gas.

Applicants to the fund can submit project proposals into bi-annual solicitations for projects. The fund addresses many of the barriers to wind-diesel projects from feasibility to capital costs. Finally, there are no set limits on grant amounts either maximum or minimum contributions.

The REGP program was put into place after a significant base of projects have been developed in Alaska with the assistance of various federal and state initiatives since 1997. Furthermore, additional regional scoping and planning have been undertaken to determine the viability of wind projects for across the state (Dabo et al 2007). Initial results indicate that it has in part been responsible for at least twenty new wind-diesel projects under development (Baring-Gould and Dabo 2009). The program does not appear to set any goals for renewable energy project development in general or wind-diesel projects specifically. The level of support allocated to successful (as well as potentially unsuccessful) projects will be important to track.

The REGP is larger (250 million USD) than the entirety of the WPPI program (220 million $Cdn), the first Canadian program implemented to support 1,000 MW of wind power nationally and as such is it not likely a politically feasible model to emulate for remote communities in the Canadian context, although given the similarities between many remote communities in Canada and Alaska, it is worth noting and monitoring. Finally, it is worth noting that the establishment of the REGF has also resulted in wind mapping, training programs and the establishment of new ENGOs and university programs, none of which are funded directly by the REGF.

Australia's Bushlight program was initiated by Australia's federal government in 1999 and was extended for an additional four years in July 2007. Bushlight is funded through the Renewable Remote Power Generation Program (RRPGP) which, in 2007 was awarded an additional AUD 123.5 million over four years. The focus of the Bushlight program is solar photovoltaic systems, although its comprehensive approach to supporting the development of solar projects, their maintenance as well as assisting in overall community energy planning is worth examining.

Bushlight uses incentives, direct technical assistance and education to increase small remote indigenous communities' access to affordable, consistent and reliable renewable energy services. The program is implemented as a quasi-commercial venture with the Centre for Appropriate Technology and has three objectives, notably to improve reliability, ensure Indigenous communities have access to an integrated energy service network, and to build confidence in renewable energy systems amongst participants (Bushlight 2005).

Bushlight has been subject to boom/bust cycles based on federal government focus. The 2005 evaluation found that "Bushlight remains relevant against current federal government policies", however the program has undergone numerous renewals as the initial funding covered a four year commitment, followed by subsequent two year commitment and the two, six-month extensions. In spite of this funding uncertainty, the program has continued for over a decade.

In addition to providing grants for renewable energy projects, Bushlight directly addresses barriers that are specific to remote and rural communities by focusing appropriate technologies and maintenance agreements. It directly addresses the "softer" barriers such as lack of skilled labour or effort needed to understand technologies and process applications. The Bushlight program provides training on installation and maintenance of the solar systems, although on-going service and maintenance has often been provided by Bushlight staff as opposed to members of the remote communities. The 2005 review of the Bushlight program recommended that Bushlight "extend its role in supporting the Regional Industry and technical capacity development, and in particular to consider opportunities for indigenous people." This review also found that the application and approval process can be a "severe bottleneck" to project implementation.

1.6.12 Developing a Canadian Policy

During this research, I worked with the Canadian Wind Energy Association's small wind caucus to design a policy framework for an incentive structure that would be appropriate for Canadian remote wind-diesel systems. While there is no direct relevant policy comparison either in Canada, Alaska or Australia, lessons from similar policies were incorporated into its design. The program concept that has been given the working title the "Remote Community Wind Incentive Program" or ReCWIP. This incentive program and its structure are discussed throughout the work and its potential impacts are modelled herein. The design of the incentive is based on assessing the aforementioned policy options and recognizing which attributes have been most successful and are appropriate in the Canadian context, while taking into account the results of a stakeholder survey that was done as part of this research to determine the key barriers that an incentive would need to address. The design of ReCWIP and its potential impacts are described in Chapter 4.

1.7 Summary of Research

There are numerous reasons that remote communities may be interested in pursuing renewable energy systems such as wind power, and there are likely as many barriers that confront these same communities in doing so. There are many wind-diesel systems currently operating all over the world in extremely harsh environments from Alaska to Antarctica (Patel 2009), some of which are operating in configurations where wind energy provides over 60 per cent of the annual electricity consumption. As such, it is clear that technology and control systems are not the primary barrier that they once were for these systems, but rather current economic and policy frameworks do not facilitate the deployment of this technology in Canada. This research examines some of those barriers within Canada and possible solutions to overcome them. The first paper presented in Chapter 2 is a survey of stakeholders within the Canadian market examining their perceptions of key barriers to the deployment of wind-diesel systems. This paper identifies costs, both capital and maintenance as key barriers to deployment as well as local technical and human capacity. The second paper presented in Chapter 3 uses a novel modelling approach to examine how the economics of wind-diesel systems could be improved if power storage systems could be added to facilitate high levels of wind penetration and what the economics of such power storage systems needs to be. The final paper, which constitutes Chapter 4, models the potential for a Federal incentive to support broad deployment of wind-diesel systems in Canada. Together this research examines the state of policy barriers to wind-diesel systems in Canada and analyses how using technological advances and incentive policies can be evaluated to overcome these barriers.

CHAPTER 2: STAKEHOLDERS' PERSPECTIVES ON BARRIERS TO REMOTE WIND-DIESEL POWER PLANTS IN CANADA

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Abstract

Canada has been experimenting with wind-diesel hybrid systems for its remote communities for over 25 years with limited success. This paper discusses the results of a year-long survey that was distributed to stakeholders in wind-diesel systems in remote Canadian communities. These stakeholders include utilities, wind energy technology manufacturers, project developers, researchers and governments. The analysis shows that there is a strong agreement that capital and operating costs are the most significant barriers to the implementation of wind-diesel systems and that direct project financial incentives, notably production and capital cost incentives designed to reduce these costs are perceived as the most effective way to encourage development. There is a notable disagreement between utilities and governments on one hand who are split as to the current technical viability of wind-diesel systems, and manufacturers, developers and researchers on the other who overwhelmingly believe that wind-diesel systems are mature enough for remote applications.

2.1 Introduction

2.1.1 Wind-diesel history in remote Canadian communities

The wind-diesel hybrid systems present an opportunity for reducing fossil fuel use in many remote areas. Large-scale, grid connected wind power plants have experienced rapid rates of deployment around the world for the past two decades in large part as they are in many cases close to competitive with traditional power plants whose power sells for on the order of 5-6 cents per kilowatt-hour. However, limited access to strong winds, limited tower heights, increased transport costs and difficult operations and maintenance associated with the remote sites as well as the necessity of sophisticated controls for wind-diesel hybrid systems, result in very high costs. For this reason, the wind-diesel systems have had difficulty competing with traditional diesel power plants even though their generation cost can be five to ten times that of conventional, grid-connected power plants. The market for large-scale wind turbines has drastically outpaced the medium-size turbines appropriate for most community-scale wind-diesel power plants and as a result have seen much slower rates of growth and technology maturation compared to their on-grid counterparts.

Canada has over 200,000 citizens in approximately 300 remote communities that are not connected to either territorial or provincial electric grids (Ah-You and Leng, 1999), many of which rely on diesel powered electric generators. The costs of diesel fuel, risks of fuel spill mitigation, local air quality and long-term sustainability are often cited as reasons for communities to look for alternative solutions. Meanwhile, the utility companies that are responsible for these jurisdictions either operate in a deficit (Reid and Laflamme, 1995) or pass on the high costs of generation to their customers, or a combination of both (Pinard and Weis, 2003). Few alternatives exist however for many of these communities as the economic constraints of construction in remote communities can quickly limit the distance that transmission wires can be strung to harvest a renewable resource such as small hydro, while communities in the far north have limited access to solar or biomass resources, or even experimental technologies such as wave or tidal.

Harnessing the wind however, has long been perceived by as a potentially viable alternative, in fact the first wind-diesel research project began in Canada in 1978 (Chappell, 1986). There has been more than 10 Canadian wind-diesel demonstration or pilot projects by utilities and governments since that time as well as a few commercial ventures where independent power producers have negotiated deals to sell wind power to remote community grids (Weis and Ilinca, 2007). Most of the projects were met with marginal success, some had earlier mechanical problems such as in Sachs Harbour, Northwest Territories and Big Trout Lake, Ontario, which after having overrun initial installation budgets were abandoned. Others, such as Kasabonica Lake, Ontario, Rankin Inlet, Nunavut and Cambridge Bay, Northwest Territories failed as a result of a lack of ongoing operations and maintenance. Finally, projects such as Kuglutuk, Northwest Territories had unusual accidents including being hit by lightning. In all cases, the diesel savings were not deemed to be significant enough to warrant reconditioning or repairing the projects after the initial pilot or grant money had been spent to build them. While mechanical failures are part of the normal operation of any rotating machinery, including diesel engines, wind generators do not have the same availability of replacement parts, or locally trained technicians to troubleshoot and repair equipment. As a result by the late 1990s much of the interest in wind-diesel systems had waned. Since the year 2000 only one system has been installed in Canada.

Owing, in part at least, to the several successful wind-diesel projects operating in Alaska, which are outlined in Section 2.2, there has been a renewed interest in wind-diesel systems in the Canada in recent years. The Alaska projects have demonstrated that wind-diesel technology can work in harsh climates and remote conditions given the right circumstances (AWEA, 2007). This is illustrated by the fact that wind monitoring stations have been installed in more than ten remote communities across Canada since 2005 to help remote communities gauge the potential for of developing local wind power systems,. The Government of the Northwest Territories also recently committed to developing an operating wind turbine by the year 2009 (GNWT, 2007).

2.1.2 Rationale for examining stakeholders' perceptions

Identification of the barriers, and the relative perception of these barriers, is key to focusing the discussion on issues to be resolved. Lundsager et al. (2004) suggested identifying barriers "is about eliminating the deadlock situation that the market for wind power in isolated power systems has not developed because the product is not there and the product has not developed because the market is not there."

This paper characterizes and classifies barriers to wind energy development in remote Canadian communities from the stakeholders' perspectives. Having identified the prevalent barriers to development, they can be systematically addressed and removed. Energy projects in remote communities inevitably involve governments be they Federal, Provincial or Territorial, as well as local utilities. In order to encourage long-term wind-diesel developments, it is therefore important that barriers perceived by these groups be addressed such that effective policies can be implemented to foster the technology. To that end, the survey also examines the stakeholders' perception on potential policy mechanisms to encourage wind-diesel development.

The current research aims to inform some of the impending decisions about remote wind-diesel systems with the hopes of encouraging long-term growth in wind-diesel projects as opposed to sporadic pilot projects that to date have been largely unsuccessful in Canada.

2.2 Methodology

2.2.1 Stakeholder survey

This study involved collecting data from surveys distributed to stakeholders to the development of Canadian wind-diesel systems. A multi-stakeholder approach was employed as it was deemed necessary to identify all of the barriers (Painuly, 2002), and also has the advantage of illustrating the varying perceptions about wind-diesel technology across the industry. The methodology is similar to that of Reddy and Painuly (2004) who used a multi-phased stakeholder approach to examine barriers to renewable energy technologies in the Indian state of Maharashtra. For the current study, targeted stakeholders included wind energy technology manufacturers, researchers, electric utility companies, project developers and governments, all of whom will be directly involved in any future wind-diesel developments in Canada.

The survey asked respondents to rank the most significant barriers to wind-diesel systems from a list of major constraints. Respondents were also asked to comment possible policy and financial incentive mechanisms that would encourage development of wind-diesel systems. Finally each respondent was asked if, in their opinion, wind-diesel systems are "ready" to be deployed in the Canadian Arctic. In each case respondents were also invited to comment on each category to delve deeper into areas of personal concerns or experiences.

Wind-diesel systems are a fairly small niche within the much broader wind energy industry, as such the number of people with direct experience in such projects in Canada is fairly small, nonetheless the responses to the survey captured a broad spectrum of stakeholders in the industry with close to a 80% success rate in survey responses. Table 5 lists the number of surveys that were distributed to members of each category and the number of responses. The results of these responses are the basis of the analysis in this paper.

Table 5: Survey respondents

	Manufacturer	Researcher	Utility Employee	Project Developer	Gov't Employee	Total
Persons approached	10	11	10	11	11	53
Responses	7	11	7	9	8	42
Response Percentage	70%	100%	70%	82%	73%	79%
Percentage of Respondents	17%	26%	17%	21%	19%	100%

While the survey focused specifically on off-grid wind-diesel systems, responses were collected from stakeholders in nine of the ten Canadian provinces and all three territories. Surveys were targeted at those who are, or have been in the past, directly involved in wind-diesel development in Canada. The surveys were conducted between October 2006 and July 2007. The following describes each category of respondent:

Manufacturers: of medium-scale wind turbines (30-100 kW) as well as manufacturers of wind-diesel integration equipment such as controllers and software. Manufacturers were not restricted to Canadian companies, but were only included if they had experience with remote communities in North America.

Researchers: include academics, NGOs and research consultants who are involved in remote community issues. Many within this category are also involved in the early steps of project development by completing energy planning studies, feasibility assessments, wind analyses or other desktop studies at the early stages of projects. Within this category are those who are often responsible for initiating projects or assisting communities in becoming aware of wind energy opportunities, as well as advocates for policies that would encourage renewable energy systems to be implemented.

Utilities: who were contacted and replied to the survey are responsible for remote communities that are serviced by their company. In the case of the Canadian territories, all the utilities deal explicitly with remote communities, while members of larger provincial utilities who were contacted were those directly involved within a division of their companies that deal with the subset of remote communities within their service areas.

Developers: are people whose companies are involved in building, financing and/or operating wind-diesel projects as independent power producers. To be included in this category, project developers needed to be involved in the stages of a project when capital investments are made. Not all developers included in this category have successfully developed wind-diesel projects.

Government: employees were contacted from territorial, provincial and federal levels who are involved in policies or programs that either regulate, offer incentives to or assist in funding renewable energy projects and who's jurisdiction includes remote communities.

It is important to note that members of remote communities are interspersed among the various stakeholder groups.

2.2.2 Barrier ranking

Barriers to remote wind energy systems in Canada need to be seen in light of recent successful wind-diesel projects in Alaska and Newfoundland. In 1999, a high-penetration wind-diesel system was commissioned on St. Paul's Island using a single 225 kW turbine and by the year 2002 Wales, Alaska had installed two wind turbines totalling 100 kW of wind power also in a high-penetration configuration. Kotzebue, Alaska now has 17 wind turbines installed, the first three of which have been operating for ten years having been commissioned in 1997. The present total in Kotzebue is one megawatt of wind power capacity, while the community is aiming to reach 2-4 MW to reach high-penetration wind levels. In 2004, Selawik, Alaska installed 150 kW of wind energy capacity onto their remote grid. At the time of writing this paper in the year 2007, the total installed wind energy capacity in the state is close to 2 MW (AWEA, 2007). During this same period of time very little has gone on in Canada, with the exception of six, 65 kW wind turbines that were installed in the remote fishing village of Ramea on the south shore of Newfoundland in 2003 and have been operational ever since, in a medium penetration configuration. The are all important projects as they were frequently cited by respondents to the survey to indicate that there are barriers specific to the Canadian north that are preventing the uptake of similar systems there.

The survey asked each respondent to rank their top five barriers to wind-diesel development in Canada out of a list of ten that included: (i) awareness amongst communities, (ii) awareness amongst utilities, (iii) capital costs, (iv) operational and maintenance costs, (v) perceived technical risks, (vi) regulatory barriers, (vii) market failures, (viii) environmental issues, (ix) local access to equipment/labour and (x) technology maturity as well as an opportunity for respondents to list other barriers they believed to be important. These barriers were selected after conducting numerous interviews with various stakeholders about failed projects in Canada. The list was intended to be specific to highlight key issues, such that costs for example were broken into capital and operating and not lumped together, as was awareness barriers that was specific to utilities and communities.

Respondents were asked to rank the barriers on a scale of '1' through '5', with '1' indicating the most important barrier, such that from their point of view, the removal of which is the most critical step towards the adoption of wind-diesel systems in Canada. To normalize the data relative values were given to each barrier were 5/5 points for a '1' ranking, 4/5, 3/5, 2/5 and 1/5 for a '5' ranking, while a 0 was given to each barrier which the respondent did not rank in the top five. The valued average was thus obtained within each respondent category as follows:

$$r_i = \sum_{j=1}^{N} \frac{W_j M_j}{N}$$

where r_i is the normalized rank of each barrier and W_j is the value assigned to the j^{th} rank, M_j is the number of respondents enumerating the barrier at the j^{th} rank and N is total number of respondents within each category. The normalized value for each barrier is therefore a maximum of 1 if every respondent rank the barrier as '1', and 0 if that barrier is not ranked by any of the respondents as being in the top five.

2.2.3 Discussion of barriers

This section provides a description of each barrier that was listed in the survey and how it impacts wind-diesel projects. The following ten barriers below include those that were listed on the survey.

i. Awareness amongst communities: projects that take place in remote communities require the input, assistance and acceptance of the community residents and leadership. Renewable energy projects in particular can take many years to develop and remote communities typically have limited human resources and need to choose carefully their local priorities. Therefore, if communities and in particular their leadership are not aware of the potential benefits of a wind energy system they are unlikely to invest the required time and effort to foster the development of such a project.

ii. Awareness amongst utilities: while some remote communities in Canada have their own independent power authority, the majority are serviced by a territorial or province utility, who own and operate the local diesel power plant and/or power grid. Connecting wind turbines as an independent power producer therefore requires at minimum the approval of the local utility to connect to their system and negotiate a power purchase rate. Ideally, utilities will be active participants in the project such that the wind turbines can be most effectively integrated with the diesel power plan to optimize how each operate. Alternatively, utilities may develop such projects on their own if they believe such systems will accrue financial benefits. In either case, the utility needs to be aware of the potential impacts and benefits a wind energy system will have on their diesel grid as they can typically prevent or make such projects difficult to pursue.

iii. Capital costs: like most renewable energy projects, wind turbines are capital intensive and can take many years to pay back. Small communities and small developers may have limited access to capital or credit to either invest in such projects, or to tie up for the time that it takes to be repaid. The capital costs thus dictate in large part the level of financial risk that project investors are subjected to.

iv. Operational and maintenance costs: capital and ongoing costs were intentionally separated in this survey as they pose two significantly different obstacles and have potentially different solutions. In the past pilot and demonstration projects have received special grants to get established in order to purchase wind energy equipment, but are rarely supported on a long-term basis. Therefore if unexpected difficulties are encountered once a project has been built it may be difficult to continue to operate after the initial funding is used. In any case, be it a pilot project or a commercial venture, annual operations and maintenance is directly tied to annual profits and therefore need to be minimized.

v. Perceived technical risks: in contrast to technical maturity which is listed below, this barrier is the perception of risk, be it real or imagined, which can prevent any of the stakeholders from endorsing or participating in the development of such projects.

vi. Regulatory barriers: include such things as having access to the local power grid, rules concerning who is allowed to sell power in the jurisdiction and at what rate. Other regulatory barriers may include access to build on public lands, permits, environmental assessments, etc., which either may be direct barriers or result in additional time and/or costs.

vii. Market failures: this barrier refers to the fact that diesel fuel is often subsidized in northern and remote communities such that alternatives such as wind power may be unfairly competing against a fuel price that is artificially lowered. Different subsidies are available to different communities across Canada, ranging from direct diesel fuel subsidies to indirect subsidies through local diesel electric costs included into the overall provincial or territorial rate base. Other communities, particularly aboriginal communities may have direct arrangements with the Federal government. Market failures can also be perceived to occur if the utility or whoever sets the electricity rate undervalues the price of wind generated electricity. In many cases in Canada, utilities are willing to offer only the displaced costs of diesel fuel for any electricity generated by the wind, while developers and advocates may argue that there is additional value to this electricity such as minimizing operations and maintenance on the diesel plant, reducing local air emissions and reducing the risks of local fuel spills and costly clean-ups, therefore perceiving the avoided cost of diesel as an unfair price thus a market failure.

viii. Environmental issues: include impacts on wildlife such as bird collisions, ground water impacts or construction in ecologically or culturally protected areas that could impede or prevent projects.

ix. Local access to equipment/labour: equipment, notably cranes and other heavy machinery is not readily available in most remote communities, nor the skilled labour required operating such equipment in the construction and/or the long term maintenance of wind turbines.

x. *Technology maturity*: not only do the wind turbines need to operate in remote locations, the machinery is, in the majority of remote Canadian communities, operating in extreme cold temperatures during the winter months. There are various components of the technology that all need to operate with minimal supervision from those outside the community including within the turbine itself such as gearboxes, brakes and yaw control, while the control systems also need to perform in such a way that not only is the wind power maximized but that the grid remains stable with respect to voltage and frequency.

The following three barriers are those that were not on the survey but were suggested by more than one respondent, and are described based on comments provided in the surveys:

xi. *Government responsibility*: the federal or territorial/provincial governments have a responsibility to their constituents in remote communities who otherwise have limited access to capital and technical expertise.

xii. *Lack of Wind Data*: wind energy systems are very sensitive to wind speeds as the power output is cubically related to the wind speed. Adequate wind regimes are thus critical for the economic such of any wind project. While most remote communities have airports, very few record long term wind data in their community, and if in cases when it is recorded the towers may not be ideally situated and/or are below the height that a wind turbine would ultimately stand.

xiii. *Lack of technical training programs*: there is currently no formal technical training for wind energy systems for either operators or utilities. To date, projects have relied on retrofitting diesel engineers and operators to be responsible for any hybrid system.

2.2.4 Incentives

Respondents were also asked to indicate what type of incentive would best encourage wind-diesel system development. Each respondent could choose up to two types of incentive, although they were not asked to rank their selections. The following five options that were listed on the surveys are types of incentives that already exist in Canada for other renewable energy technologies and/or applications:

Production Incentive: is paid on top of the selling price of electricity to the owner of the system. Contrasted to capital cost grants, a production incentive is only received when the renewable energy is delivered so that it encourages long-term operation and maintenance and also offers policy makers the ability to track the actual renewable energy produced as a result of their program. A 1 cent/kWh production incentive has been in place in Canada since 2001, although the minimum size requirements for this incentive is 1 megawatt, thereby excluding most remote projects.

Capital Cost Grant: is a simple rebate for the installation of a targeted system. A grant helps overcome high upfront costs and is simple to administer, but does not guarantee the project will operate after the grant is received. An example of a such a program in Canada is the "ecoENERGY for renewable heat program" whereby commercial solar air and hot water heating systems receive a 25% installed cost grant (Government of Canada, 2007). Some of the past wind-diesel projects in Canada received special one-time research or pilot project funding but there has never been an established program.

Renewable Energy Portfolio: requires utilities to incorporate a certain amount of generation from renewable sources. Examples of renewable energy portfolios in Canada are the province of Prince Edward Island that set a renewable portfolio minimum of 15% by the year 2010 (Government of Prince Edward Island, 2004) and British Columbia where all new and existing electricity will need to be greenhouse gas neutral by the year 2016 (Government of British Columbia, 2007).

Tax Credits: do not require a cash outlay from governments but instead involves forgone tax revenue, making it less prone to annual budget cuts, and can be offered to third-party investors as 'flow-through' credits to attract outside capital. A production tax credit has been implemented in the United States for many years to stimulate large-scale wind energy development.

Green Energy Attribute Sales: the environmental benefits of a renewable energy project such as the reduction in greenhouse gas emissions or acid rain precursors can have a value on voluntary and regulated markets, both domestically and internationally. The greenhouse gas reductions associated with wind-diesel projects is typically too small for such markets without being aggregated.

The following two types of assistance were suggested by more than one respondent to the survey and are described below based on their comments:

Demonstration Projects: establishing a working model in Canada is important to help improve the confidence of utilities, to build human capacity in the north and to help improve the technology, notably control systems and cold weather operations.

Training Programs: offer training courses not only for local machine operators but also to utilities who have a tendency to use in-house engineering resources, but who have little experience with a new technology that behaves significantly differently than diesel systems.

2.3 Results and Discussion

2.3.1 Barrier overview

Of the barriers that were listed in section 2.2 there was a strong agreement amongst the various stakeholders on the top four issues, which in decreasing order of importance were found to be capital costs, operations and maintenance costs, perceived technical risks and access to equipment and labour. By normalizing all of the ranking data, the barriers can be listed in order of concern for each respondent group. Table 6 lists the top five barriers for each respondent group based on their normalized ranks, but not the normalized rank itself.

Table 6: Top five perceived barriers by respondent category

	Manufacturer	Researcher	Utility	Developer	Gov't	Ave.
Capital costs	2	1	3	1	1	1
Operation and maintenance costs	5	2	2	2	3	2
Perceived technical risks	1	4	5	2	2	3
Access to equipment/labour	5	3	3	5	4	4
Technology maturity	8	7	1	6	5	5
Market failures	7	5	6	6	6	6
Awareness amongst utilities	2	6	10	8	7	7
Awareness amongst communities	4	9	8	9	7	8
Regulatory barriers	10	8	9	4	11	9

In order to capture the top five barriers compiled by each group, nine of the ten barriers are listed above, with only environmental issues not being considered to be amongst the top five by any of the stakeholder groups. On average, each of the five category of respondent type ranked the top four barriers in at least their top five barriers. Technological maturity was the next highest average rank as it was ranked number one by utility respondents and fifth by government respondents, although notably 6th, 7th, and 8th by developers, researchers and manufacturers respectively. While market failures, utility awareness, community awareness and regulatory barriers were each ranked in the top five by one of the five respondent groups, none were ranked in the top five by more than one group.

As was discussed in the methodology section, the data for each group was normalized to return a relative ranking between 0-1. The top five average barriers are shown in Figure 20 with the normalized ranks of each of these five barriers from each respondent group. It is important to point out that a lower ranking does not necessarily mean that a particular issue is not recognized as a barrier, but rather that as a group, other barriers were perceived to be more pressing.

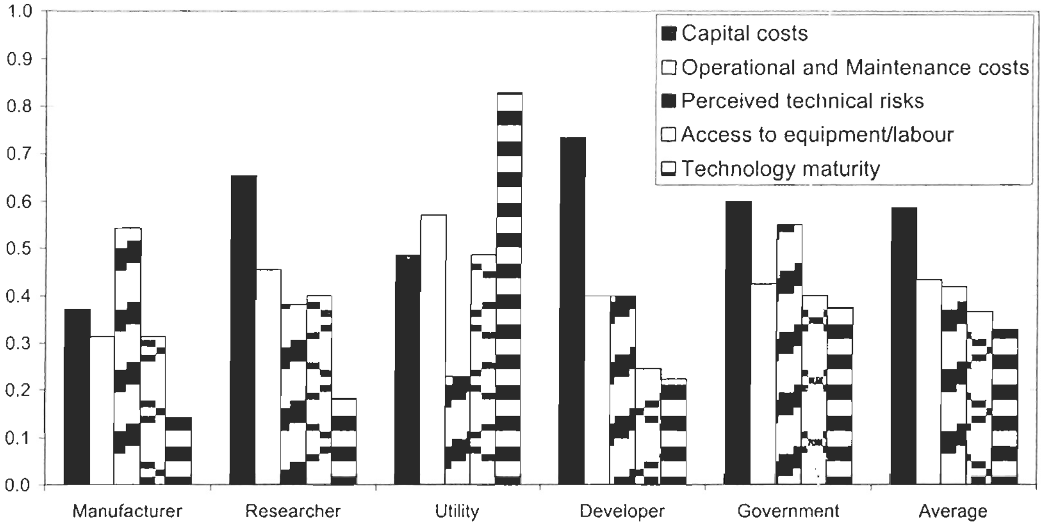

Figure 1: Normalized values of each barrier for each respondent group

Clearly system costs, both capital and operation and maintenance are identified as major concerns for each respondent group. Every group identified both costs within their top five barriers, and all but manufacturers identified them both in their top three. There are several reasons why these costs are crucial. Firstly, while wind energy systems are operating in an arena with high electricity costs, it is important to note that the avoided cost of diesel fuel is often the cost that the turbines are competing against. So, while the retail cost of electricity in remote communities can be on the order of 0.50-1.50 $Cdn/kWh, the avoided cost of fuel is often only 30% of the final cost (GNWT, 2007), therefore it often takes longer for such systems to return on their investment than it would appear solely based on the retail costs. Transportation of both equipment and skilled labour to install and perform major repairs to remote communities is very expensive. Heavy or large equipment that is shipped by sea typically has a single annual delivery in Arctic communities, such that missing or damaged equipment can result in yearlong gaps in project implementation and thus in revenue generation possibilities.

Current estimates range from 5,000 $Cdn to 7,000 $Cdn per installed kW for remote wind energy projects with operations and maintenance costs ranging from 80 $Cdn to 250 $Cdn per year per installed kW (Pinard and Weis, 2003). Assuming median values for each cost, and a 20-year loan at 8%, a 25% capacity factor and a 0.30 $Cdn/kWh power purchase rate (Maissan, 2006), the annual costs would average 770 $Cdn/kW, compared to revenue generation of 660 $Cdn/kW installed. Although this is just an illustrative case and specific projects will vary from these general estimates, clearly costs would need to be improved significantly from current estimates over and above any unplanned or unbudgeted trips during construction or operation will further erode the economics of such projects. For example, a single round-trip for a technician from southern Canada to a remote community can cost on the order of magnitude of 10,000 $Cdn including flights and labour costs, which can represent as much as 30% of the expected annual revenue of single 50 kW machine using the above estimates. It is important to note that the costs are relatively high in the current economic circumstances where wind energy systems are competing with the current avoided cost of diesel fuel. The costs are therefore high in relative terms, but not necessarily in absolute terms as it is conceivable that the costs of diesel fuel could increase significantly, or the value paid for wind generated electricity be increased from simply the avoided costs of fuel to recognize benefits such as reduced fuel shortage requirements or reduced risk of fuel spill contamination remediation.

Technical risks ranked the next highest overall barrier. Perceived technical risks ranked on average third while 'actual' technical risks or technical immaturity ranked fifth. The technical risks were intentionally categorized to distinguish between respondents who felt that at least one key component of wind-diesel technology (not necessarily the turbines) was not technically mature enough for remote applications, contrasted to the barrier that a perception of technical immaturity, likely amongst key decision makers, was a problem and not necessarily that wind-diesel systems themselves are not ready. This distinction is fairly clear as manufacturer, developer and government respondents ranked the perception of technical risks as either first or second most significant barrier, while the utility respondents ranked technical maturity on average as their primary barrier. It is reasonable to assume therefore that the manufacturers, developers and government respondents who have attempted to initiate or facilitate wind-diesel projects have encountered resistance from members of utility companies who do not believe that the technology is ready for remote applications. Notably, all of the other respondents ranked the actual technology maturity on average as the fifth most significant barrier or higher.

There is therefore clearly a gap between the utility employees' and the other stakeholders' understanding of current wind-diesel technology. This is illustrated by the responses to the direct question that each respondent was asked separate from the barriers ranking: "In your opinion are wind-diesel systems ready for deployment in the Canadian Arctic today?" While the overall responses were almost 3:1 in favour, the responses from utility employees was almost exactly 3:1 against. The summary of responses is listed in Figure 2. While government employees were roughly split on their perception of wind-diesel readiness, the unfavourable opinion of responses from utilities is in stark contrast to the manufacturers', researchers' and developers' responses were close to 90% in favour in each case.

Based on the average of all of the respondents, access to local labour and equipment was on average the fourth most significant barrier. Local capacity constraints were ranked fairly consistently by each respondent group, either third, fourth of fifth in each case, it is therefore viewed by all stakeholders as a very prominent issue, but not the most pressing obstacle.

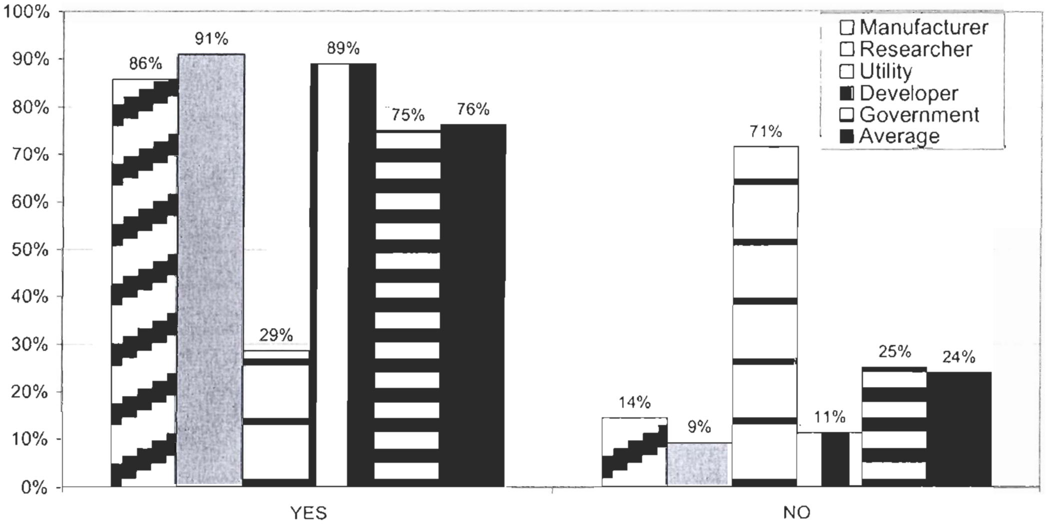

Figure 2: Percentage of respondents perception to wind-diesel systems' readiness for remote community deployment

Four other barriers were ranked within the top five by only one of the various respondent groups. Researchers' responses ranked market failures as the fifth most significant barrier, while developers on average reported regulatory barriers as the fourth most important barrier to wind-diesel development in Canada. Manufacturers were the only stakeholder group to have two of their top five barriers outside of average top five responses. Awareness amongst utilities and awareness amongst communities were ranked as the second and fourth most significant barriers respectively by manufacturers, but these barriers were ranked relatively low by all of the other stakeholder groups.

2.3.2 Manufacturer perceptions

As was noted earlier, the most noticeably aspect of manufacturer responses was the emphasis on a perception that wind-diesel technology is not ready to be deployed as well as a lack of awareness amongst utilities. Both of these clearly point to a perception that utilities do not understand the current state of the technology. This was elaborated upon in written comments on the returned surveys that included suggestions that the legacy of failed projects continues to haunt the industry in spite of advances since such projects. A suggestion that independent peer reviewed information on projects that have been implemented could help overcome some of these concerns as well as life-cycle costs and actual performance information to establish objective project evaluation. Manufacturers also noted that there are no programs available to help them innovate in areas such as cold weather packages, grid integration as well as foundation and tower design.

2.3.3 Researcher perceptions

While the researchers' ranking of top five barriers was fairly consistent with the overall average rankings, the issue of market failures was ranked higher by researchers than any other respondent category. This issue was also emphasized in respondents' comments who frequently noted that diesel fuel is typically subsidized in remote communities in one form or another, such that wind energy systems are competing unfairly with artificially lowered costs. Researchers frequently noted that there are no specific incentive or subsidy programs for wind power systems in remote communities that would help such systems compete with diesel plants. It was suggested that such programs are required in order to help the technology mature as technological improvements would not occur without practical experience. Such programs would thus help wind-diesel systems to become cost competitive on their own, as well as to help establish the technology before it is needed more urgently if fuel prices continue to rise and/or warmer temperatures make winter road access to many remote communities more difficult.

2.3.4 Utility perceptions

Comments from utility respondents tended to focus on economic barriers to development in remote communities. Most Canadian utilities with remote communities in their jurisdictions have experience with pilot wind-diesel projects, including many of those who responded to the survey. Utility respondents generally indicated that there are limited economies of scale in the diffuse remote communities in the North to bring either capital or operations and maintenance costs down. A notable comment stated that: "while there is much talk about the success of wind in recent years, there still seems to be little experience with small-scale wind-diesel integration into arctic, remote, off-grid communities", reinforcing the notion that there is a lack of confidence in wind energy systems by the utilities whose responsibility it is to supply reliable power to the communities, and who see that the economics do not make this an efficient use of funds.

2.3.5 Developer perceptions

Beyond the barriers identified earlier, written responses from developers emphasized the importance of local community involvement in such projects, from decision making, to project management to long-term project operations and maintenance. Respondents emphasized a need to educate community leaders in order to make informed decisions about potential projects and potential project partners, but also to ensure that the project is ultimately driven from within the community itself as opposed to either utilities or even developers outside of the community. Developers also noted a lack of policy instruments that would either encourage wind-diesel development or simply streamline regulatory issues such as equipment standards, interconnection processes and market access rules.

2.3.6 Government perceptions

The average responses to perceived barriers from government employees were very similar to the overall response average, particularly the top five barriers that were virtually identical. Comments from government employees indicated a need and a willingness for governments to play a role in facilitating future projects as past project failure have created a "stigma". "The government's role must be to support the private sector, utilities and communities to offset these costs and ensure proper operation and maintenance are not sacrificed when margins are slim." Government responses on how best to support project development included local capacity building, creating a technical training centre in the North, assisting in the development of demonstration projects in addition to monetary incentives such as capital and production grants which will be discussed in more detail in the following section.

2.4 Incentives

There is broad support for wind-diesel systems among those surveyed, as well as an understanding among stakeholders who are more apprehensive about the technology that there is a desire for such systems. There was also a broad acknowledgement, not only through the identification of costs as the most significant barrier, but also repeatedly highlighted in respondent comments, that there is a need for government support to enable wind-diesel projects. In addition to ranking their perception of barriers, respondents were asked to select which type of government assistance would best stimulate wind-diesel projects in Canada by choosing up to two types of programs listed in section 2.4, or suggesting alternative types of programs. The percentage of respondents who chose a given incentive are illustrated in Figure 3. It should be noted that because each survey asked for two choices, the total for each stakeholder category is 200%, while tax credits and green attribute sales are not listed as they were selected by no or only a single respondent respectively, and were thus categorized as 'other' in the overall presentation of results.

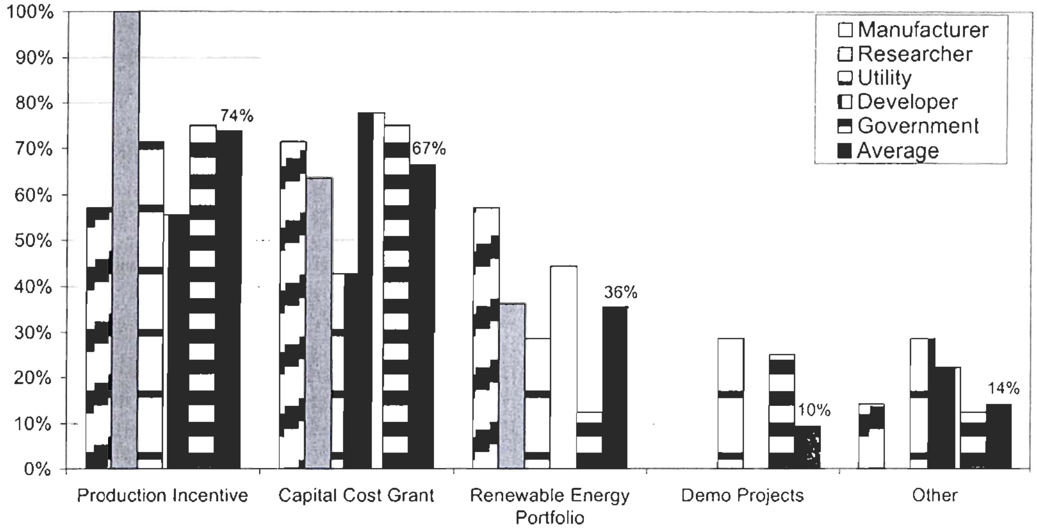

Figure 3: Stakeholder perceptions of potential incentive programs to stimulate wind-diesel development

Once again the importance of system costs is highlighted the responses to potential incentive programs as both production and capital cost incentives were selected by almost 70% of the stakeholders. A production incentive was favoured over a capital cost grants overall, and particularly researchers and utilities with the hopes that an incentive of this nature would encourage long term maintenance would be a result. A capital cost grant was favoured by manufacturers and developers, as it would facilitate enable access to cash for small communities and small companies developing the projects. While decreasing the capital cost of a system is clearly an important barrier, such grants do not necessarily ensure that a project will operate long-term and in fact run the risk of creating projects that are abandoned after they are commissioned.

A renewable energy portfolio, or a requirement either imposed by the local government or voluntarily adopted by a utility to generate a certain portion of electricity from specific sources, wind power in this case, was perceived to be the next most effective measure to encourage wind-diesel systems, with one in three respondents selecting this type of incentive. It was seen most favourably by manufacturers and developers and least favourably by utilities and governments. So long as wind energy systems are more expensive then conventional electricity generation, a portfolio will increase overall electricity rates. While this may be small in a territorial or provincial context, it may be significant locally if rates are community specific as is the case in some Canadian remote communities, also the prospect of increasing energy costs can be politically difficult particularly where energy costs are already very high.

Demonstration projects were also suggested by utility and government stakeholders as a way of encouraging wind-diesel development with the goal of increasing local experience with such systems. No stakeholders outside of these two suggested this type of incentive, possibly as a result of previous failed demonstrations. Other programs that were suggested included local training programs and wind monitoring programs.

2.5 Conclusions

2.5.1 Key barriers

Capital and operating costs were consistently ranked significant barriers to wind diesel systems by all of the stakeholders. Given current displaced diesel fuel prices and without incentive measures for wind systems in place, these concerns are well founded. It is highly unlikely that manufacturers will be able to reduce costs through improved design and production volumes without installing equipment in remote applications, but without cost improvements, projects are equally unlikely to be deployed in the current economic environment.

In spite of the cost, utilities may be interested in investing in wind-diesel projects for various reasons such as reducing price variability, minimizing greenhouse gas and other local air emissions or savings in fuel shipping and storage requirements. However, the survey highlighted that the majority of utility respondents are not confident in the technical maturity of wind-diesel systems, further compounding purely cost barriers. However, there is a very significant discrepancy as a strong majority of stakeholders outside of the utility respondents believe that wind-diesel systems are indeed technically ready for deployment in remote applications. These stakeholders recognize the utility trepidation towards the technology as a significant barrier and ranked the perception of technical risks as the most significant barrier outside of capital and operational costs.

Access to appropriate equipment and skilled labour in remote communities was also ranked as the next most significant obstacle to wind-diesel deployment in Canada. As with the other barriers, many of these issues are interrelated and lacking access to equipment and labour can increase system costs if the machinery is not properly maintained, if skilled labour needs to travel great distances to install and repair the equipment and can limit the size and thus performance of the equipment that is installed. Some of these limitations are intrinsic to small remote communities and small projects in particular. However, if a significant number of projects were to take place in a given region, some of the local expertise and equipment could be acquired and shared amongst communities and amongst projects. As with the other barriers mentioned above there is a vicious circle stalemate as the best solution to overcoming barriers to implementing projects is in fact implementing projects.

2.5.2 Incentives

Overall, the majority of stakeholders felt that wind-diesel systems are ready to be deployed in remote Canadian communities with many of the respondents noting successful projects in other jurisdictions, most notably Alaska, at the same time there was a important discrepancy amongst utility respondents who by and large disagreed. However, even amongst the stakeholders who felt that wind-diesel systems are ready, there was still a guarded optimism that the projects would not be successful without significant and long-term incentives.

Financial incentives were seen as the most likely to encourage wind-diesel systems, likely to break the cost barriers described above. Production incentives were slightly favoured over capital cost grants, although both were perceived to be effective methods by a strong majority of respondents. The implementation of a portfolio standard was seen as the next most effective strategy, while some respondents also suggested that demonstration projects and capacity building training would be effective. Tax incentives and the sales of green attributes were not perceived to be effective types of program.

It was also highlighted that in addition to an incentive designed to overcome the cost barriers any type of program needs it needs to be coupled with a strategic deployment of wind energy systems such that a long-term working model is developed that can then support/foster future developments.

2.6 Addendum

The text of this paper appears closely as it was published in 2008, with minor language corrections for clarity. The survey that was developed and distributed by the Pembina Institute for this research can be found in Appendix A. It is important to note that the purpose of this survey was to examine the perceptions of stakeholders who are or were directly engaged in wind-diesel projects in remote Canadian communities. As such there is no category specifically for members of remote communities. While there are members of remote communities who participated in the survey, they were all also members of other categories, such as developers, utilities or researchers and were therefore classified as such. It should also be noted, that while the pool of possible stakeholders was relatively small given aforementioned criteria for including stakeholders, responses were obtained from governments and utilities from four of the six provinces with remote communities and all of the three territories. No more than two responses from any one organization were sought or obtained. Given the small sample size, the relative ranking of the different barriers is qualitative, but uses the same evaluation system as Painuly (2002) to differentiate the relative emphasis of the stakeholder groups' collective responses. The ten barriers that were selected encompassed the most frequently cited concerns that were raised in attending conferences, personal meetings and reviewing literature specific to wind-diesel projects in Canada. There was also an option for respondents to include barriers that were not listed. Only three out of the fifty-one respondents did, and none repeated each other's non-listed barriers.

CHAPTER 3: THE UTILITY OF ENERGY STORAGE TO IMPROVE THE ECONOMICS OF WIND-DIESEL POWER PLANTS IN CANADA

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Abstract

Wind energy systems have been considered for Canada's remote communities in order to reduce their long-term costs and dependence on diesel fuel to generate electricity. Given the high capital costs, low-penetration wind-diesel systems have been typically found not to be economic. High-penetration wind-diesel systems have the benefit of increased economies of scale, and displacing significant amounts of diesel fuel, but have the disadvantage of not being able to capture all of the electricity that is generated when the wind turbines operate at rated capacity.

Two representative models of typical remote Canadian communities were created using HOMER, an NREL micro-power simulator to model how a generic energy storage system could help improve the economics of a high-penetration wind-diesel system. Key variables that affect the optimum system are average annual wind speed, cost of diesel fuel, installed cost of storage and a storage systems overall efficiency. At an avoided cost of diesel fuel of 0.30 $Cdn/kWh and current installed costs, wind generators are suitable in remote Canadian communities only when an average annual wind speed of at least 6.0 m/s is present. Wind energy storage systems become viable to consider when average annual wind speeds approach 7.0 m/s, if the installed cost of the storage system is less than $Cdn 1,000 per kW and it is capable of achieving at least a 75% overall energy conversion efficiency. In such cases energy storage system can enable up to an additional 50% of electricity generated from wind turbines to be delivered.

3.1 Introduction

3.1.1 Wind energy in remote Canadian communities

Many of the close to 300 remote Canadian communities shown in Figure 4, who primarily rely on diesel powered electrical generators have been found to have wind regimes adequate for wind turbines installation (Lodge, 1996). The high cost of energy particularly in diesel powered communities, along with a desire to become more self-sufficient has led to an interest in wind energy systems from communities, governments and utilities. In fact, the Yukon Energy Corporation began investigating commercial wind power systems, not for environmental benefits, but as a cost-saving alternative to diesel power generation (Maissan, 2001).

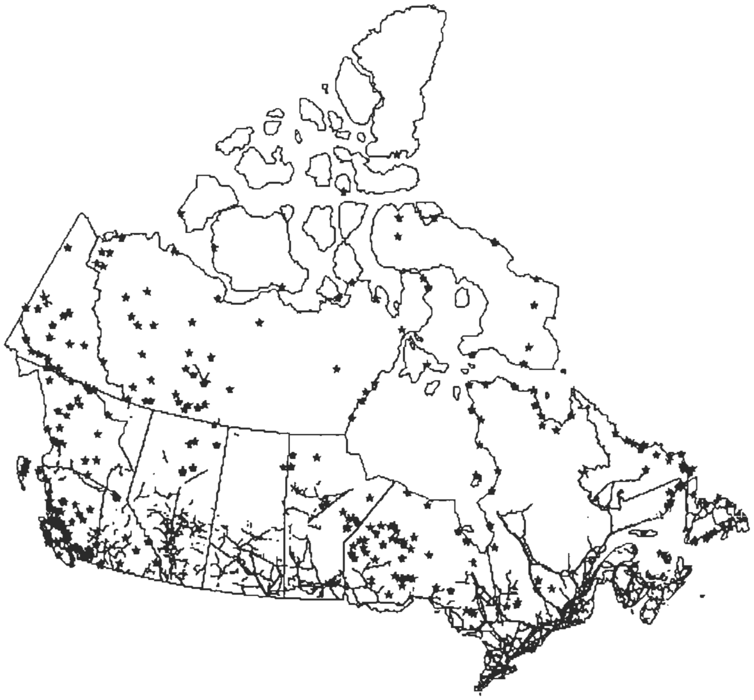

Figure 4: Canadian remote communities

Beginning in the 1980s, at least ten low-penetration wind-diesel projects were installed in various remote communities across Canada. The track record of wind-diesel systems in remote Canadian communities has been fraught with failed projects. Over the past 20 years, wind-diesel systems have been installed in many remote Canadian communities including; Big Trout Lake (ON), Cambridge Bay (NU), Ellesmere Island (NU), Fort Severn (ON), Igloolik (NT), Iqaluit (NU), Kasabonika Lake (ON), Kugkluktuk (formerly Coppermine) (NU), Kuujjuaq (PQ), Omingmaktok (NT), Sachs Harbour (NT), Ramea (NL), Rankin Inlet (NU) and Winisk (ON). Only Cambridge Bay and Kuujjuaq operated for more than 8 years, with the majority of the other projects having lifetimes of two years or less. With the exception of Ramea, all of the aforementioned projects were low-penetration systems and by 2006 only two wind-diesel systems were operating in Canada, neither of which have been in operation for more than 8 years (Whittaker, 2006).

Many of these systems were developed as pilot projects and as a result often underestimated or did not budget sufficient funding beyond installation costs. In general it was found that servicing small, individually installed machines drove up the relative operations and maintenance costs, often to the point of outweighing any diesel savings.

In spite of the relatively high fuel costs, the displaced diesel fuel cost is often on the order of 30% of the final cost of the electricity (GNWT, 2007). Combined with the relatively high capital and maintenance costs of wind energy systems, it has meant that the potential for long-term savings is not as attractive as it often appears at first glance. However, in spite of the past difficulties, there is a renewed interest in wind-diesel options in Quebec, Manitoba and the Northwest Territories in particular.

3.1.2 Rationale for high-penetration systems

The word 'penetration' is often used in reference to the rated capacity of the installed wind turbines compared to the maximum and minimum community loads. Although no formal definition exists for different levels of penetration, systems are typically categorised as either ‘low’, ‘medium’ or ‘high’ penetration. General descriptions of each system follow below.

A strict definition of a low-penetration system is one when the maximum rated capacity of the wind component of the system does not exceed the minimum load of the community. In practical terms however, a low-penetration system is one where the wind turbines are sized so as not to interfere with the diesel generators’ ability to set the voltage and frequency on the grid. In effect, the wind-generated electricity is ‘seen’ by the diesel plant as a negative load to the overall system. As such, low-penetration systems can be expected to supply up to 10-15% of the community load without significant changes to the system control or the grid stability. It is important to note however that because such a system needs to be designed for the peak capacity of the wind generator it will typically operate with an average annual output of 20-35% of its rated power, such that while low-penetration systems will have noticeable fuel and emissions savings they will be fairly minor (Lodge, 2001). In many cases it is likely that similar savings could be achieved through energy efficiency upgrades in the community for similar capital costs. An example of the outputs from a low-penetration wind energy system compared to the primary load can be seen in Figure 5.

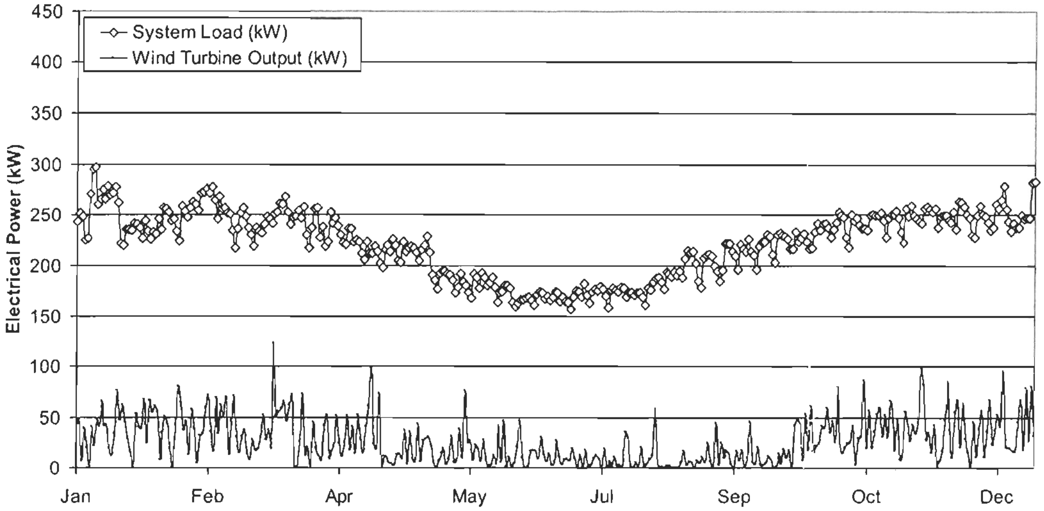

Figure 5: Example of a low-penetration wind-diesel system outputs

A high-penetration system is one where the output from the wind generators frequently exceeds the community's demand as shown in Figure 6 below, for extended periods of time (10 minutes to several hours), such that the diesel generators can be shut off completely when there is significant wind. The diesel generators therefore are required only during periods of low winds and/or to meet peak demands. The advantage of such systems are that very significant fuel savings can be achieved, thereby reducing import and storage costs, but also will extend the life and servicing frequency of the diesel generators as they will log less hours. Such systems can also benefit from economies of scale for construction and maintenance, but require much more significant and expensive control systems. A dispatchable or a 'dump' load is required during periods when the power from the wind turbines exceeds the demand in order to maintain system frequency and voltage. Convenient dump loads are large thermal loads such as community schools, day-care or administration buildings. The major disadvantage to such a system is the need for more complex controls, to regulate the diesel engines as well as to control grid frequency.

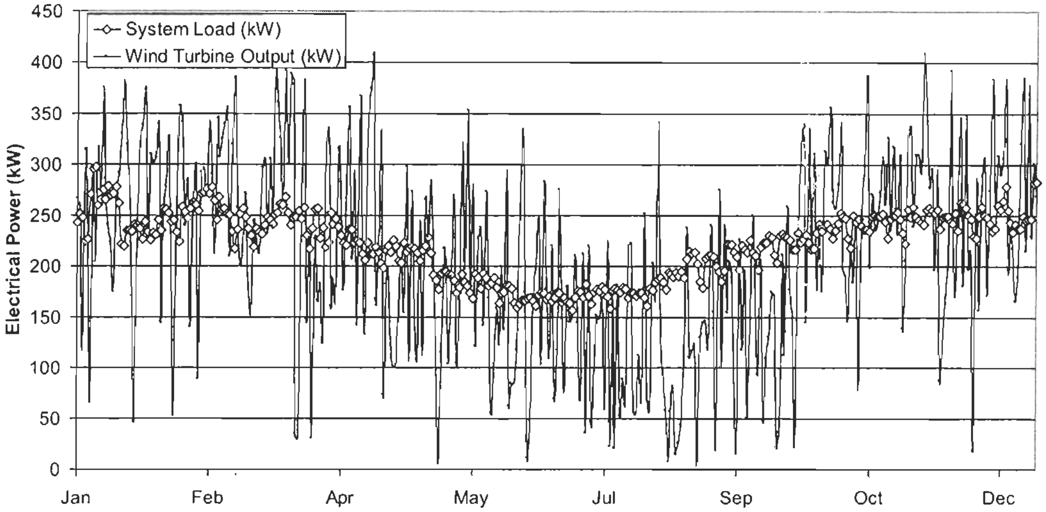

Figure 6: Example of a high-penetration wind-diesel system outputs

A medium-penetration system refers to a system in between the low and high penetration configurations. A medium-penetration system will have periods of time when the wind-generated electricity dominates the diesel-generated electricity and may also be able to meet the system load for brief periods of time (30 sec-5 min). When wind speeds are high and/or the community demand is very low, the diesel generators may not be required at all, but are not shut off, rather they are left to idle to be able to respond quickly to load demands. A medium-penetration system is potentially subjected to both the benefits and the drawbacks of low- and high-penetration configurations (Pinard and Weis, 2003)

Several studies have suggested that increasing the penetration of wind-diesel systems is one way to improve the overall economics of such systems by reducing the per kW installation costs (Pinard and Weis, 2003), (AEA, 2001). Both medium and high-penetration systems have the advantage of not only displacing significant amounts of diesel fuel, the increased wind energy equipment required for such systems reduces the per kW installation and maintenance costs. However, the increase in capital costs of advanced control systems and the use of a dump load detracts from the overall economics of such systems.

If used effectively, such as displacing a local heating load, a dump load will improve the overall environmental performance of such systems by offsetting additional fuels typically used for heating. It is important to note that this may only marginally improve the economics. Electricity used for heating is less cost effective than if it is consumed directly, as such any electricity generated at lower periods of consumption that end up in the 'dump load' will have a reduced value. As the penetration level is increased in order to improve the overall impact of wind energy systems on a diesel grid, an increasing proportion of the electricity generated over the course of the year will be diverted to the dump load. Storing this power to sell as high value electricity opposed to at a lower value as heat could help improve the economics as well as the overall percentage of renewable power delivered by the overall system. Storage systems can therefore theoretically improve the overall economics of a system, as well as increase the overall penetration of wind into a system. The purpose of the current research is to examine the economic impact that energy storage systems could have in remote Canadian communities to further increase the wind energy penetration and reduce the long-term electricity costs and what the costs of the storage systems need to be to have the desired effect. No specific storage system is modeled, but rather an examination of what performance characteristics would be required of theoretical storage systems.

3.2. Methodology

3.2.1 Micro-power modeling with HOMER

The micro-power energy modeling system HOMER was used to simulate model communities for this work. HOMER was developed by the National Renewable Energy Laboratory (NREL) in the United States and is freely available at www.nrel.gov/homer. HOMER was deemed an appropriate choice of modeling software for this analysis as it uses hourly time steps to model both demand, renewable energy resource and diesel generator operations to optimize an overall system (Lambert, et al, 2006). HOMER optimizes a system by running an individual scenario for every possible permutation of sensitivity variables input by the user and comparing the final net present values. Natural Resources Canada's RETScreen™ is capable of performing similar systems analyses, but requires that the wind penetration levels to be input into the model as opposed to being capable of determining or optimizing such a system.

The model requires data for each of the 8,760 hours in a year for the electrical load as well as the resource that is being harnessed, in this case wind. Constraints on system costs, size ranges and sensitivities are also required inputs. The software will then step through an entire year to optimize the given system's performance. A similar study was performed for the four Inuvialuit communities using HOMER, but the systems were all modeled without any storage options (Thimot, 2004).

3.2.2 Wind turbine selection

A library of various models of wind turbines are built into the HOMER software and there exists an option to create custom machinery as well. For consistency, a 65 kW, downwind machine on a 25 m tower was modeled in all scenarios. These turbines are manufactured by both Atlantic Orient Canada Inc. (AOC 15/50) and Entegrity Wind Systems Inc. (EW15), the turbine and its power curve are shown in Figure 7.

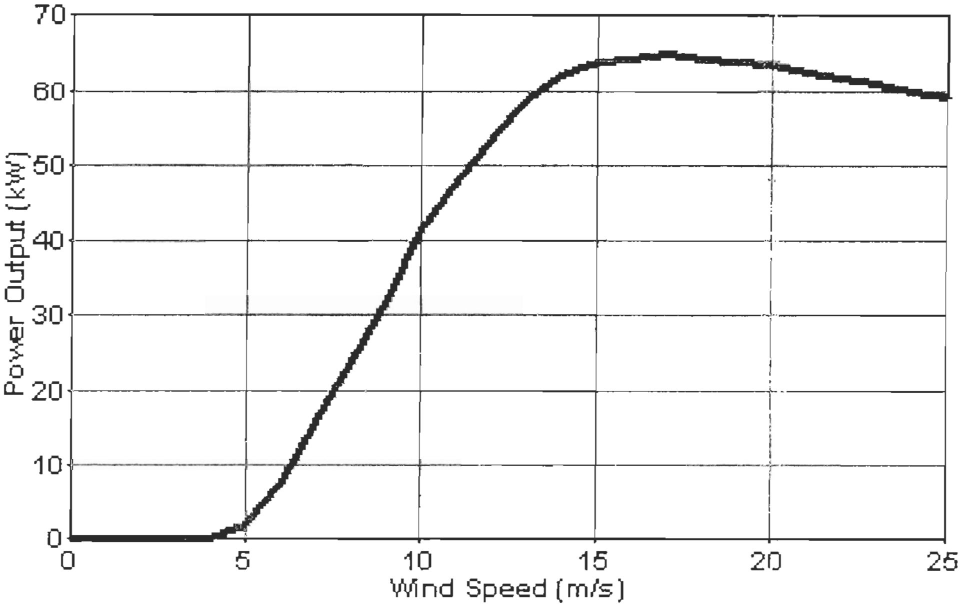

Figure 7: 65 kW wind turbine power curve used for simulations

These turbines were selected for this analysis as they are conceivably accessible to all remote Canadian communities, can be installed in remote communities without a crane and are considered robust enough for cold climates (Maissan, 2006). They have been operating in the remote community of Kotzebue, Alaska for the past nine years.

3.2.3 Community load profiles

While there are approximately 300 remote communities in Canada, not all of them are suitable candidates for wind-diesel energy systems. Many of these communities, simply do not have a wind resource sufficient to consider wind energy, others have their own alternative energy supplies such as small hydro, while other are too small to support the modeled technology. The largest remote communities such as Iqualuit, Îles de la Madeleine and industrial sites such as the diamond mines in the Northwest Territories were also not considered, as they would likely employ significantly larger scales of technology.

Using the Natural Resource Canada's (NRCan) remote community database (NRCan, 1999) as a starting point, communities were screened-in or screened-out based on having a minimum average annual wind speed of 5.0 m/s at a 30 m height and a diesel power plant with less than 1 MW peak. While the NRCan data set is close to ten years old it is the only comprehensive national list currently available and was therefore used as a common reference for screening purposes and assessing overall general trends. In order to account for community growth, the NRCan data was compared to recent Hydro-Quebec data from the Nunavik region (Maissan, 2006). All of the communities had grown by between 110%-145%, with an average growth of 130%. The NRCan load data was therefore scaled by 130% to reflect increases in populations and therefore load sizes.

No individual communities were specifically modeled in the work, therefore the modified load data based on the NRCan database was considered to be adequate for the purposes of this study. It is important to note that further details would clearly be required for an in depth examination of any individual community's wind energy options. Communities in British Columbia were not considered for this study as it has been the author's experience that mini-hydro systems are likely to out-compete wind-diesel configurations.

Communities were screened based on their peak load into small (0-500 kW peak) and medium (501-1000 kW peak) sizes. The communities modeled in this study are shown in Table 7 below.

Table 7: Screened Canadian remote communities

	Ave. Annual Wind Speed (m/s)	Scaled Installed Capacity (kW)	Scaled Peak (kW)	Category
Northwest Territories				
Aklavik	5.3	1,701	937	medium
Colville Lake	6.0	182	105	small

Deline	5.9	1,612	823	medium
Fort Good Hope	5.4	1,599	910	medium
Holman	7.4	1,482	649	medium
Lutsel K'e	5.2	962	465	small
Paulatuk	6.0	975	343	small
Rae Lakes	6.1	715	445	small
Sachs Harbour	5.5	969	354	small
Trout Lake	5.5	338	957	medium
Tulita	5.3	1,144	647	medium
Wha Ti	6.0	1,320	606	medium
Nunavut				
Arctic Bay	5.6	936	716	medium
Broughton Island	6.1	1,443	616	medium
Chesterfield Inlet	7.5	1,053	443	small
Clyde River	7.5	1,326	776	medium
Coral Harbour	5.0	1,677	901	medium
Grise Fiord	5.6	605	276	small
Hall Beach	5.3	1,554	718	medium
Kimmirut	6.0	1,092	581	medium
Pelly Bay	6.6	910	554	medium
Repulse Bay	6.2	897	556	medium
Resolute	6.0	3,965	1,061	medium
Taloyoak	5.7	2,074	802	medium
Whale Cove	7.7	975	497	small
Yukon				
Destruction Bay	6.0	1,170	351	small
Old Crow	6.5	910	529	medium
Nunavik				
Akulivik	8.5	1,105	445	small
Aupaluk	7.5	715	260	small
Ivujivik	7.5	1,365	316	small
Kangiqsualujjuaq	8.0	2,288	755	medium
Kangiqsujuaq	9.0	1,976	545	medium
Kangirsuk	8.0	1,365	530	medium
Quaqtaq	6.5	1,268	389	small
Salluit	7.5	2,600	936	medium
Tasiujaq	7.5	683	316	small
Umijuaq	11.0	1,365	416	small
Newfoundland-Labrador				
Black Tickle	8.5	995	374	small
Cartwright	8.5	1,931	995	medium

Charlottetown	7.5	806	499	small
Davis Inlet	9.0	904	416	small
Francois	7.0	715	296	small
Grey River	6.5	679	265	small
Harbour Deep	7.0	855	400	small
Hopedale	8.5	1,755	707	medium
La Poile	6.0	530	226	small
Little Bay Islands	8.5	1,755	926	medium
Makkovik	8.5	1,820	718	medium
Mary's Harbour	8.5	1,690	874	medium
McCallum	7.0	679	229	small
Mud Lake	6.5	234	79	small
Paradise River	7.5	189	70	small
Petites	6.0	494	121	small
Port Hope Simpson	7.5	1,807	764	medium
Postville	7.5	884	364	small
Rencontre East	7.0	892	335	small
Rigolet	8.0	962	504	medium
South East Bight	7.0	425	221	small
Manitoba				
Sayisi Dene	7.0	1,885	348	small
Shamattawa	5.5	1,723	541	medium
Lac Brochet	6.0	1,885	633	medium
Ontario				
Fort Severn	7.0	715	447	small

Community load patterns were modeled using the Alaska Village Electric Load Calculator (Devine and Baring-Gould, 2004), a tool also developed by NREL to assist remote communities in Alaska plan to meet their current and future electricity needs. The tool requires inputs including the community population, number of community and commercial buildings as well as information on large buildings such as the local school, communications equipment and water treatment system.

A sample community was modeled for each of the small and medium community sizes in this study, which can be seen in Figure 8 below. The model requires inputs of community population and number of various buildings, although final results are aggregated monthly and then a seasonal variability is overlaid on this data. The split between housing, government and commercials sectors will vary from community to community although residential loads are the major use. Only the community school, which is present in each community in Canada has significantly different seasonal patterns than other buildings in the community including housing. In all cases electrical loads are more in the winter than they are in the summer, however, the school has two very low use months, namely July and August. The other buildings follow roughly the same seasonal patterns and so while a breakdown can be entered to help model a community without any data, specific breakdown between residential, commercial and government buildings ends up being aggregated. As there is inherent variability between communities, the small and medium sample communities were scaled to desired peak and average loads rather than constructed from the bottom-up.

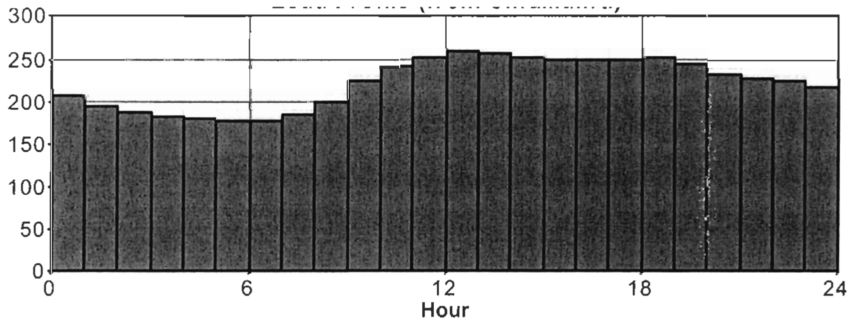

Figure 8: Small community simulated daily load profile

The small community was modeled using a peak load of 350 kW, with and average load of 220 kW, while the medium community was modeled using a peak load of 750 kW and an average load of 470 kW. These loads are scaled to actual 15- minute data from communities in Alaska such that appropriate "noise" also appears in the hourly data set as can be seen in Figure 9.

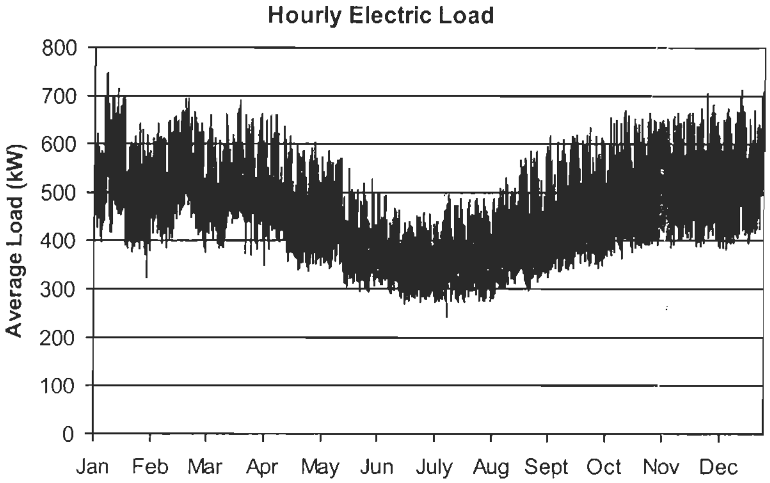

Figure 9: Medium community hourly load data

3.2.4 Wind resource modeling

Community wind data were collected using the Canadian Wind Atlas. The wind atlas is a computer model developed by Environment Canada and is freely accessible at www.windatlas.ca and described by Yu et al (2006). Communities that were screened in were found to have average annual wind speeds between 5.0 m/s to 11.0 m/s at 30 m above ground level. The map is a meso-scale model using 5-kilometer resolution for the entire country. Given the scale of resolution the map is not an accurate tool for predicting the actual performance of a wind turbine in a specific community, but it was used as a consistent data source for all of the communities in the country. Using the average wind speed calculated by the wind atlas, Weibull distributions (Figure 10) were created using a scale factor of 2.0 as a typical value (Ilinca et al., 2003). Sensitivity values were modeled for wind speeds of 5.5, 6.5, 7.5, 8.5 and 9.5 m/s.

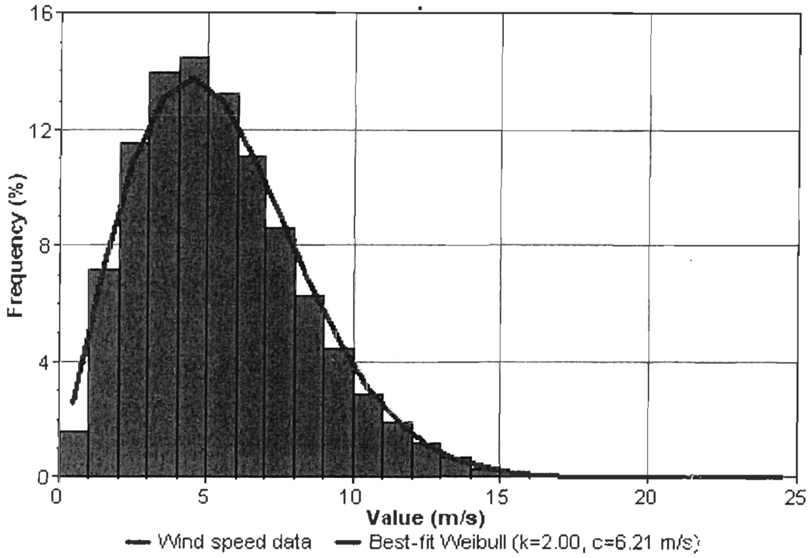

Figure 10: Simulated wind speed distribution

3.2.5 Electrical system modeling

For both small and medium communities, the diesel generators were modeled simply as a grid that is capable of meeting whatever load the wind, or stored wind cannot. Therefore the price set for the grid power is the only factor that the model uses to choose between wind, stored energy or diesel power. While this configuration does not model the impacts that a wind power plant will have on the operating efficiencies of diesel power plants, it does however illustrate the economic model that an independent power producer (IPP) would operate under if the IPP secured a long-term fixed power purchase agreement (PPA), which is a likely economic model in Canada.

An electrolyzer/hydrogen tank/hydrogen generator system was used to model a generic energy storage system, where the electrolyzer behaves as a converter from the excess electricity to the storage system, the hydrogen tank represents storage capacity, and the generator represents any conversion system back to AC power (Figure 11). It is important to emphasize that the current analysis is not necessarily modelling a hydrogen storage system, but rather using a feature that is built into the software to model the components of a generic system.

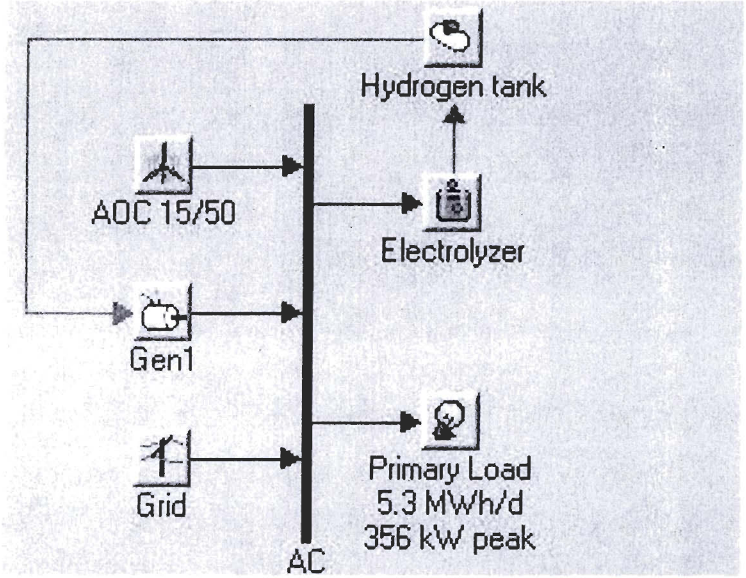

Figure 11: Community energy system model

3.2.6 Economic model

HOMER uses a net present value to compare and optimize system configurations, therefore in every scenario it will find the least cost system with the given constraints. This study used a 20-year project life, with a borrowing rate of 8%. None of the system's mechanical or electrical components explicitly required replacement during that period. All prices are expressed in Canadian dollars. As was mentioned earlier, the cost of diesel generators were not modeled either from a capital or operations and maintenance point of view, as from the point of view of an IPP these costs are beyond their control. In addition it is assumed that the utility would maintain a full diesel system in place. The model assumes a $1.00/L, with an overall diesel plant efficiency of 3.5 kWh/L, such that the avoided fuel cost which the wind turbine competes against is approximately 0.30 $/kWh, which was assumed to be the fixed PPA price for the life of the project. These prices are continually in flux, but are similar to recent estimates for projects in Canada (Maissan, 2006 and Maissan, 2007)

The wind turbines installation costs were based on a review of current estimates for installation in remote communities. While there are some economies of scale as additional machines are purchased, there is also a step jump in installation costs when a high-penetration system was installed, for the purpose of this study it was assumed when there are more than five turbines. Annual operations and maintenance costs were modeled at $5,000 per year per turbine. Table 8 outlines the assumed turbine costs, while the capital cost of any system beyond nine turbines was linearly extrapolated. The model optimized the number of wind turbines in the system between 0 and 30.

Table 8: Wind turbine project costs

Variable costs	1 turbine	3 turbines	5 turbines	7 turbines	9 turbines
Turbines	$ 120,000	$ 360,000	$ 600,000	$ 840,000	$ 1,080,000
Spare parts	$ 3,600	$ 10,800	$ 18,000	$ 25,200	$ 32,400
Transformer and Controller	$ 15,000	$ 45,000	$ 75,000	$ 105,000	$ 135,000
Transportation	$ 10,000	$ 30,000	$ 50,000	$ 70,000	$ 90,000
Foundation	$ 12,500	$ 37,500	$ 62,500	$ 87,500	$ 112,500
Installation	$ 35,000	$ 105,000	$ 175,000	$ 245,000	$ 315,000
Transmission	$ 20,000	$ 60,000	$ 100,000	$ 140,000	$ 180,000
Integration & SCADA	$ 15,000	$ 45,000	$ 75,000	$ 105,000	$ 135,000
Penetration controls	$ -	$ 10,000	$ 100,000	$ 100,000	$ 100,000
Contingency (20%)	$ 46,220	$ 138,660	$ 231,100	$ 323,540	$ 415,980
Subtotal	$ 277,320	$ 841,960	$ 1,486,600	$ 2,041,240	$ 2,595,880
Fixed costs					
Project design	$ 30,000	$ 30,000	$ 30,000	$ 30,000	$ 30,000
Project management	$ 15,000	$ 15,000	$ 15,000	$ 15,000	$ 15,000
Contingency (20%)	$ 9,000	$ 9,000	$ 9,000	$ 9,000	$ 9,000
Subtotal	$ 54,000	$ 54,000	$ 54,000	$ 54,000	$ 54,000
Total	$ 331,320	$ 895,960	$1,540,600	$ 2,095,240	$ 2,649,880
Cost per turbine	$ 331,320	$ 298,653	$ 308,120	$ 299,320	$ 294,431

The energy storage system was modeled using a hydrogen electrolyzer, storage tank and hydrogen generator. Both the electrolyzer and storage tank were modeled as 100% efficient and without capital or annual costs. All of the economics and overall efficiencies for the storage system are thus modeled through the generator.

The generator was modeled with a capital cost of $1,000/kW and an initial overall (or round-trip) system efficiency of 100%, which is equivalent to 0.03 L/hr/kW of hydrogen. No operation and maintenance costs or replacement costs were factored explicitly into the storage system model. The capital cost of the storage system therefore assumes not only the cost of the storage equipment, but the net present value of operations and maintenance costs as well. Sensitivity parameters were given to the storage system for both the overall system costs and overall system efficiency. The ideal scenario of 100% round trip efficiency was considered with no capital costs, and other sensitivities are listed below in Table 9.

Table 9: Energy system sensitivity values

Variable	Initial Value	Sensitivity Multipliers
Cost NPV	1,000 $/kW	0, 0.5, 1.0, 2.0, 3.0, 5.0
Storage system efficiency	100%	0.5, 0.75, 1.0
PPA value	0.30 $/kWh	1.167 (0.35$/kWh), 1.333 (0.4 $/kWh)

The model was run separately for both the small and medium community sizes and was optimized for net present value at the aforementioned wind speeds of 5.5, 6.5, 7.5, 8.5 and 9.5 m/s. Avoided emissions were assumed to be 0.985 kg/kWh, and no monetary value was placed on electricity sent to the dump load.

3.3 Results and Discussion

3.3.1 Idealized storage system

This section provides the results of the HOMER simulation using the methodology and inputs outlined in Section 2. Each model required 100 system configuration simulations, with 225 sensitivity permutations, or 22,500 possible settings. Idealized systems were considered initially in order to determine if storage systems could even theoretically be useful, afterwards non-ideal systems were considered. In every scenario the least net present cost system given the input parameters is selected by the model as the preferred system design and is illustrated by the various shading or hatching of areas in figures 12 and 13.

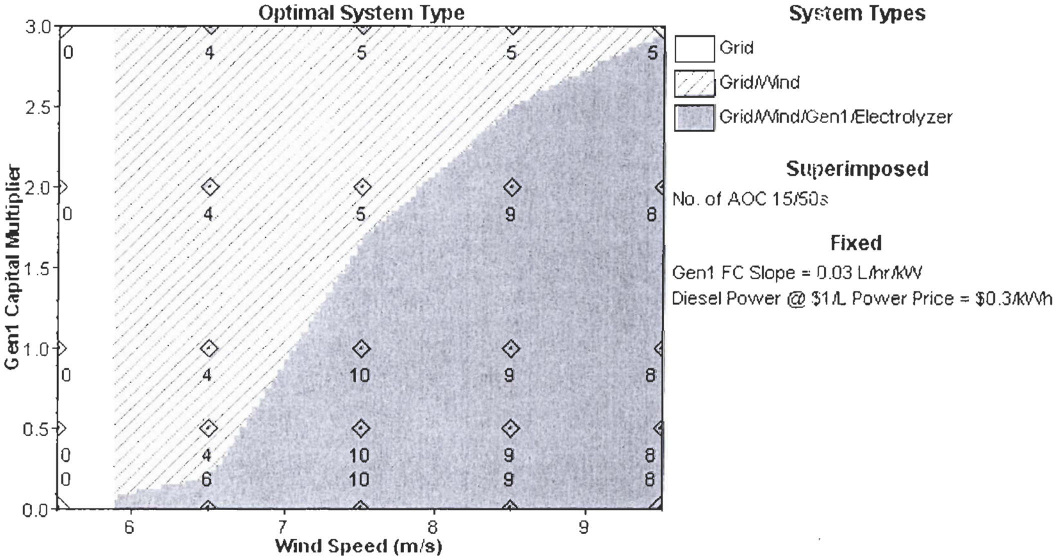

Figure 12: Optimization results for small model community with idealized storage

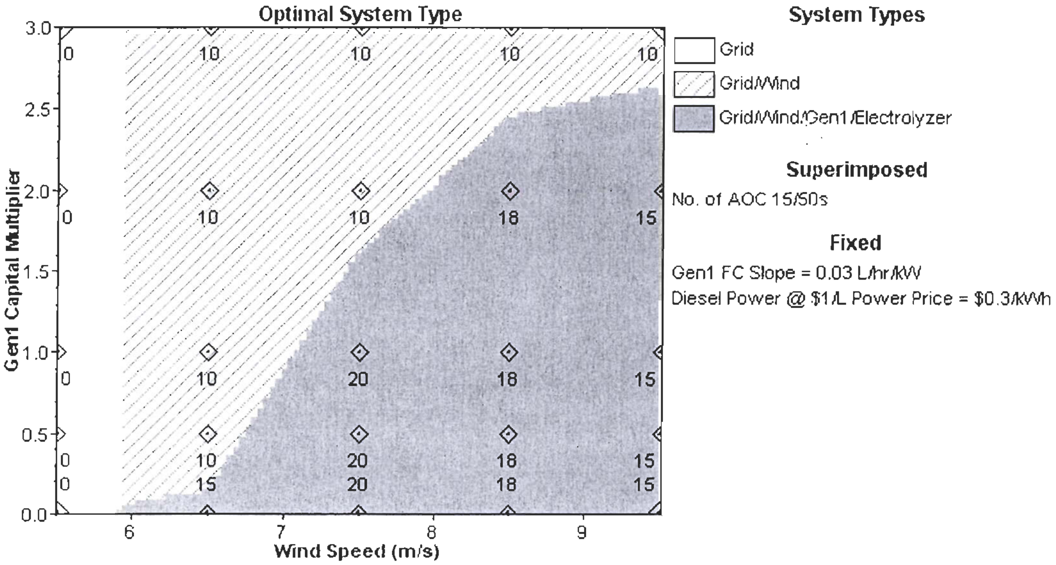

Figure 13: Optimization results for medium model community with idealized storage

For the two community models it was found that wind turbines were not economically feasible until the average wind speed reached approximately 6.0 m/s even if a 100% efficient storage system was available at no additional system cost. It was also found that although the small community and medium community load patterns were modeled differently (more relative community infrastructure in the medium community), the overall systems trends were very similar in each case. Figure 12 and Figure 13 illustrate both of the aforementioned results, with the optimal number of wind turbines for each given system configuration superimposed on the sensitivity chart. As the trends are similar, for the remainder of the discussion only the small community will be examined.

Both figures also show that without energy storage there is a saturation point where additional wind turbines become uneconomic to add to the system. Without any storage system, the optimal number of wind turbines for the small community is approximately 5, and 10 for the medium sized community. In both cases the numbers approximately double when an idealized energy storage system is available. Table 10 below lists the optimal system configurations with an idealized and free energy storage capacity for the small community (1,942 MWh/yr) and the medium model community (4,162 MWh/yr).

Table 10: Optimal system configurations with idealized energy storage at no cost

Community	Wind Speed (m/s)	No. of Turbines	Energy Cost* ($/kWh)	Renewable Fraction (%)	Energy From Wind Directly (MWh)	Energy From Storage (MWh)	Displaced Diesel** (L)
Small (0.3 $/kWh)	5.5	0	0.30	0	0	0	0
	6.5	6	0.29	42	750	64	232,570
	7.5	10	0.23	87	1,145	550	484,285
	8.5	9	0.19	95	1,265	574	525,428
	9.5	8	0.16	98	1,354	557	546,000
Medium (0.3 $/kWh)	5.5	0	0.30	0	0	0	0
	6.5	15	0.29	48	1,749	266	575,714
	7.5	20	0.23	84	2,405	1,041	984,571
	8.5	18	0.19	91	2,666	1,104	1,077,143
	9.5	15	0.17	90	2,811	933	1,069,714

*does not include diesel O&M and other admin overhead costs
**calculated using 0.0035 MWh/L

3.3.2 Non-ideal storage system efficiency

The previous section demonstrated that an idealized electricity storage system can significantly increase the overall energy delivered by the wind by up to 50%. While the idealized system (no cost, 100% efficient, infinite storage) provides a benchmark it is clearly unrealistic. It should be noted however, that even in the idealized system, a 100% wind powered system was not the most economic for any scenario because the increased capital costs required to purchase sufficient wind turbines do not pay for themselves. Furthermore, as can be seen in Figure 12 and Figure 13, even perfectly efficient storage system becomes uneconomic for all of the scenarios modeled when the net present value of the installation costs exceed $3,000 per installed kW, which in this case is about 60% of the installed cost of the wind turbines (approximately $5,000/kW).

In reality, some energy will always be lost when energy is converted from one form to another. This occurs twice in any storage system, first when the electricity is taken to be stored and secondly when it is converted back to electricity to complete the 'round trip'. Storage systems such as batteries, compressed air and flywheel storage will have different round trip efficiencies as well as capital costs, it is not the purpose of this paper to examine the range of costs of such systems but rather to set what targets such systems would need to achieve to be useful. The model looked at the idealized case where the system is 100% efficient, as well as two non-idealized scenarios with round-trip efficiencies of 75% and 50% respectively. Figure 14 demonstrates that when the storages system's round-trip efficiency reaches 50% the system needs to be very inexpensive to be useful in almost any given scenario. A 50% round-trip efficiency is not necessarily a floor benchmark as to when a storage system is useful at all in a wind-diesel configuration, as the overall economics depend also on the avoided fuel costs as will be seen in the next section.

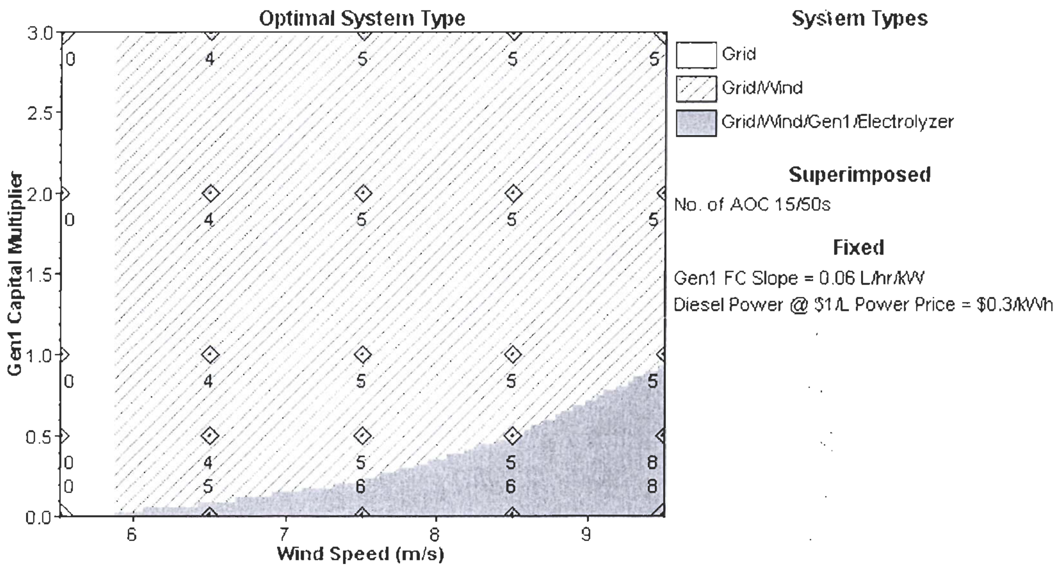

Figure 14: Optimal system configuration with 50% efficient storage

3.3.3 Power purchase rates

Table 10 demonstrated that it is possible to displace a significant amount of diesel fuel from an electrical system, by simply allowing for the avoided cost of fuel to be the threshold a wind energy system is implemented. However, there can be several reasons why a utility and/or a community would be interested paying a premium price (i.e. above the simple avoided cost of fuel) for generating power with the wind. Such factors include reduced fuel shipping and storage, long-term price hedging, reduced risks of fuel spills and reduced operations and maintenance requirements on the diesel power plant, all of which have a tangible local economic advantage that could theoretical be given a dollar value which arguably is not a premium but a real displaced cost on top of the avoided fuel savings.

Additionally, the use of a local renewable resource, reduced local air emissions and reductions in greenhouse gas emissions to the atmosphere are all further benefits of using wind energy, and do not have as easily quantifiable values, but are clearly benefits that may be recognized by either the utility, the local community or one or more levels of government who may wish to place a premium price on. Therefore, while the avoided cost of fuel at the time of this study was approximately 0.30 $/kWh, 0.05-0.10 $/kWh premiums are not unrealistic, in fact the Canadian Wind Energy Association is currently seeking a 0.15 $/kWh incentive for remote community wind power projects (Whittaker, 2006).

Figure 15 below shows how the optimum system changes as the avoided fuel cost or the purchase cost of wind power is varied at a round-trip storage efficiency of 50%. It should be noted that at an average annual wind speeds over 7.5 m/s, a 0.10 $/kWh increase in electricity price has the effect of doubling the optimal number of wind turbines (superimposed). Figure 16 illustrates the same curves assuming a 75% efficient round trip storage system, with the renewable energy fraction of the system overlaid. Renewable energy fractions can be above 85% for average annual wind speeds above 7 m/s, while without storage the same system would only achieve renewable energy fractions on the order of 46%. It should be noted that the aforementioned analysis was done without constraints on the size of the storage tank, it will be seen in the follow section that very large storage systems do not make significant differences in the overall performance of a storage system.

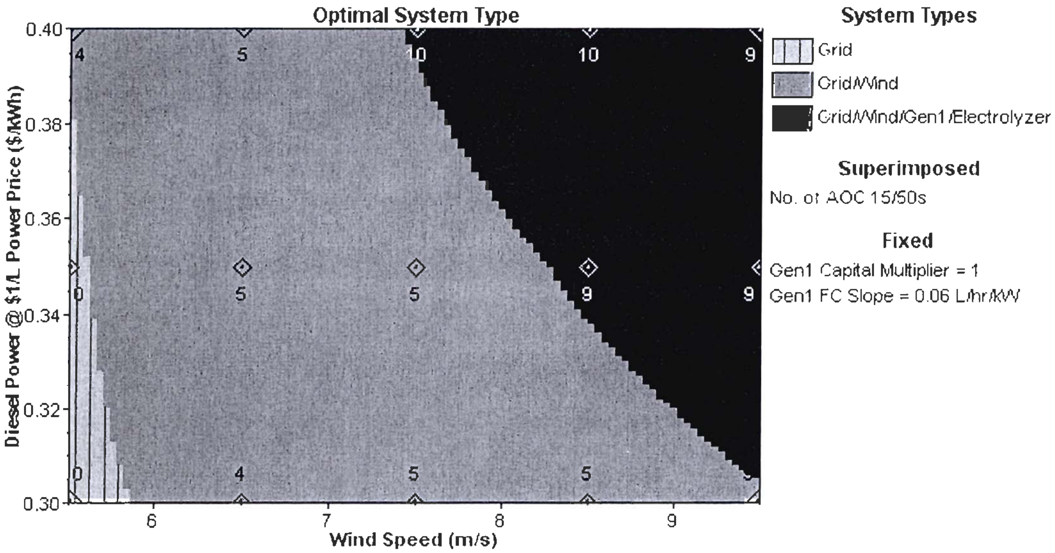

Figure 15: Effects of avoided fuel costs on system optimization with 50% efficient storage

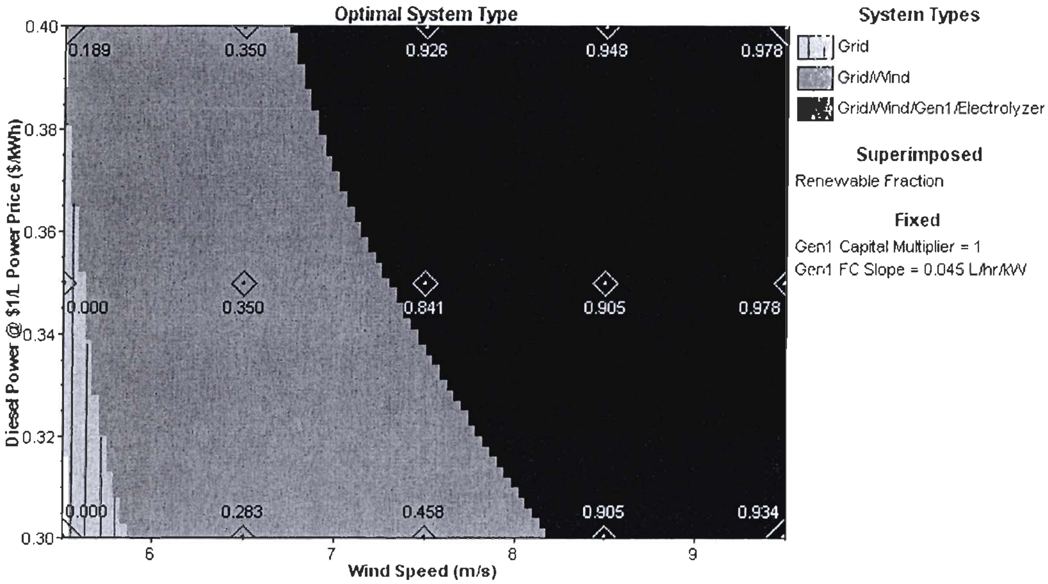

Figure 16: The effect of increasing the PPA using a 75% efficient storage system

3.3.4 Storage capacity

The energy that is available in the wind to a wind turbine is governed by Betz's law where the available power is proportional to the cube of the wind speed. While wind turbines reach a designed operating point and their output plateaus as the winds reach the design speed, nonetheless this cubic relationship between wind speed and generated electricity means that turbines will ramp up and down between peak values outputs and no output at all. In a high penetration system it is these peak periods where energy can be stored. Periods of prolonged high winds offer large amounts of excess energy, but also increase the required storage size. Sizing a system for these events will increase the overall amount of wind energy that can be delivered to the load, but at reduced return rate for the additional storage required. Table 11 below illustrates how the renewable energy fraction (wind and stored wind) is impacted by increasing the storage capacity for a system with 10 wind turbines operating at a wind speed of 7.5 m/s and a round trip storage efficiency of 75%.

Table 11: Diminishing returns of storage capacity

Storage Capacity (kWh)	Modeled Capacity (kg H_2)	Energy Cost ($/kWh)	Renewable Fraction (%)
0	0	0.33	70
1,667	50	0.30	77
3,333	100	0.29	80
16,667	500	0.28	84
33,333	1000	0.27	84
166,667	5000	0.27	84

Figure 17, Figure 18 and Figure 19 below illustrate how doubling and then increasing the storage capacity five-fold has decreasing benefits to the overall system's renewable energy fraction. Recall that the "grid" indicates the purchases from the diesel generators, the energy that was supply to the system from storage is shown as "Gen1", and the remainder of the energy is supplied directly from the wind. This diminishing benefit is amplified as the round-trip efficiency of the storage process decreases.

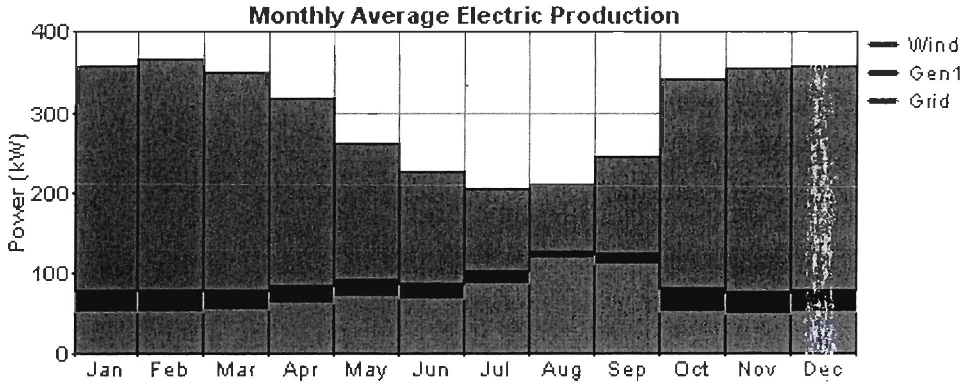

Figure 17: System model with 1,667 kWh storage capacity (7% of load serviced through storage)

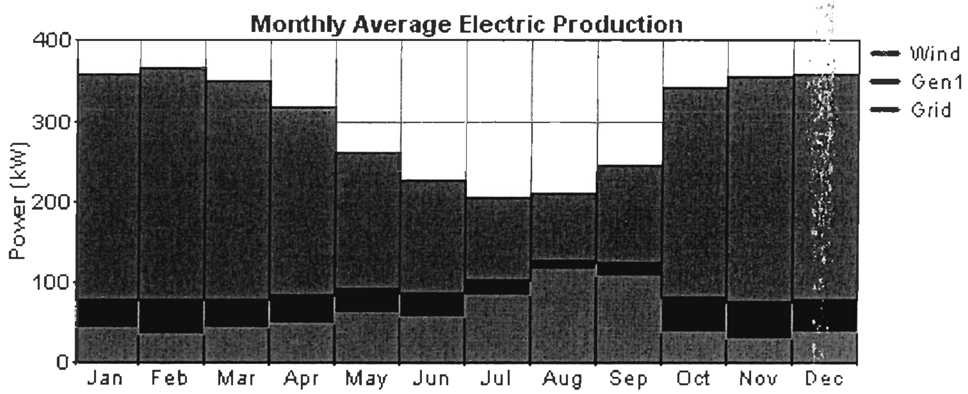

Figure 18: System model with 3,333 kWh storage capacity (11% of load serviced through storage)

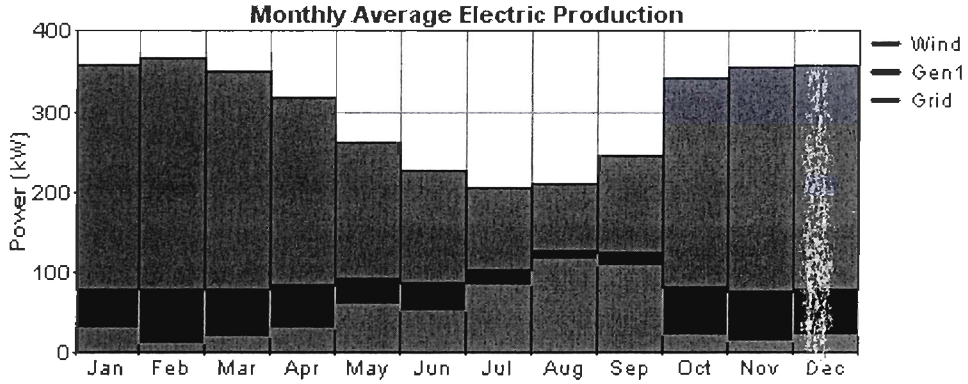

Figure 19: System model with 16,667 kWh storage capacity (14% of load serviced through storage)

3.3.5 Modeling particular storage systems

Many different energy storage systems have been proposed for wind turbine systems including batteries, reverse pumped-hydro, hydrogen conversion, flywheels and compressed air. The current model attempted to create a generic system that models any of these particular ones. While the model is an useful tool to determine the optimal wind turbine configuration, as well as the system constraints even on an idealized storage system, in reality each of the particular storage systems have very unique behaviours in terms of how efficiently they draw and supply grid power, as well as their economics in terms of capital, replacement and operations and maintenance costs. For example, in the case of battery storage, the batteries behave differently depending on the rates at which they are charged and discharged and have lifetimes that are dependent on their rate and depth of charge and discharge cycles. This however is not necessarily true for all energy storage systems, notably a flywheel.

Finally, it should be noted that a storage system that was integrated with the entire system and not just the wind turbine could not only optimize the energy generated by the wind, but the system as a whole by also charging the storage system from the diesel generators when they might otherwise be operating at less than ideal efficiencies allowing them to be shut off at other times.

3.4. Conclusions and next steps

3.4.1 Utility of storage systems

Energy storage systems can be a useful way of increasing the amount of wind power that is used in a high-penetration wind-diesel configuration. It was determined that various factors, notably the local wind resource, the value of the wind generated electricity, the round-trip efficiency of an energy storage system, the capacity of a storage system and the costs of a storage system all have major impacts on the utility of a given system.

In the Canadian context, a realistic system can be assumed to have a round-trip efficiency of 75%, where a battery system's rectifier and inverter might have efficiency's on the order of 90%. At current avoided diesel prices, the value of the wind generated electricity is likely to be on the order of 0.30 \$/kWh. In such cases, a wind regime with an annual average wind speed of close to 7 m/s or higher would be required before storage systems should be considered, should the storage system's installed costs be on the order of \$1,000 per kW or less.

3.4.2 Modeling storage with HOMER

While HOMER is a useful tool for modeling overall system performances because of the 1 hour time steps it does not measure how a shorter term energy storage system may perform that would be able to capture gusts.

HOMER does have detailed models for battery/converter systems, as well as for hydrogen storage. As was demonstrated in this research, the hydrogen model can be used to model generic and theoretical systems.

3.4.3 Next steps

The generic storage system model developed for this research is useful to illustrate the overall potential benefits and limitations of an energy storage system for wind-diesel generators. The model also illustrates under what circumstances wind-energy storage systems even ought to be considered, and what the minimum requirements on such systems needs to be in order for them to be effective.

The model used in this research is limited in predicting the behavior of specific energy storage systems, and in particular how they interact with the diesel generators. Higher penetration systems have the potential drawback of forcing the diesels to operate in less than optimal ranges of efficiencies. At the same time a storage system can offer the benefit of improving the operating efficiency of the diesel generators. These effects were intentionally not considered in this model, but would be important to consider in order to understand the overall impacts such systems will have on small diesel grids.

It is important to note that a wind energy developer may not always have access to the diesel power plant, as was the scenario modeled in this research. In these cases, where the wind energy plant operates as a unique IPP, the model used in this work would be appropriate from the point of view of optimizing the economics for the wind energy developer although it will not necessarily optimize the overall system. It therefore makes sense that high-penetration wind-diesel systems, be they with or without storage be developed and designed in partnership with and to be integrated directly into the existing diesel power plant for the benefit of both the IPP and the utility.

CHAPTER 4: ASSESSING THE POTENTIAL FOR A WIND POWER INCENTIVE FOR REMOTE VILLAGES IN CANADA

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Abstract

This paper discusses the uptake potential for a wind-diesel production incentive designed specifically for Canadian northern and remote communities. In spite of having over 300 remote communities with extremely high electricity costs, Canada has had little success in developing remote wind energy projects. Most of Canada's large-scale wind power has been developed as a direct result of a Federal production incentive implemented in 2002. Using this incentive structure as a successful model, this paper explores how an incentive tailored to remote wind power could be deployed. Micropower simulations were done to demonstrate that the production incentive designed by the Canadian Wind Energy Association would cost on average 4.7 \$Cdn milllion and could be expected to result in 14.5 megawatts of wind energy projects in remote villages in Canada over a 10 year period, saving 11.5 \$Cdn million dollars in diesel costs annually, displacing 7,600 tonnes of CO_{2eq} emissions and 9.6 million litres of diesel fuel every year.

4.1. Introduction

4.1.1. Wind-diesel opportunity in remote Canadian communities

The diesel fuel volatility is a major concern to remote Canadian communities, many of whom depend on diesel generators for their electricity. Many remote Canadian communities, particularly those in the Arctic, rely on a single annual shipment of supplies to their community, and as a result are forced to purchase annual supplies of diesel fuel on the spot market. This uncertainty makes annual budgeting difficult and can lead to very high energy prices such as in 2009 when despite falling global oil prices, fuel supplies where purchases in the summer of 2008 when oil had reached record highs. Introducing fuel-free alternative energy systems such as wind power, can not only reduce pollution levels, but help stabilize and reduce long-term electricity costs reducing the relative importance of diesel fuel in the overall price of electricity.

In spite of being home to some of the early research into wind-diesel systems, as well as five manufacturers of community-scale wind turbines (Marbek and GPCo, 2005), there have been very few successful wind-diesel projects in Canada (Weis and Ilinca, 2007). Worldwide, since 2005, there have been numerous wind-diesel developments in remote areas, notably including projects in Australia, Alaska as well as Antarctica.

4.1.2 Rationale for policy support at a Federal level

While wind-diesel systems present an appealing opportunity to many remote communities, limited access to strong winds, limited tower heights, increased transport costs and difficult operations and maintenance associated with remote sites and weak grids result in higher costs compared with utility scale wind farms. The results of a multi-stakeholder survey in Canada (Weis, et al, 2008) identified a need for government support to facilitate the development of wind-diesel systems. Installation costs as well as operations and maintenance were identified as the top two barriers to the wind energy systems in remote communities.

The reduction of diesel fuel consumption in remote communities was stated as a goal of the government of Canada's department of Indian and Northern Affairs' "Aboriginal and Northern Community Action Program" from in 2003-2007 (INAC 2007) and the subsequent "ecoENERGY for Aboriginal and Northern Communities Program" launched in 2007. To date, there have never been any long-term support programs targeted specifically at renewable energy systems in remote Canadian communities, and neither of the aforementioned programs have resulted in a single wind-diesel system in Canada.

The Federal government is an appropriate host to provide an incentive program, whether it be on its own or in addition to provincial or territorial programs. There are remote communities in all three territories and five of the ten provinces (NRCan, 1999), and as such, a Federal program would have broad national coverage. In addition, the Federal government has specific responsibilities to Aboriginal communities in all parts of the country, as well as Aboriginal and non-Aboriginal communities located north of 60 degrees of latitude.

While electricity policy is not controlled at a Federal level in Canada, there are precedents of Federal incentives for renewable power development, notably the "Wind Power Production Incentive" (WPPI) launched in 2002, and its continuation and expansion the "ecoENERGY for renewable power program" (eERP) launched in 2007, both of which reward large-scale renewable power systems with a 1 ¢/kWh incentive for the first ten years of power production. By late 2008, almost 90% of the installed wind power capacity in Canada was developed under one of these two programs (Royer and Zborwoski, 2008), and the implementation of WPPI program was a pre-cursor to all provincial and territorial renewable power programs and goals. Neither of these programs have resulted in the development of remote wind-diesel systems as the installed capacity of wind turbines for a community-scale wind-diesel systems in Canada would not qualify for the minimum capacity requirements of the incentives, as well as the fact that a 1 ¢/kWh incentive is inconsequently to the economics of remote electricity prices which can be on the order of 40-100 ¢/kWh (Weis and Ilinca, 2007).

The purpose of this paper is not to make the case for an incentive for wind-diesel systems, but rather to examine what options are available for remote wind energy incentives in Canada, the design of a production incentive, and the potential uptake in Canada over a 10 year period. The goal of this research is to illustrate the possible effects of direct support for wind-diesel projects in Canada with the intention of informing future policy decisions.

4.2. Policy Overview

4.2.1 Policy considerations

Various policy options are used throughout the world for encouraging the development of renewable electricity, some of which include production incentives, net metering, capital cost grants, establishing renewable energy portfolio standards, tax write-downs, green attribute purchase programs, demonstration projects and funding training programs. While these types of policies are becoming more and more common throughout the world, Ekins (2004) suggests that "no optimal model has emerged, and probably none will do so in the contexts that are shaped by different histories and cultures". There have been fewer policies targeted specifically at off-grid communities, although the general principles of each of policies could be applied in remote settings.

A survey by Weis et al (2008) of the Canadian wind-diesel development stakeholders found that capital and operating costs were perceived to be the most significant barriers to the deployment of wind diesel systems. A support policy therefore needs to be targeted at directly addressing the cost gaps as opposed to training or demonstration projects. The survey also indicated that a production incentive was perceived by stakeholders to be the most useful mechanism to encourage development. Given the familiarity and success of renewable energy production incentives in Canada, the expressed support from stakeholders for such a policy and the precedent that the Federal government has set in providing this type of support, a production incentive has been proposed by the Canadian Wind Energy Association (CanWEA 2006). The potential for their proposed policy as it pertains to small communities was modelled for this work.

4.2.2 Policy objectives

There are numerous outcomes that can be targeted by incentive policies which can vary vastly in importance and emphasis often as a result of political considerations by the decision makers. The overall motivations for promoting renewable energy, particularly wind energy systems in remote communities has been cited as being the reduction of fossil fuel use, reduce fuel prices as well as increasing overall local sustainability (GNWT 1988, CANMET 1995, Maissan 2001). Additional motivations for support mechanisms can be job creation, capacity development and assisting in technological development.

The goal of the policy discussed in this work is one that is designed to create enough market certainty to support a critical mass of projects, as opposed to creating a very large subsidy where practically any energy project can be made viable regardless of its technical merit. Benefits of a long-term incentive availability include avoiding an early rush of projects simply to take advantage of an incentive, but rather allows projects to develop at their own pace, as well as offering a long-enough market signal, that diesel plant refurbishments and rebuilds can be done with incorporating wind energy systems in mind such that difficulties in retrofitting can be avoided such as those described by Drouilhet (2001) in Wales, Alaska.

4.2.3 Number of Canadian communities

Canada has many remote sites that use electricity beyond just villages, including mine sites and logging camps that would be classified as "remote communities" by not being connected to the North American electrical grid or piped natural gas network and are permanent or long-term (at least 5-year) settlements with at least 10 permanent residences . For the purposes of this work, they will collectively be referred to as "communities" in spite of potentially very different electrical patterns and demands. This number of communities is always in flux as new industrial sites are developed, while others close or are decommissioned, at the same time some communities have been connected to provincial or territorial power grids, while occasionally a new village is settled.

The RETScreen™ Database – Canadian Remote Communities was compiled by Natural Resource Canada (NRCan, 1999) found that there were close to 300 remote communities with a population over 200,000 by using the above criteria, while Indian and Northern Affairs Canada (INAC) compiled a narrower list of remote communities that fall under its mandate, which does not include industrial sites or non-Aboriginal communities such as fishing villages in Atlantic Canada. This list comprises only 150 communities, with a population close to 100,000 (Van Vliet, 2009).

The current study draws on both of these previous compilations to analyze which of these communities could develop wind-diesel hybrid systems if the necessary incentives were in place. While not all remote communities in Canada are reliant primarily on diesel power, this was not considered a pre-requisite for incentive eligibility as larger communities such as Whitehorse or Yellowknife, for example, both of which are power predominantly by hydro-electricity, use diesel power to meet peak diesel requirements and/or to supplement for inadequate water reservoir level. In addition two communities in the Northwest Territories use natural gas for the electricity generation. In any case, diesel fuel would make up the overwhelming supply of displaced fuel for wind turbines built in Canada in the next 10 years. Small telecommunications sites, as well as the distant early warning sites are not included in this study.

4.2.4 Policy design

The value of electricity is an important consideration in setting an appropriate incentive level. The Northwest Territories Power Corporation issued a request for proposals in February 2008 for remote wind power projects, offering the avoided cost of diesel fuel for wind generated electricity (NTPC 2008). As many of the fixed costs associated with operating and maintaining a diesel plant are unaffected by the presence of a wind-hybrid system this is not an unexpected position to take, although it does not recognize any potential environmental benefits, or risk mitigating aspects of adding renewable power. The cost of importing and storing diesel fuel vary from community to community depending largely on accessibility, and in the request of proposals varied from 0.98 $Cdn/litre to 1.27 $Cdn/litre in 2007, translating into an avoided diesel cost ranging from 0.26 $ CAD/kWh to 0.43 $Cdn/kWh, for a median price of 0.35 $Cdn/kWh. While prices will vary from year to year and across the differing territories and provinces in Canada, these numbers were used as a basis and as a conservative assumption, it was assumed that average displaced fuel price would remain at 0.35 $Cdn/kWh over a ten year period for policy design considerations.

While installation costs will vary from community to community as a result of accessibility, system architecture and local geological conditions typical costs of medium scale turbines was calculated by Weis and Ilinca (2007) to be on the order of 4,500-5,000 $Cdn/kW for remote communities. These estimates can range significantly between 10,000-6,000 $Cdn/kW as suggested by Maissan (2006) to as low as 3,800 $Cdn/kW by Thompson and Duggirala (2009). Translating capital costs into cost per unit of electric generation is strongly dependent on the local wind speed.

Overall costs also depend on the size of the community, as larger communities tend to have better access to labour, equipment and other necessary infrastructure that facilitate the development and installation of wind power projects.

Recognizing the distinct differences in relatively large and small communities in Canada's North, CanWEA (2006) has proposed a Remote Community Wind Incentive Program (ReCWIP) that distinguishes two categories for wind power development:

Large communities and industrial facilities. This category includes large communities (with an average electrical load of 2 MW or higher) as well as industrial facilities in remote areas. Examples include Iqaluit, Yellowknife, Les Îles de la Madeleine, and the Diavik and Ekati diamond mines.

Small remote communities. This category includes all small remote communities that are accessible either seasonally or year-round by air, water, or road.

The large communities and industrial sites are likely to use utility-scale wind turbines in order of magnitude of 1,000-2,000 kW, while remote communities would likely use 'mid-range' wind turbines typically 50-300 kW. Proposed incentives for this program are equivalent to 0.03 $Cdn/kWh for the larger facilities and up to 0.15 $Cdn remote communities. The economics of these two different scales of project are quite distinct, and while all projects clearly need to be considered individually at a development stage, the relatively few number of 'category 1' projects makes them difficult to make generalized models for. As such, only communities that would be treated as 'category 2' communities are considered in this analysis.

The CanWEA proposal includes a portion of the production incentive as a capital grant that is calculated by taking the net present value of one third of the production incentive. While this may facilitate financing a project, modelling its effect on the overall economics of a project will be very similar to pure production incentive.

4.2.5 Identification of technical potential

Production data was collected from various sources for each region. Hydro-Quebec data for the Nunavik region was available through a 2006 study by Leading Edge Projects (Maissan 2006), Northwest Territories data was obtained through the 2007 General Rate Application to the NWT Public Utilities Board, a 2006 study for by Edward Hoshizaki Development Consulting for demand in remote communities in Northern Ontario and Nunavut's power corporation Qulliq's online rates (Qulliq, 2009). Communities where data was not specifically provided were extrapolated from Natural Resource Canada's remote community database (1999). While this data set is close to ten years old it is the only comprehensive national list currently available and was used as a common reference. In order to account for community growth, the NRCan data was compared to communities within the database where recent data also existed and where scaled by the average growth rate of such communities.

Communities were screened-in or screened-out based on having a minimum average annual wind speed of 5.0 m/s at 30 m using wind data that is available from the Canadian Wind Atlas. If more accurate numbers were available as a result of current or historical wind speed measurements, they were used in place of the wind atlas data. While average annual wind speeds of 5.0 m/s is a modest wind resource, it was deemed an acceptable cut-off where communities could begin to consider wind energy. While an average annual wind speed of 5.0 m/s is unlikely to be profitable given current system costs, a number of factors could lead to significant improvements in the economics in the foreseeable future such as improved tower heights, increasing diesel costs, reductions in wind-diesel system costs and significant government incentive programs, and as such it was deemed to be an acceptable cut-off for determining if a community could be considered as having at least the potential for projects that may ultimately be feasible. While this is somewhat of an arbitrary decision, as high enough incentives can make any project feasible, an average annual wind speed of 5.0 m/s is commonly used within the wind energy industry as being the minimum acceptable starting point for consideration. If lower-speed turbine technology develops in the marketplace such as large rotor sizes, this assumption could be re-visited.

Eighty-nine (89) of all the small remote communities in Canada have been identified as having the possibility of wind energy systems by meeting the minimum average annual wind speed criteria of at least 5.0 m/s, with a total population of over 52,000 people and a total of 257,345 MWh of combined annual electricity demand . Figure 20 illustrates the range of village load sizes, and that two-thirds of the villages fall between average loads of 1,500 MWh-4,000 MWh per year. The technical potential for system uptake would include all of these communities if costs were not a factor. Making a broad assumption that, on average, the displaced electricity would range between 20 per cent and 50 per cent, the overall technical potential of wind generation stands between 51,469 MWh and 128,672 MWh. While it is not practical to expect these levels of uptake at current prices for both fuel and wind energy equipment, this illustrates the theoretical upper bound for development that could be reasonably be expected with current technology.

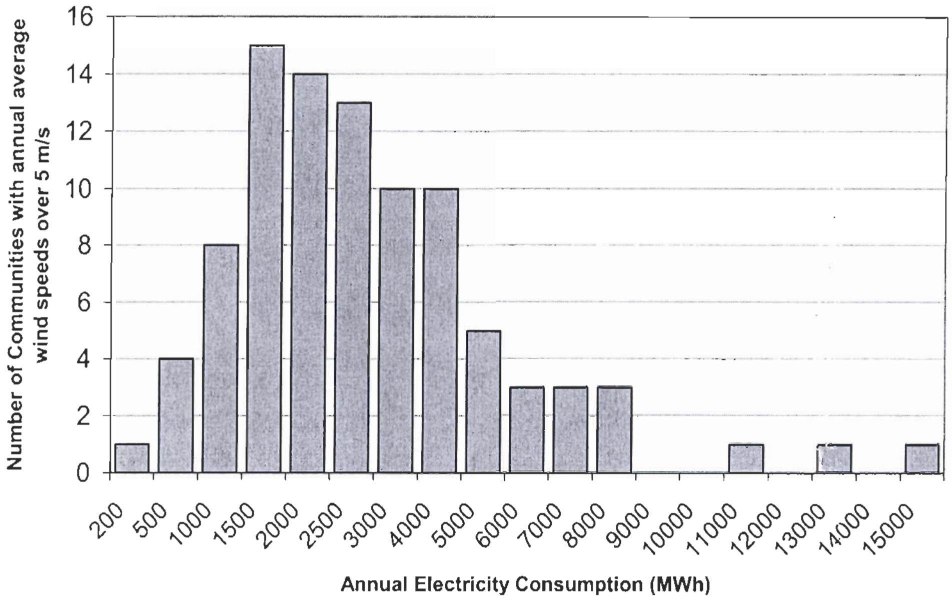


Figure 20: Distribution of annual load for remote Canadian villages

4.2.6 Modelling the economically achievable potential

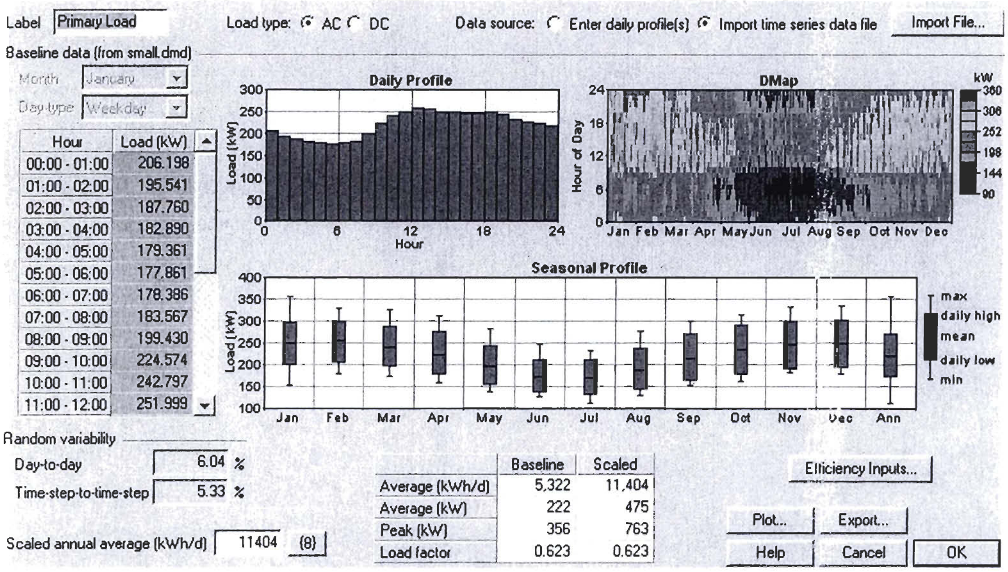
Community load data were simulated using the Alaska Village Electric Load Calculator developed by Devine and Baring-Gould (2004), and was scaled to representative loads for the selected communities Figure 21. Optimization scenarios were constructed for wind-diesel systems without power storage for each community using the micro-power energy modeling system HOMER developed by the National Renewable Energy Laboratory (NREL) (Devine and Baring-Gould, 2004).

The model uses hourly load and local renewable resource data, and will compare and optimize technology options(wind, hydro, solar, etc.), different manufacturers and overall system configurations based on system and economic constraints and is described in detail by Devine and Baring-Gould(2004).The following assumptions were used in creating the models:

- 0.35 $ CAD/kWh (on average a diesel price of $1.20/L)

- 6,000 $ CAD/kW installed costs and 5,000 $/kW for communities with over 4,000 MWh/yr
- 0.10 $/kWh O&M costs and $0.05 for communities over 4,000 MWh/year
- 0.15 $/kWh incentive available for first 10 years of project

Costs were modelled at a rate that accounted for profit margins and construction contingencies, as well as an explicit 8 per cent discount rate. These costs based on the cost analysis by Maissan (2006) and are significantly higher than commercial, utility-scale wind power development due to a lack of economies of scale and high travel costs to remote communities. In order to isolate the project costs for the wind power component of the model, the diesel generators were modeled simply as a grid with a fixed power cost equivalent to the avoided cost of diesel plus the incentive. Otherwise, HOMER will model the overall system economics, including the variations of the diesel generators with respect to changes in load. Treating the diesel generators as a fixed price is not the best technical model, nor necessarily overall system economic model. However, if a fixed displaced cost of fuel rate is negotiated for a power purchase agreement, modeling the diesel power as a grid is perfectly accurate for an economic model, from the point of view of a wind energy project as is discussed by Weis and Ilinca (2007).



Label: Primary Load

Load type: ● AC ○ DC

Data source: ○ Enter daily profile(s) ● Import time series data file

Baseline data (from small.dmd)

Month: January

Day type: Weekday

Hour	Load (kW)
00:00 - 01:00	206.198
01:00 - 02:00	195.541
02:00 - 03:00	187.760
03:00 - 04:00	182.890
04:00 - 05:00	179.361
05:00 - 06:00	177.861
06:00 - 07:00	178.386
07:00 - 08:00	183.567
08:00 - 09:00	199.430
09:00 - 10:00	224.574
10:00 - 11:00	242.797
11:00 - 12:00	251.999

Random variability

Day-to-day: 6.04 %

Time-step-to-time-step: 5.33 %

Scaled annual average (kWh/d): 11404

	Baseline	Scaled
Average (kWh/d)	5,322	11,404
Average (kW)	222	475
Peak (kW)	356	763
Load factor	0.623	0.623

Figure 21: HOMER assumptions for community load (Barring-Gould, 2004)

The models were run for varying community sizes and wind speeds in order to determine under what conditions wind power projects are viable, given the assumptions listed above, and what size of system is optimal in the cases where the addition of wind power is economic under these conditions. Sample results are illustrated in Figure 22, where the shaded area indicates the conditions under which wind energy systems are feasible as well as the optimum installed capacity and expected annual output of the wind generators. The installed capacity is expressed on the graphs as the number of equivalent 50 kW AOC15/50 wind turbines, the power curve for which has been used for the analysis as an illustrative turbine. The optimizations were all run with this power curve, but the results are not markedly different if a similar scale turbine with similar cost parameters are modelled in its place.

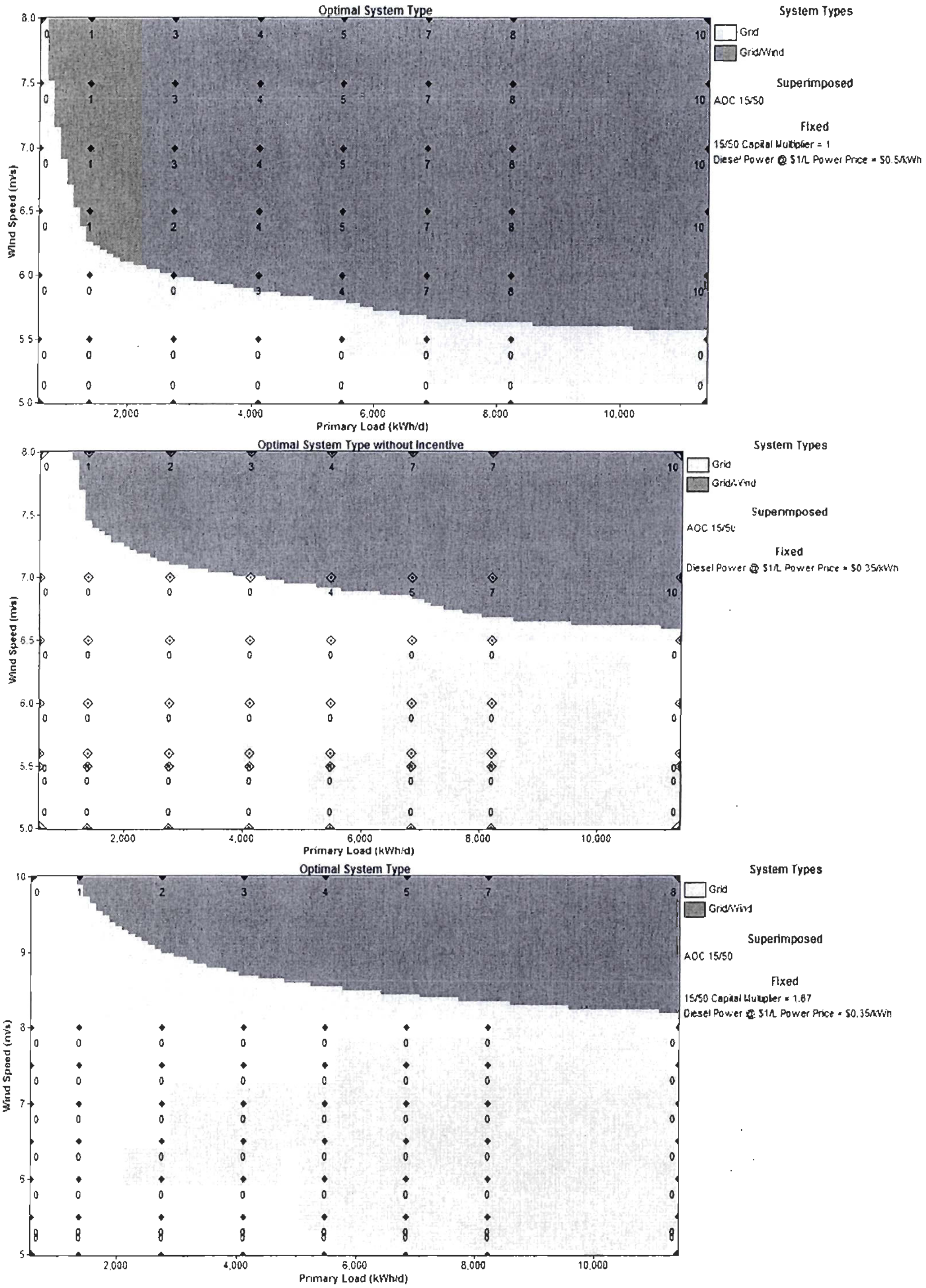


Figure 22: Modeling results with and without incentives

4.3. Results and Discussion

4.3.1 Results overview

The model results are listed in Table 12, which shows the model's prediction for optimal wind power size in each community given the model inputs. It should be noted that the community of Ramea, on Newfoundland, is not listed in spite of having a strong wind resource because it already has Canada's only operational wind-diesel system. In total, of the 89 communities identified with reasonable wind regimes, the model predicts that 62 could develop economically viable projects if a 0.15 $Cdn/kWh incentive were in place, for a total of 29.4 MW of installed capacity that could generate over 65 GWh, with an average system size of 470 kW, generating just over 1,000 MWh on average annually. Systems that are not deemed economically viable are those that are more expensive than continuing to use diesel fuel as the only source of electricity over the life of the modelled wind energy project. While the size of the community's electrical load impacts the viability of a project, the minimum average annual wind speed for a viable project was at least 5.6 m/s, with the median community's average speed being 7.0 m/s. Without an incentive in place, just over half of these communities would have the potential for projects and the minimum and median annual wind speeds rise to 6.5 m/s and 7.5 m/s respectively.

Table 12: Summary of model results for community uptake

	Site	Annual Load (MWh/yr)	Ave. Wind Speed @ 30 m (m/s)	Model Wind Capacity (kW)	Annual Wind Production (MWh)
	Northwest Territories				
1	Aklavik	3,107	5.3	0	0
2	Colville Lake	419	6	0	0
3	Deline	2,269	5.9	325	486
4	Fort Good Hope	2,147	5.4	0	0
5	Ulukhaktok	2,060	6.5	325	611
6	Lutsel K'e	1,396	5.2	0	0
7	Paulatuk	1,396	6	195	304

8	Rae Lakes	1,068	6.1	130	211
9	Sachs Harbour	1,388	7.5	195	486
10	Trout Lake	590	5.5	0	0
11	Tulita	1,920	5.3	0	0
12	Tuktoyaktuk	4,585	5.6	520	676
	Nunavut				
13	Arctic Bay	2,262	5.6	0	0
14	Arviat	6,700	7.3	1,170	2,776
15	Baker Lake	6,279	5.9	975	1,459
16	Broughton Island	2,066	6.1	325	528
17	Cambridge Bay	7,692	6.7	1,300	2,607
18	Cape Dorset	5,061	6.3	650	1,140
19	Chesterfield Inlet	1,766	7.5	325	810
20	Clyde River	2,683	7.5	455	1,134
21	Coral Harbour	2,736	5	0	0
22	Grise Fiord	828	5.6	0	0
23	Hall Beach	2,303	5.3	0	0
23	Kimmirut	1,817	6	325	507
24	Kugluktuk	4,490	6	650	1,015
25	Pelly Bay	1,905	6.6	325	631
26	Rankin Inlet	14,016	6.5	1,950	3,667
27	Repulse Bay	2,450	6.2	455	769
28	Resolute	3,872	6	520	812
29	Taloyoak	2,460	5.7	0	0
30	Whale Cove	1,574	7.7	260	679
	Yukon				
31	Destruction Bay	794	6	0	0
32	Old Crow	1,589	6.5	260	489
	Québec				
33	Akulivik	2,050	8.5	325	998
34	Aupaluk	1,025	7.5	195	486
35	Inukjuak	7,288	8	1,300	3,622
36	Ivujivik	1,480	7.5	260	648
37	Kangiqsualujjuaq	3,189	8	520	1,449
38	Kangiqsujuaq	2,278	9	455	1,523
39	Kangirsuk	2,733	8	455	1,268
40	Kuujjuaq	12,755	6.4	1,625	2,970
41	Kuujjuarapik	7,744	7	1,235	2,705
42	Puvirnituk	6,377	6.5	1,105	2,078
43	Quaqtaq	1,480	6.5	260	489
44	Salluit	4,555	7.5	650	1,620
45	Tasiujaq	1,253	7.5	195	486
46	Umijuaq	2,050	10	325	1,259
	Newfoundland-Labrador	0			

47	Black Tickle	1,737	8.5	325	998
48	Cartwright	3,371	8.5	520	1,597
49	Charlottetown	1,407	7.5	195	486
50	Davis Inlet	1,578	9	260	870
51	Francois	1,248	7	195	427
52	Grey River	1,185	6.5	195	367
53	Harbour Deep	1,493	7	260	570
54	Hopedale	3,064	8.5	520	1,597
55	La Poile	925	6	0	0
56	Little Bay Islands	3,064	8.5	520	1,597
57	Makkovik	3,177	8.5	520	1,597
58	Mary's Harbour	2,950	8.5	520	1,597
59	McCallum	1,185	7	195	427
60	Mud Lake	408	6.5	0	0
61	Nain	5,142	6	715	1,116
62	Paradise River	330	7.5	65	162
63	Petites	862	6	0	0
64	Port Hope Simpson	3,154	7.5	585	1,458
65	Postville	1,543	7.5	260	648
66	Rencontre East	1,557	7	260	570
67	Rigolet	1,679	8	260	724
68	South East Bight	742	7	130	285
	Manitoba				
69	Sayisi Dene	2,572	6.5	325	611
70	Shamattawa	3,196	5.5	0	0
71	Lac Brochet	2,505	6	325	507
72	Ontario				
	Fort Severn	2,653	7	455	997
73	Bearskin Lake	2,735	6	455	710
74	Kitchenumaykoosib Inninuwug	5,554	6.5	195	367
75	Deer Lake	3,798	5.5	0	0
76	Keewaywin	2,364	5.5	0	0
77	Kingfisher	1,900	5	0	0
78	Gull Bay	1,088	6	65	101
79	North Spirit Lake	1,743	5.5	0	0
80	Peawanuck	1,226	7	195	427
81	Sachigo	2,862	5.5	0	0
82	Sandy Lake	10,773	5	0	0
83	Wapekeka	1,511	6.5	0	0
84	Wawakapewin	220	5	0	0
85	Weagamow	4,224	5.5	0	0
86	Webequie	2,739	5.5	0	0
87	Wunnummin Lake	2,094	5.5	0	0

	BC				
88	Gilford Island	569	6	0	0
89	Hesquiat	591	6.5	65	122
	Total			29,445	65,068

While the model uses an average project cost of 6,000 $Cdn/kW installed, early projects will have significantly higher installation costs. As such, while the model predicts that there are projects that are viable without the incentive, the installation costs would need to be reduced to 6,000 $Cdn/kW in order for that to happen. Without incentives, a 10% and 50% increase in capital costs raises the minimum average annual wind speed to over 7 m/s and over 8 m/s respectively, narrowing the prospective communities to less than 10 at the high end, which according to Maissan (2006) is the expected cost range for early projects. With the modelled incentive in place, the impact on increasing installed costs from 6,000 to 6,600 and 9,000 $Cdn/kW, only changes the minimum average annual wind speed to 6 m/s and 6.5 m/s, making many more communities viable for early projects.

It is important to note, that simply because the model predicts that a project is viable, does not mean that in practical terms it will or even can happen. Many other barriers exist to such projects ranging from technology awareness to utility willingness, to regulations that prevent third party developers. The role of an incentive would therefore be in reducing the risk to encourage initial projects that would help reduce not only the costs of future projects, but other non-financial barriers as well. Exploratory capital and long-term planning would also be facilitated with a long-term incentive.

Some communities may find improved local wind resources if a detailed monitoring program is completed in a strategic location such as a local ridge, compared to the broader resolution of the wind map. Conversely however local communities may find they have weaker wind regimes than those predicted by the model, particularly when constrained by a limited ability to build transmission lines outside of the community at reasonable costs. Some communities identified above may also have alternative options for renewable energy systems notably mini-hydro, however, there may be additional unidentified sites that could qualify such as small mining operations, long-term logging camps or military sites. These factors may increase or decrease the number of candidate communities, although it is difficult to predict to what extent, while slight moves in either direction seem equally likely, with a strong possibility of cancelling each other out. Two factors that are likely only to increase the number of potentially viable communities are increasing fuel costs beyond $1.20 per litre and the reduction of operations and maintenance costs as more and more systems are deployed, such that additional communities that were not viable under the current conditions would become viable. In addition, the population of remote communities has shown to be consistently growing and as such the potential listed in this research should therefore be considered as a floor for realistic near-term deployment.

4.3.2 Practical uptake potential

While there are at least 62 communities that could be considered as candidates for viable wind-diesel projects if a 0.15 $Cdn/kWh incentive were implemented, there is a practical limit to deploying such systems based largely on human resource capacity as well as the time required to begin deploying anemometers and other exploratory steps. When attractive incentives are in play, exponential growth rates are of renewable energy systems are fairly common globally, including wind power in Canada as illustrated by Royer, J., and Zborowski, D. (2008). It was estimated that only one project would be implemented in the first year after the launch of an incentive program, after which a 20 per cent annual growth rate in projects over a ten year period would result in the deployment of 31 projects for a total of 14.5 MW of installed capacity that would generate on average 32 GWh of electricity per year.

The practical deployment of wind-diesel is therefore half of the communities that have been identified as being viable in the near term. At an incentive rate of 0.15 $/kWh, such a program would cost on average 4.7 million $Cdn per year, and would result an annual reduction of diesel fuel costs of 11.5 million $Cdn assuming a typical diesel engine electricity conversion efficiency of 0.3 L/kWh. This would also result in avoiding 7,600 tonnes of CO_{2eq} emissions by displacing of 9.6 million litres of annually.

4.4 Conclusions

In Canada, eighty-nine villages (89) have wind speeds identified as being at least 5.0 m/s that could one day be considered as candidates for remote wind energy applications. Without any incentive, a maximum of ten (10) villages are possible candidates for economically viable wind-diesel projects. An incentive rate of 0.15 $/kWh extend this number to sixty-two (62) potential candidates for such project. At a realistic deployment pace, half of them can benefit of wind energy projects over a 10 years period.

CHAPTER 5: CONCLUSIONS

Abstract

This research is a multi-disciplinary approach to examining how barriers to wind-diesel systems can be overcome in Canada. The final section highlights some of the original findings of this work as well as the limitations of the research. Of the policy options available, a Federal incentive that combines of capital grants and production incentives could address up front as well as operations and maintenance costs, both of which were found to be perceived as key barriers to deploying wind-diesel systems by stakeholders. This research used HOMER software as a simulation tool to examine how power storage in wind-diesel systems as well as a proposed production could influence the development of projects in Canada. While it is an appropriate tool, it should be noted that the models herein do not necessarily reflect any specific community, and would need to be refined or even rerun with data specific to any proposed project. Varying the proposed incentive level will reduce the number of communities that are potential candidates for projects, although it is important to note the early projects will have significantly higher costs which need to be considered.

5.1 Overview

Diesel engines have been extremely successful at providing reliable power to remote communities in Canada. This success, however, has not been without significant local environmental and economic costs to these same communities. Fuel spills as well as local air pollution and a rising concern about greenhouse gas emissions are all often cited as increasingly pressing reasons to reduce diesel consumption in remote communities. Reliance on imported fuels into the community as well as frequent and sometimes abrupt increases in the cost of diesel fuel is also driving these communities to look at alternatives to either supplement or replace diesel systems as a primary power source. Improvements in energy efficiency are always the most cost effective methods of reducing fossil fuel consumption and should be pursued regardless of supply alternatives, however there remains the need for a locally generated, clean supply source and as such wind-diesel hybrid systems represent a significant opportunity for Canada's northern, remote and Aboriginal communities currently reliant on diesel generators.

Wind energy projects in Canada's northern, remote and Aboriginal communities to date have not been able to benefit from Federal power production incentive programs for wind energy because these incentive levels do not reflect the higher costs as well as other technical and non-technical barriers in off-grid communities. While wind-diesel systems are increasingly being deployed globally, they remain rare in Canada in spite of Canada having been an early leader in research and deployment of the technology, while being home to close to 90 suitable communities.

Given the federal government's jurisdiction with respect to Aboriginal peoples as well as northern communities in Canada, it is appropriate that a federal policy framework be developed to assist in their development and deployment. Of the policy options available to the government, a combination of capital grants and production incentives can address two of the key barriers to deploying wind-diesel systems in

Canada, notably capital as well as operations and maintenance costs, so long as it is a part of a broader set of policies to support communities pursuing these systems, the latter need not necessarily be federal, but could be regional, provincial or territorial in nature. This research highlighted that while overcoming financial constraints – both capital and operations and maintenance – are key to the further development of wind-diesel systems in Canada, they are not the only barriers facing the adoption of this technology into remote communities, and that many of the barriers are interconnected. As such, policy development needs to be cognisant of the fact that grant money alone will not likely succeed in successfully deploying wind-diesel systems in Canada. Successful jurisdictions that have supported renewable power in remote and off-grid communities, notably Australia and Alaska have had comprehensive community engagement and support structures that have been put in place in conjunction with monetary incentives.

Finally, this research also examined the opportunities for electrical storage capacity to reduce the overall costs for wind-diesel systems, thereby not only improving their economic performance but also their environmental benefits.

5.2 Wind-diesel development needs in Canada

A broad survey of stakeholders engaged in wind-diesel systems in Canada found that while costs remain a significant barrier to the deployment of such systems, but other factors including risk aversion and a lack of human capacity within remote communities also play important roles in limiting the deployment of such systems.

A financial policy, such as the Remote Community Wind Incentive Program (ReCWIP), described herein would not only directly address financial barriers, but the long-term establishment of such a program would create a potential market for wind-diesel systems, thereby force utilities and local policy makers who are responsible for servicing off-grid communities, to begin to prepare for such systems.

There is significant potential uptake for such a program all across Canada as modeled within this research, should there be federal support to implement such a policy. However, given the other barriers that need to be overcome, support policies also need to include complimentary efforts from training to information dissemination. There is a role for provincial and territorial government support to provide these complimentary measures, as well as creating local strategic development plans.

In developing the design of the ReCWIP policy, it was recognized that a standard incentive or a "one-size fits all" level of support may over-incent some of the more financially attractive project locations in theoretical terms. Practically speaking, the first projects, or the early adopter communities, will be faced with additional, likely unforeseen, costs that the overall performance and financial analysis developed within this research does not model and as such additional theoretical margins may not, for early projects, necessarily result in excessive compensation. On the other hand, projects with exceptional wind speeds as well as significantly high diesel prices may be able to benefit more than other projects. This may make the incentive somewhat inefficient as it would be potentially offering more of an incentive than is required to make a project feasible. Tailoring the level of incentive to individual projects or resources could minimize this, but doing so would not only make such a policy administratively complex for governments but also for those trying to access the support which may deter their interest. However, enabling early projects to be a more lucrative than others may help to encourage projects that are most likely to succeed to be developed first, thereby creating hub communities. Finally, it needs to be stressed that ReCWIP is not the only possible support model, but it does represent the level of support that is needed for broad adoption, as well as a model of the key areas to target for this support.

To the extent possible, policy support of wind diesel systems across Canada should be tied to ensuring that they be developed in an open fashion such that design parameters, operations and maintenance schedules and performance data be public to assist in the development of additional projects. The challenges to widespread development are broad enough that successes and failures need to be well documented and built constructively.

As was discussed in Chapter 3, energy storage has the potential to improve the overall performance of wind-diesel systems should the storage technologies become technically and financial viable. However, based on the track record of wind-diesel systems in general, it is unlikely to expect that this maturity will happen in isolation from commercial deployment, and as such encouraging power storage systems should be a part of future policy support for wind-diesel systems, as these components are likely to face many of the same barriers that wind-diesel systems in general have faced from cost to awareness.

Additional areas of development assistance are community energy planning in order to help decision makers in remote communities understand their energy costs and potential alternatives. Coordinating such efforts broadly can help neighbouring or even communities to collectively pool skills and resources where possible, as well as highlight the need for long-term planning.

International collaboration, particularly with Alaska will be important going forward in developing best practices for system design, community consultation and engagement, project installation, maintenance, cold weather performance as well as decommissioning, recycling and repowering equipment. Establishing standardized protocols for system design, commissioning, decommissioning and operations is necessary to ensure comparable system operations.

5.3 Model limitations

5.3.1 Alaska Village Load Calculator limitations

As no detailed data sets were available for consumption patterns in Canadian remote communities, it was necessary to use the Alaska village electric load calculator developed by NREL as a basis for developing typical community load patterns for the modeling analysis done in both Chapters 3 and 4. It was developed for Alaskan communities as there were no comprehensive data sets available to assist in designing village electric power systems.

There are several distinct advantages of using this calculator including that it produces hourly data which can be used directly in models such as HOMER. Data is available for Canadian communities through their local governments or utilities, but it is typically presented in terms of monthly or annual consumption only. Having hour to hour variability is important when modeling the performance of wind-diesel systems as it captures important fluctuations within the winds (and thus the output of the wind turbines) as well as the diesel plant itself. Hourly load data is essential for examining the performance of medium and high penetration wind-diesel systems as their economics depends heavily on their ability to sell the electricity they generate and not have it lost to a dump load. The calculator was constructed from data monitored from six different communities in Alaska, namely Kiana, Scammon Bay, Kasigluk, Brevig Mission and Chevak, and as such incorporates real world variability, both seasonal and hourly. The calculators is also transparent in how it builds the load data based on residences and non-residential building demand and can be manually altered if better data is available to the user.

It was for the aforementioned reasons that the calculator was chosen as a basis for the broad models developed in this research, but it is also important to note its limitations. While the model is built using actual community data, this is also one of its limitations, as there is significant differences in consumption patterns between communities as by Devine and Baring-Gould (2004), who note that per capital residential electricity consumption can vary by 50 per cent above and below the average. The authors suggest this is in part due to average income within the community, as suggested by the Energy Information Administration (2004). Other variables that can influence community to community consumption patterns include level of street lighting, electrical defrosting of water pipes as well as the level of access to plumbing within the community.

Specific limitations with respect to Canada are that that calculator is developed from Alaska data, which is inherently influenced by the latitude of communities in the state, not only for the length and severity of the winter, but also in the relative seasonal lighting patterns. While many Canadian remote communities are of comparable latitude, particularly in the three territories, Northern Quebec and Labrador, there are also a significant number of communities in British Columbia, Northern Ontario and the island of Newfoundland that would not have as extreme variations in daylight between seasons as those experienced in the Arctic.

Variations in electricity consumption can also vary depending on local economic activity as well as fees structures for electricity. These not only vary within the Alaska communities themselves that were used to develop the model, but will vary across the spectrum of Canadian communities.

At the same time, it is impossible to accurately predict how consumption patterns will change over the course of the next twenty years, over which the models are applied, and so there is also a limit to what potential benefits would accrue if more accurate current data were sought on a community by community basis.

In spite of these limitations, the calculator was used as a basis for the research as it provides a consistent basis for electricity consumption based on real world data, in the absence of actual utility data being available in Canada. It is important to note that, because of the limitations listed above, the results should not be applied to any individual community, and any potential project should be evaluated individually, even if the results of this study screened a particularly community in or out of economic viability, as there are numerous variables that affect the overall economics of a project that are not captured in a generic model.

5.3.2 Limitations of HOMER model

The modeling tool HOMER was the primary software used to model both the opportunities for storage as well as incentive potential uptake. When modeling medium or high penetration wind diesel systems, it is critical that the model be able to emulate periods of time when power generated from the wind turbines exceeds, as well as is incapable of meeting the community load demands. HOMER uses hourly data for both the system load and to model the wind (or other renewable energy) resource. This is adequate for capturing these variations in output, although it does not capture variations on smaller time scales such as second to second turbulence or minute to minute gusts in the wind. These variations can be important, particularly when examining the performance of the diesel generators with respect to increasing levels of wind penetration. However, in both of the models that were developed in this work, the systems were examined from the point of view of an independent power produce, with a fixed power purchase agreement contract. As such, the more detailed interactions with the diesel power plant are not relevant to the performance of the wind energy system.

Actual systems will interact with the diesel generators and will affect their performance. These impacts could potentially be minimized if the storage systems also monitor and incorporate diesel loads, to ensure the generators are operating as close to optimal efficiencies. This was not a part of the current research, but is something that can be considered in real system deployment, as well as power purchase arrangements. HOMER is capable to modeling these interactions, and so it is not a limitation of the software that these were not considered, rather it was a reflection on the current status of likely power purchase agreements between utilities and developers.

Limitations that are inherent to HOMER is how the load profile may change over time as well as using only a single year of wind data. Given the lack of detailed wind data as well as difficulty in predicting electricity consumption trends, the model is no more limited than the best available data.

5.4 Sensitivity to incentives

The incentive level for the Remote Community Wind Incentive Program was developed in conjunction with the Canadian Wind Energy Association's northern wind caucus in examining the level of incentive likely required to encourage the leading candidate communities to be able to pursue wind-diesel systems. There was also a level of political reality that informed the maximum this number could be as it was limited to being of a similar proportion to incentives the Federal government had offered to large wind energy systems in the past.

Nonetheless, it is worth examining the changes in potential for update if the incentive were scaled to a different level, namely 5 and 10 cent per kWh production incentives. These would correspond to power prices of 0.40 $Cdn/kWh and 0.45 $Cdn/kWh in the models for the current research, and the results for each scenario are shown respectively in Figure 23 and Figure 24 below.

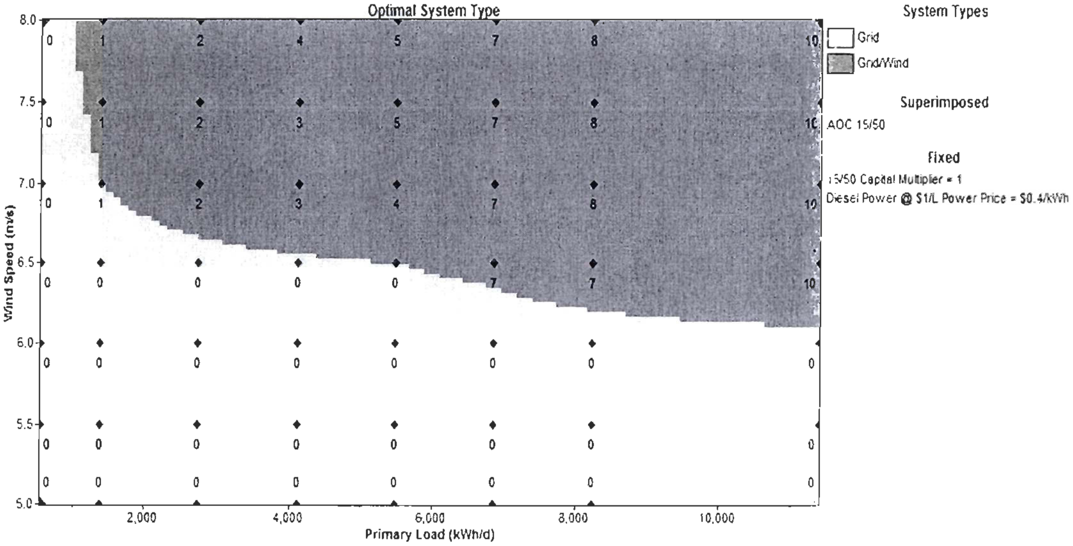


Figure 23: Potential community uptake with 0.05 $Cdn/kWh incentive

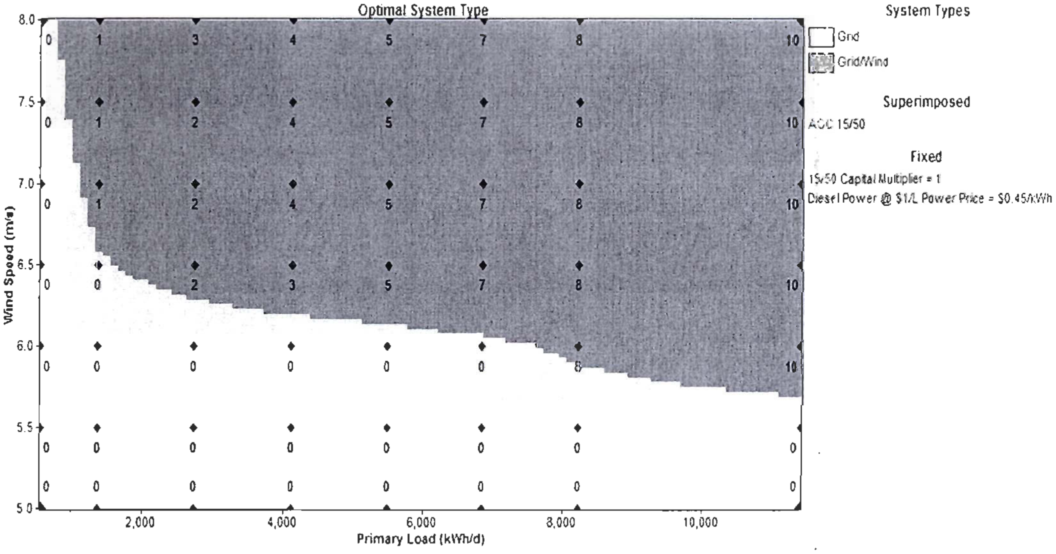


Figure 24: Potential community uptake with 0.10 $Cdn/kWh incentive

As would be expected the results of a lower incentive level raise the floor at which projects are viable. In the case of a 0.10 $Cdn/kWh incentive, the minimum wind speeds would be raised to between 6.4 m/s to 5.8 m/s for communities ranging from 2,000 kWh/day to 10,000 kWh/day respectively, compared to minimum average annual wind speeds of 6.1 m/s to 5.6 m/s for the same size range if a 0.15 $Cdn/kWh incentive were in place as proposed in the ReCWIP policy. This would also reduce the number of potential communities from 62 to 52, and would be further reduced to 43 communities if the incentive were reduced to 0.05 $Cdn/kWh.

It is important to re-emphasise the point made earlier, that the model predicts there are close to 30 communities in Canada that could develop economic projects without incentives, if they could build projects at the forecast costs of 6,000 $Cdn/kW installed, however, costs for the initial projects are expected to be significantly higher, likely in the 9,000 $Cdn/kW range.

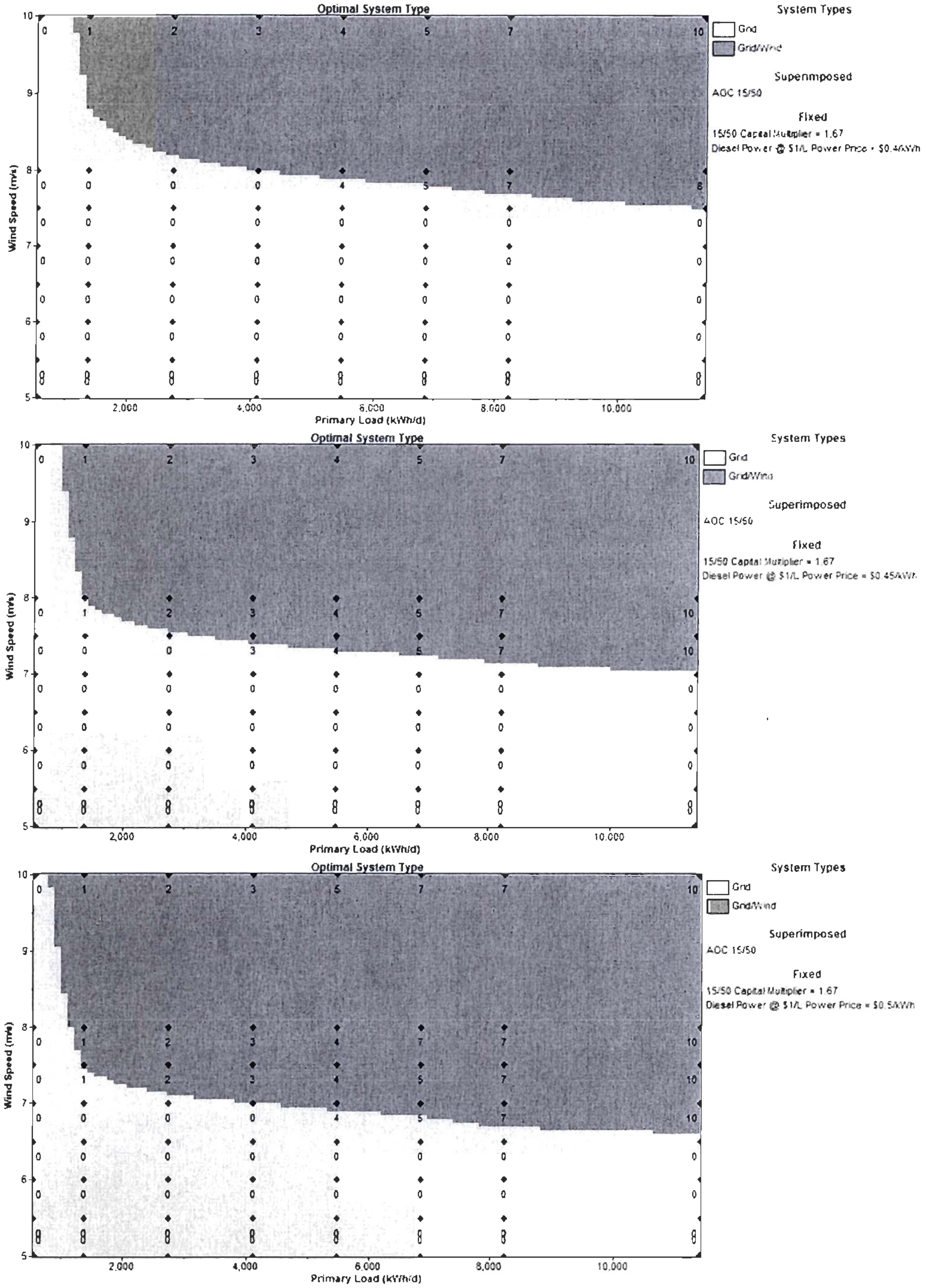


Figure 25: Effects of changing incentives for early wind-diesel projects

Figure 25 illustrates the effects of changing the incentive level if project installation costs are assumed to be 9,000 $Cdn/kW. It can be seen that the floor of candidate communities is lifted from an average of 7.0 m/s to closer to 8.0 m/s when the incentive level is moved from 0.05 $Cdn/kWh to 0.15 $Cdn/kWh respectiely. This reduction in incentive level reduces the pool of potential initial communities to 13 from 37 communities, and would concentrate potential communities only in Northern Quebec and Newfoundland and Labrador compared to a 0.15 $Cdn/kWh level which would also enable early adopter communities in Ontario, Nunavut and the Northwest Territories.

It is worth repeating that the economic models do not necessarily apply exactly to any given community. There is already a significant range in electricity price between the remote communities, which is in part correlated with the accessibility of each community. There are also likely changes in electricity prices, most likely as a result of changes in diesel fuel prices, which have seem recent rapid spikes in 2008 as well as 2011. Other factors such as accessibility and complexity of the terrain for installing turbine foundations will also vary between communities. It is also important to recognize that just because a community has favourable economics that a project will necessarily materialize there. Therefore, any incentive that were put in place would need to be sufficient to address the initial high costs of leading projects, and have a significant enough pool of potential communities that is larger than the targeted size of the incentive. A 0.15 $Cdn/kWh incentive level addresses both of those requirements.

5.5 Future research needs

While the models developed in this work examine the opportunities for policy development in Canada, significant work remains even if such a policy were to be adopted and implemented.

Unlike Alaska, there remains no comprehensive study of local renewable energy resources across Canada's remote communities that could help inform priorities as well as the strategic implementation of alternatives, although the Arctic Energy Alliance, who are based in Yellowknife has undertaken preliminary desktop analyses of the communities in the Northwest Territories, to which their mandate is constrained.

As part of this overall research, I worked closely with the Hamlet of Tuktoyaktuk, who at the time of writing this document, was developing the first new wind-diesel system in Canada in close to a decade. Should this project be successful, there are numerous important research opportunities for this project both technical and policy focused. Additionally, if broader government support for the deployment of wind-diesel systems emerges in the wake of this project there will be a need as well as an opportunity for strategic development of projects as well as research priorities.

A strategic deployment of projects, starting in communities that can adequately address local capacity issues both human and local resources (such as cranes and grid accessibility), needs to be developed if adequate government assistance is put forward that enables broad future deployment. Part of the intent of targeting the community of Tuktoyaktuk for development by the government of the Northwest Territories, and more importantly by the community elders and leaders in the Inuvialuit region was to start development in a community that has the local resources to service the project. While the wind speeds in Tuktoyaktuk are marginal (less than 6.0 m/s), it is the largest community in the region, and because of natural gas exploration in the area, has heavy equipment and technical capacity within the community itself to support the development there. The intent is therefore to have trained human capacity specific to wind turbine operations and maintenance within Tuktoyaktuk that can eventually service some of the smaller communities, which have better wind regimes. This development has been dubbed to be "hub and spoke" model, and is a worthy of further study should it be able to materialize beyond the creation of a potential hub in the initial project, not only for wind-diesel systems, but also for other renewable energy, and/or new technology being deployed widely in remote communities.

Technical issues that require further study range from the performance of the foundations in the permafrost to the impact of the wind turbines on the performance of the diesel generators. Many analytic studies of wind-diesel hybrid systems do not account for changes in diesel generator performance as a result of the presence of wind turbines, particularly at high sample frequencies. To the extent possible, system performance data, particularly in cold temperatures should be made public in order to being to build empirical systems models that are currently non-existent. Optimization models, as well as the addition of storage capacity either to enable the use of more energy from higher-penetration systems or to smooth second-to-second power fluctuations will all help to inform future system designs in Canada.

Publishing performance data will not only help to improve the technical aspects of this as well as future projects, but will also help to overcome awareness and the perception of technical risks amongst utilities and other decision makers identified as key barriers to deployment within this research. Information availability is also important for the design of future business plans, as well as future technical research for wind-diesel systems.

Policy issues that require further examination include how fuel subsidy policies can be adjusted to avoid perverse deterrents to the deployment of alternatives such as wind-diesel systems, both at a national as well as at provincial, territorial and individual community levels. Regional strategic and efficient implementation models for wind-diesel systems or other alternative need to be developed across remote communities in order to benefit from economies of scale during implementation as well as operations. These plans should not only examine community deployment options but also technology deployment ranging from low-penetration to high penetration systems with storage, as well as regional service strategies. This can assist in mitigating any potential significant price increases in diesel fuel costs while ensuring that projects are rolled out in such a way that proponents have adequate technical resources to design, build, operate, and trouble-shoot future projects.

5.5 Concluding Remarks

The current lack of consideration of environmental impacts of power generation in general has in part allowed for the continued reliance on fossil fuels including diesel power. Remote communities however, are already subject to elevated energy costs, and are vulnerable to price fluctuations that may be imposed either by market forces or in attempts to curb emissions such as carbon pricing. Early adoption and strategic deployment of alternatives such as wind-diesel systems will be increasing important enabling these communities to remain viable before price shocks or steady annual price increases forces a more costly rapid technological deployment of systems that may not be as well field tested as they could have been through a more deliberate approach.

When I began examining challenges to the development of wind-diesel systems in remote Canada, my intent was to examine performance and control issues from a technical point of view. Several years into the research and in working with many communities, governments and industries combined with the long-term operating successes of individual wind-diesel projects from Alaska to Newfoundland, I concluded, that while there remain technical challenges, these were not holding up the adoption of these systems, but rather it was decisions being made by governments and utilities made in part by information gaps and lack of support. This research, as well as the accompanying field work that I undertook is intended to help bridge some of those gaps towards the deployment of cleaner energy systems in remote communities.

There are many key reasons why investing in sustainable energy sources in northern and remote communities is important, not only because of environmental concerns or the risks associated with rising fossil fuel costs, but also for Canada to protect its political and geographic strategic interests. Having environmentally and economically stable communities in the North in particular is therefore important for the country as a whole.

To quote Barring-Gould and Dabo (2009) "the option of waiting for another 10 years to 'see how the technology matures' just guarantees that in 10 years, hundreds of diesel plants will have been installed or upgraded without consideration of alternatives, and little new information will have been gained."

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APPENDIX A – SAMPLE STAKEHOLDER SURVEY

The following is a copy of a survey that was distributed to stakeholders as part of the research discussed in Chapter 2 of this work. The barriers and policy options were randomized prior to distribution such that they did not always appear in the same order, the attached survey is listed in the same order as the issues are discussed in Chapter 2. Grey boxes illustrate respondent input opportunities.

the PEMBINA institute
Sustainable Energy Solutions

SURVEY - Barriers to wind energy development in remote Canadian communities

The following is a survey conducted by the Pembina Institute to garner input from those involved in the development of wind energy projects in remote communities including developers, researchers, manufacturers, governments and community leaders.

The survey should only take you 5-10 minutes and if you are interested in seeing a copy of the final results please contact Tim Weis of the Pembina Institute (timw@pembina.org or fax: 780-485-9640).

A. Please indicate your relationship to the remote wind industry

☐ Manufacturer
☐ Researcher/Advocate
☐ Remote Community Member

☐ Utility
☐ Developer
☐ Government Regulator

B. Please rank the TOP 5 ONLY barriers to developing wind energy in remote communities

Barrier	Rank only 1-5	Comments
Awareness amongst communities	6+	
Awareness amongst utilities	6+	
Capital costs	6+	
Operational and Maintenance costs	6+	
Perceived technical risks	6+	
Regulatory barriers (please specify)	6+	
Market barriers/market failures	6+	
Environmental issues (birds, noise, etc)	6+	
Access to equipment/labour	6+	
Technology maturity (please specify)	6+	
Other:	6+	
Other:	6+	

C. Check the TWO types of incentive would be most effective in stimulating remote wind energy development

☐ Renewable Energy Portfolio Requirements
☐ Tax Credit
☐ Capital Cost Grant
☐ Green Attribute Sales
☐ Production Incentive (like WPPI)
☐ Other:

D. In your opinion are wind-diesel systems ready for deployment in the Canadian Arctic today?

☐ Yes	☐ No
Why?	Why?

E. Other Comments: